

# The Seafood Industry

**This book is dedicated to the memory of**



**Kevin P. Granata  
1961–2007**

Dr. Granata was recognized for his scholarly, creative, and innovative research and teaching programs in biomechanics, specializing in muscular-skeletal dynamics and control.

Beginning in 2003, Dr. Granata was a Professor at Virginia Tech in the Engineering Science and Mechanics Department as well as the Virginia Tech-Wake Forest University School of Biomedical Engineering and Sciences.

A devoted husband and father, Dr. Granata was also dedicated to mentorship of his undergraduate and graduate students. He also took time from his demanding academic life to serve as a Boy Scout leader and a lacrosse coach.

While Dr. Granata will always be missed by his family, colleagues, and students, the memory of his loss will be overshadowed by the enthusiasm, thoughtfulness, and dedication to excellence he brought to all endeavors.

# **The Seafood Industry**

Species, Products, Processing, and Safety

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**Second Edition**

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# Preface

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Although there are excellent books on specific aspects of the seafood industry, few, if any, offer both the breadth and depth of information that the editors and authors of *The Seafood Industry*, 2nd edition, provide here.

*The Seafood Industry*, 2nd edition, is designed to cover the spectrum of seafood topics, taking the products from the water to the dinner plate and every stop in between. Information and insights into commercially important species of finfish and shellfish and their handling and processing are furnished. New chapters added for this edition include one on HACCP regulation, surimi, waste (by-product) utilization, species identification, biological safety of shellfish, and toxins, allergens, and sensitivities.

The information is written so that the processor, wholesale buyer, retailer, or consumer can understand it and put it to practical application. Yet, the student and the scientist can find much valuable information within the various chapters.

The editors and authors have made every effort to furnish the most up-to-date information and technologies available. However, as with any dynamic industry, change is constant. Fishery stocks ebb and flow, consumption patterns shift, new technologies are devised and implemented, and government rules and regulations are rewritten and enacted.

In seeking the best information available, chapter authors were selected from among the most knowledgeable seafood experts from around the United States.

Although this book is intended to encompass the vast topic of seafood and the industry built around this resource, certain limitations had to be imposed. The materials focus primarily on the industry in the United States, although innovations or activities in other countries have an impact on the US industry; those are covered. Each chapter in *The Seafood Industry* could receive—and in many cases has received—book length treatments. However, for this text, the editors decided to provide information on as wide an array of topics as possible and then to give each topic as much detail as space permitted.

We have drawn together what we feel is the broadest spectrum of information currently available on this dynamic industry. It is our sincere hope that this information will serve the seafood industry, those interested in this important industry, and the consumer.

## ACKNOWLEDGMENTS

As with any undertaking of this size and scope, there are many people who need to be thanked

and whose efforts need to be recognized. First, we owe a tremendous debt of gratitude to the various authors who have readily given their valuable time and expertise to make this book what it is.

We would also like to acknowledge the National Sea Grant College Program and the National

Institute of Food and Agriculture for their financial support that helped make this publication possible. In addition, two individuals at Virginia Tech should be singled out. We would like to thank Sarah Diersing and Sheila Holliman, who also read over the manuscript to check for punctuation, format, and spelling.

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# 1

## A History of the Seafood Industry

---

Roy E. Martin

Humans fished before the dawn of written history using bird's beaks for hooks and plant stalks for line. Early cave pictures show drawings of fish and fishing. Mounds of cast-off shells from prerecorded times have been found in China, Denmark, Brazil, and the United States. Although fishing was difficult because of a lack of efficient gear, it was easy to walk out at low tide and pick up shellfish, or spear fish in shallow water.

As populations grew, people tended to settle near the sea or large river systems where fish and shellfish were readily abundant as food, and sea-lanes became important for commerce, trade, communication, and transport. The need for more food and bigger fish encouraged fishermen to develop new gear design and more efficient methods of fishing and to travel even farther from shore. As a result of larger catches, the fishing enterprise expanded from a small boat, local village business to one that permitted additional onshore people to enter the business.

Fishing was often the reason, accidentally or not, for discovering new lands, finding new travel routes using trade as an excuse for expansion, and sometimes going to war. As nations organized large fishing fleets, they became sea powers.

The enormous fishing grounds of the North Atlantic lured European fishermen westward even before 1500. In fact, commercial fishing was the first industry of the New World; cod was the draw of the Grand Banks of Newfoundland. So numerous were these fish that in the early 1600s the Englishman Bartholomew Gosnold named a nearby peninsula Cape Cod. Fish were salted and packed in barrels, then shipped back to England. The state seal of Massachusetts has a codfish on its crest and shield.

The fishing industry is diverse and many segments developed independently.

### The fish curing industry

The fish curing industry of the North Atlantic coast of North America dates back to the year 1500, at least, and legends of activities go back even earlier. An extensive fish curing industry was carried on for more than 100 years before there was a permanent settlement. As early as 1580, over three hundred ships from Europe were salting cod in this area. Newfoundland was colonized because of the fish curing industry, which remains a factor in the province's economic life.



Early colonists in New England and the Maritime Provinces could not have survived without the salt cod and the smoked herring they prepared. Although fish meant food to these colonists, cured fish soon became their capital resource and their stock in trade for purchasing supplies. Cod, their most abundant fish, could be manufactured into a durable protein food product, withstand the primitive shipping and storage conditions of the day, and was comparatively low in price. Other cured fish such as smoked halibut and herring, pickled sturgeon, and salt salmon were soon being shipped abroad. Out of this grew the so-called triangular trade: salt fish to Europe; manufactured goods from Europe to the West Indies; and sugar, rum, and molasses to New England.

The trade in salt fish stimulated other industries, and capital was gradually accumulated so that the colonists could go into the shipping business. Before the end of the sixteenth century, more efficient, faster vessels were developed to meet the needs of an expanding fishery.

The fish curing industry continued to grow and prosper, dominating the economic life of the New England colonies in the late seventeenth and early eighteenth centuries. The large amount of money to be made led to disputes between the British and the French over fishing grounds and fish curing locations. Both groups wanted to secure this trade for themselves. Attempts were made to establish fishing boundaries, but they were poorly defined, and fishing rights over a wide area was the cause of frequent bickering, sometimes flaring up into undeclared warfare. The fishermen and curers of New England and Nova Scotia played an important part in England's conquest of Canada, because for them the fishing rights meant life or death.

The disputes did not end with the ousting of the French, but continued between the New England colonists and the English. The English Parliament in 1775 prohibited the New England colonies from trading directly with foreign countries and prevented New England vessels from fishing on the banks off Newfoundland, in the Gulf of St. Lawrence, and on the coasts of Labrador and Nova Scotia where they had been accustomed to fishing. This restriction meant ruin to the New England fish curing industry, and the edict was one of the causes of the Revolutionary War.

The treaty of peace negotiated in 1783 was delayed because the American delegates insisted on securing favorable fishery rights. They regarded

these rights as so important that they refused to sign a general treaty of peace that left the fishing rights for later adjudication. Finally, the American delegation obtained a treaty article on fisheries that granted favorable conditions to the United States.

The New England fish curing industry generally prospered under the new republic and was able to secure salt cod markets in southern Europe and the Mediterranean. Disputes again arose with Great Britain over trade, the interpretation of fishery rights, and the conscription of American fisherman and seamen into the Royal Navy. Restrictions and embargoes were imposed by both Great Britain and the United States, resulting in a decline in the salt fish industry after 1807. The War of 1812 almost ruined the industry; the war was so unpopular among shipping, commercial, and fish curing groups that there was a move toward secession in some New England states.

At the end of the War of 1812, the British claimed that the war abrogated the treaty of 1783; the United States claimed that the treaty was still valid. The British seized some American fishing vessels, and it seemed for a time that a new war might break out. Tension was eased by the signing of a new fishery convention in 1818. However, it was followed by a whole series of disputes about interpretation, at times resulting in severe diplomatic tension for the United States with Great Britain and with Canada.

Trouble occurred less frequently during the last decades of the nineteenth century as refrigeration developed and wider markets were created in the United States for fresh fish, making salting and drying of fish on the northeastern coast less important.

## **Fish canning**

An overview of the US fish preserving industry during the past half century shows a decline in production of cured fish but an almost continuous growth in the canning industry.

The first record of canned seafood in the United States was in 1815 when Ezra Daggert and Thomas Kensett canned salmon, lobsters, and oysters on a site near what is now Battery Park in New York City. In 1825, Kensett applied for US patents for "preserving of animal, vegetable, and other perishable foods," but these patents were not granted until some 10 years later, presumably because patent

officials doubted the idea's practicality. For years following these early canning operations, there was no significant development in seafood canning.

The production increase was gradual over a 25-year period beginning in 1844. The first large increase in demand came during the Civil War when preserved foods were needed for the troops. This increased demand also created additional consumers for canned seafood. Men who became acquainted with these products in the army demanded canned foods on their return home and introduced them to their neighbors.

Kensett was the first to break away from home kitchen methods and deserves credit for developing the first canned product, oysters, to receive wide distribution. The pioneer development of the industry in the Chesapeake Bay area, the first important canning center, is due to his efforts. Others are said to have engaged in the industry in the Baltimore area before Kensett, and it is believed that oysters were canned as early as 1819. However, the first systematic effort at large-scale development was made by Kensett in 1844 when he began packing oysters in Baltimore. Oysters were the first canned product that became popular. Large inland cities could get fresh Baltimore oysters packed in ice through the winter, but people in smaller communities seldom enjoyed such a luxury. The countryman's greatest treat when he went to town was an oyster stew. Baltimore and Boston firms canned oysters, so they would keep for months and could be bought at any country grocery store by people who had never eaten a fresh oyster.

Tin containers for packaging processed foods were first used in the 1840s. Sardines were first canned in Maine about 1850; a turtle cannery was established in Florida in 1866; a cannery for menhaden was established on Long Island in 1872; and it is known that mackerel, clams, lobsters, and crabs were being canned by 1880. It is probable that tuna, alewives, and shad were not canned until early in the twentieth century. The production of canned products in the United States and Alaska in 1880 had an estimated value of \$15 million.

## Canning salmon

Salmon canning industry, one of the most important canning industries, had its beginnings during the Civil War period. Although it is claimed that

the first salmon canned on the American continent was the Atlantic salmon packed in St. Johns, New Brunswick, in 1839, the salmon fishery was never of economic importance on the Atlantic Coast. The industry really began in California, where George and William Hume with A.S. Hapgood started the Pacific salmon canning industry. The Hume Brothers, who had worked as fishermen at their home in Maine, went to California as Forty-niners. They noticed that salmon were plentiful in the Sacramento River and believed that money might be made canning the fish. They went back to Maine on a visit, persuaded Hapgood, a lobster canner, to return west with them, and the first Pacific salmon pack was made in Sacramento in 1864.

Using these primitive methods, 2000 cases of salmon were canned that first year and sold at 5 dollars per dozen cans to a San Francisco merchant. Reacting to reports of extremely favorable conditions on the Columbia River, the Humes moved to Eagle Cliff, Washington, and made the first pack of Columbia River salmon in 1866.

As a result, the rush to pack salmon was on, and within a few years hundreds of operations were set up on the Columbia River and in Alaska. Having to make cans by hand hampered operations, but because of the great demand, the pack by 1876 was 450,000 cases.

As the sale of canned salmon increased steadily, the industry sought new and profitable locations, first at New Westminster on the Fraser River in British Columbia in 1867; then at Mukilteo, on Puget Sound, Washington Territory, in 1877; and, although Alaska is today the most important salmon canning area, its first cannery was not built until 1878 at Klawak, on Prince of Wales Islands.

Today, consumers have many canned fish and seafood products available, thanks to the ingenuity of the fishery industry. Canned fishery products total more than 750 million lbs and are worth over \$1.0 billion.

## The shrimp fishery

The shrimp industry, as it is known today, began off the coasts of Georgia, North Carolina, and South Carolina. Around 1915, the first shrimp trawl was employed from open skiffs converted from the blue-fish hook and line fishery. Gasoline engines became the major source of power during the 1920s. A small single otter trawl was manually operated from the

vessel. Flat nets of a very simple design were utilized during the early days. Interestingly, this trawl proved so efficient that it is still used today.

During the 1930s, diesel engines were first utilized aboard shrimp boats, eventually making it possible to use larger and more powerful vessels. The use of larger trawls coincided with this important evolutionary process in the shrimping industry. The large offshore vessels used today were not necessary then because fisheries were confined to inshore waters.

Expansion of fisheries occurred significantly after World War II aided by the availability of large war surplus diesel engines. Numerous fishermen entered the fishery during the postwar boom.

The offshore white shrimp grounds were fished on a significant scale. Fishermen regularly ventured into water more than 18.3 m (60 ft) deep in pursuit of shrimp. White shrimp became such a highly exploited resource that production declined.

During the late 1940s, several changes contributed to the evolution of shrimping vessels and gear. Declining stocks of white shrimp led fishermen to direct their efforts toward catching brown shrimp, a deepwater fishery, that when established changed the requirements of vessels and shrimping methods. The establishment of brown shrimp fisheries also generated interest in the pink shrimp that stocks Florida's Tortugas grounds.

The increased interest in shrimp led to improvements in gear technology. First, the two-seam balloon trawl was introduced (1947) in the Gulf. This net, with its redesigned jib, was an improvement over the earlier flat net, producing a better overhand and more even mesh strain than the flat net. Greater horsepower meant larger trawl capabilities and increased harvesting capacities. Numerous fishermen increased their trawl sizes, vessels of 15.2–16.8 m (50–55 ft) and up to 18.3 m (60 ft) were beginning to appear at the close of the 1940s. During this period, some electrical devices, including fathometers and automatic pilots, also came into common use.

Perhaps more advancements were introduced into the shrimp industry in the 1950s than during any other period. This decade saw further increases in horsepower, electronics, and gear improvements. The four-seam balloon (semi balloon) trawl was introduced in 1950. It spread more effectively than the flat and two-seam balloons and maintained a better shape in the water.

Spec Harris of Freeport, Louisiana, designed the western jib, which is essentially a flat net with modification to the corner pieces. It is still the most commonly used trawl in the Texas Gulf shrimp fishery.

The shift to deepwater brown and pink shrimp grounds necessitated larger vessels, a need compounded by the discovery and development of the fishing grounds off Mexico. A distant water fleet required larger vessels that could remain away from port for an extended period of time. Increased power, often surpassing 200 horsepower, coincided with larger vessel development.

The most important gear modification during the 1950s was the conversion to double rigged vessels. Two smaller trawls actually caught more shrimp than an equal size single trawl. This concept created a more efficient onboard handling operation and enhanced safety at sea. Also, during this period, synthetic twines came into use, increasing strength and durability of trawls.

Advancements in marine electronics continued. Virtually all vessels began using depth sounders. Radio capability was the most significant electronic change during the decade. With radios becoming common, a communications link was established that significantly enhanced harvesting efficiency. The ability to communicate with other vessels aided extensively in the location of shrimp, and greater safety at sea was ensured. Radio direction finders were installed on a number of vessels.

During the 1960s, increasing horsepower and a corresponding tendency to use larger vessels were the most significant changes to occur. Expansion of fisheries into South America greatly influenced vessel length; shrimp trawlers 22.2 m (73 ft) in length were regularly constructed.

Some larger Texas trawlers began towing a third rig from the stern of their vessels, using an A-frame to accommodate this modification, but fishermen had mixed results with the technique. The primary difficulty was that of a "robbing" effect from the trawls being towed too close together. Vessels with longer than usual outriggers were able to overcome this problem.

Further implementation of electronics continued. Radar came into use, and depth sounders and related equipment were improved. Some fishermen began experimenting with military surplus Loran equipment and rapidly identified the benefits of the navigational devices.

During the early 1970s, length of vessels increased more than the amount of engine horsepower. Although several types of engines with larger horsepower were installed on some boats, most new engines remained in the 365 horsepower range. A remarkable increase in the number of steel hull vessels occurred, although wooden vessels continued to be added to the industry at a significant rate, and the first fiberglass and aluminum trawlers entered the fisheries.

In roughly the same period, Gulf fishermen perfected a trawling technique utilizing two small nets, twin trawls, on the single cable. Again, the theory was that two smaller nets are more efficient than a single larger one. This gear modification significantly increased trawl efficiency, and the majority of Gulf shrimp trawlers soon adopted this technique, utilizing four trawls per vessel instead of two.

Another gear modification was tried although not generally accepted, but recent technological advancements may present new opportunities. The former Bureau of Commercial Fisheries gear unit developed an electric shrimp trawl designed to shock burrowing shrimp from the seabed. Experiments proved that brown shrimp could be harvested during the daytime utilizing this gear. This innovation could have been an excellent opportunity for expanding potential shrimping efforts because brown shrimp could be harvested only at night. Several trawlers experimenting with this gear achieved significant daytime catches. However, a few inherent problems with the system resulted in a profound inconsistency of catch. Because of its high expense and inconsistencies, the electronic trawl was ultimately abandoned. Recent modifications to the electronic shrimp trawl have been introduced in the United Kingdom where several vessels have adopted its use.

Improvements in electronics increased shrimping productivity. In addition to radar and depth recorders, the navigational equipment Loran A became a universal tool in the shrimping fleet, providing locations of productive fishing grounds and helping fishermen avoid numerous hazards to trawl gear.

More recently, several other gear changes have been introduced to the shrimping industry. The National Marine Fisheries Service developed a Trawl Efficiency Device, an apparatus to exclude bycatch (any species other than the targeted species) from shrimp trawls, it is also known as a Tur-

tle Excluder Device (TED). The TED consists of a frame that is installed between the body and cod end (closed saclike part) of the trawl. Shrimp are allowed to pass through the apparatus while larger fish, turtles, and debris are rerouted through an exit.

Rapid improvement of marine electronics occurred in the early 1980s. The Loran C Navigational System's increased accuracy has aided shrimping operations. Track plotters associated with Loran C have proven effective in defining concentrations of shrimp and trawlable bottom areas. Another electronic device, the depth recorder, has been greatly improved. Recent production of chromoscopes, machines that record in color, assist in defining bottom types and fish compositions of the seabed. These recorders have increased shrimp harvesting.

On the processing end of the business, the freezing of shrimp was probably the single most important factor governing the progress of the shrimp industry. The adaptability of shrimp to the freezing process allowed more time for marketing and distribution and eased the urgency that previously dictated sales policies and prices for the producer. The growth of the entire frozen food industry resulted in wider distribution for shrimp. Facilities for handling frozen vegetables and fruits were likewise suited for handling frozen seafood.

## Canning oysters, clams, and crabs

Although Baltimore was the center of the oyster canning industry for many years, oysters are packed there only occasionally today. The catch in the Chesapeake Bay region has decreased greatly, and it is now more profitable to market these oysters fresh. The greater portion of the oyster pack is now prepared on the Gulf Coast. The most recent development in the oyster industry is the establishment of oyster canning on the Pacific Coast. The introduction of the Japanese or "Pacific" oyster created a surplus, which was unmarketable in the raw condition. After several years of experimental work, this oyster was canned commercially in 1931. The pack in that year was 7930 cases, increasing to 118,853 cases in 1936.

The first clam cannery in the United States was started in 1878 at Pine Point, Maine. The pack of canned clam products was small for some years because of considerable difficulty with

discoloration, but production slowly increased when this problem was overcome. P.F. Halferty developed a method for canning minced razor clams about 1900, building up a commercial clam canning industry in Oregon, Washington, and Alaska. The inclusion of minced clams, broth, and clam chowder in the list of products increased the value of canned clams until now where they are fifth in order of importance of canned fishery products, thereby displacing oysters.

Crab was first canned in the United States by James McMenamin of Norfolk, Virginia, in 1878. The greatest difficulty was with discoloration. In 1936, a method to overcome discoloration was developed, and in 1938, the Harris Company packed the common or blue crab of the Atlantic Coast commercially. Although the crab canning process is said to have been developed in 1892, the Japanese industry was not established on a commercial scale until 1908. Japanese canned crab began to enter the US markets in appreciable quantities during World War I. In 1931, imports amounted to almost double the domestic production of fresh and canned crabmeat. A domestic crab canning industry has been developed in Alaska, Oregon, and Washington; processing and other technical difficulties have been overcome and a market has been developed in the Pacific Coast states.

## The fish canning industry

Because of the large supply of groundfish in the North Atlantic, numerous attempts have been made to develop a canning industry, but they have not been particularly successful because of competition with other canned fishery products or insufficient advertising. Cod and haddock products such as fish flakes, fish cakes or balls, and finnan haddie (smoked haddock) have not found a wide market outside the New England area and are packed on a limited scale. Fish cakes were first packed in Boston in 1878, and finnan haddie was first packed about 1890. Fish flakes, or "salad fish," the flaked meat of cod and haddock, are believed to have been developed by the Burnham and Morrill Company of Portland, Maine, in 1898.

At the turn of the century, the industry was experimenting with a variety of products; pickled sturgeon, carp, shark meat, and menhaden that are not found on the market today. Some of these

packs did not make good products; others were not in sufficient demand; in other instances, the cost of raw material became too great for profitable operation.

In the year 1900, the annual pack of canned fishery products was less than half of what is produced today, and it was thought that production could not be increased greatly or even maintained. At the same time, these gloomy predictions were being made, the canning of fishery products was actually at the threshold of its greatest development.

Canned tuna is one of the more recently developed canned fishery products, first packed commercially in 1909. The packing of tuna began at the Southern California Fish Company, which began experiments in 1905. The raw material was albacore, which when cooked resembled chicken in taste and flavor. This characteristic flavor added impetus to the experiments, but it was not until 1907 that the efforts were rewarded. The first successful pack was produced in 1909 when 2000 cases were packed and marketed.

Mackerel was canned in small quantities in New England as early as 1843, but its introduction into the general canned food market did not occur until 1927 when George Ogawa put up a pack of 10,725 cases of California mackerel "salmon style," priced to compete with cheaper varieties of salmon. Production of Pacific mackerel increased to 388,500 cases in 1928 and reached a peak of 1,795,700 cases of 48 one-pound (454 g) cans in 1935.

Sardines were first packed in France in 1834, and by 1860, a substantial market had been created for French sardines in the United States. Efforts were made to establish an American industry in 1871 utilizing young menhaden as raw material. In 1877, Julius Wolff began canning small herring at Eastport, Maine, and is credited with starting the first really successful American sardine cannery. By 1906, a large number of sardine canners were operating in northern Maine and nearby Canada. Several efforts were made during the 1890s to establish sardine canning on Puget Sound or in Alaska where large quantities of herring were available, but all of these operations were short-lived.

The famed California sardine industry began in 1900 when Frank E. Booth moved to Monterey, California. Booth and his father were already involved in the canning of salmon in their Pittsburg, California, plant. It was his background in the canning and packing of fish that prompted Booth



to consider the possibility of canning the abundant Monterey Bay sardine. Upon his move to the bayside community, Booth founded the F.E. Booth Company in a plant near the aged and historic Monterey Customs House.

Not long after Booth launched his California sardines, a second man, also destined to become an important figure in Monterey's multimillion dollar sardine industry, arrived. Knute Hovden, a recent immigrant from Norway, a graduate of the Norwegian National Fisheries College, and a skillfully trained professional in the fish packing field, teamed with Booth. Under them, the highly competitive and extremely profitable Monterey Bay sardine canning industry continued to develop and expand.

With Booth and Hovden perfecting the canning phase, the biggest problem became getting a steady supply of fish. Able to handle 5 tons ( $4.5 \times 10^3$  kg) of sardines per day, but with an inconsistent daily catch, Booth and Hovden sought ways to increase and ensure the size of the catch.

In 1904, Pietro Ferrante arrived in Monterey with many years of fishing experience, and quickly gained a reputation as both a man of vision and of considerable fishing talent. It was only natural that Ferrante soon joined forces with Booth and Hovden. Ferrante was convinced that a new approach to catching sardines was needed if they were to reap the bounty of the bay. Remembering the lampara boat and net method of fishing he had been familiar with in the Mediterranean, Ferrante redesigned the lampara net and adapted it for Monterey's deep-water bay. The lampara net is designed to encircle an entire school of fish. The word lampara was derived from the Italian word *lampe*, meaning lighting, because the net was designed for a fast cast and haul. Ferrante also urged other Italian fishermen in California to come to Monterey and join him in the hunt for sardines.

With the aid of the lampara net and with the knowledge and skill of the newly arrived fishermen, the sleepy bay community experienced a gradual but significant change. By 1913, the canning industry had "come of age," and was no longer looked upon as being in the crude and experimental stage. In keeping up with the canners, the fishing crews were catching as many as 25 tons ( $2.3 \times 10^4$  kg) of sardines in a single night. (The ideal fishing conditions were on dark moonless nights when the fishermen could best spot the phosphorescent

glow of a school of sardines and, in turn, know where to place their nets.)

With the supply of fish no longer a problem, Hovden branched out and opened his own cannery in 1914 on what was then an uncluttered stretch of Monterey beach. Others followed, and it was not long before the shoreline was lined with the noises and smells of several canneries. By 1918, Monterey boasted a total of nine canning plants and packed a total of 1.4 million cases of sardines as compared with a mere 75,000 cases 3 years before.

The early 1920s were the peak years of the lampara boat and net method of fishing. With the introduction of the half-ring net in 1925, the half-ring boat also appeared. This boat differed only slightly from the lampara boat, boasting a winch, a mast, and a boom. With the use of the rings, more fish could be caught per haul as the net rings pursed (or pocketed) the net, thus trapping the fish and making it difficult for them to escape.

In time, the lampara boats and the half-ring boats became outmoded with the introduction of the popular purse seiner, whose net, when full of trapped fish, formed a purse. With the word *seine* describing the type of net commonly used by the sardine fishermen, the vessel became known as a purse seiner. Varying in size, the largest of the purse seiners approached 30.5 m (100 ft) and carried nets capable of encircling the width of a football field and dropping to a depth equaling the height of a ten-story building. This new class of boat was capable of fishing hundreds of miles at sea and carrying  $9.07 \times 10^4$  kg to  $1.36 \times 10^5$  kg (100–150 tons) of fish. With the purse seiner, the sardine fishing in and around the Monterey Bay area took on an added dimension.

Through the 1930s and into the 1940s, the Monterey fishing fleet and its supporting cast of canneries continued to grow and prosper. In 1930, the catch was  $1.44 \times 10^8$  kg (159,000 tons); by 1935, it had jumped to  $2.09 \times 10^8$  kg (230,000 tons); and during the early 1940s, there were years when the catch approached the almost unbelievable figure of  $2.27 \times 10^8$  kg (a quarter of a million tons).

With the constant and abundant supply of fish, cannery operators learned that not only was there money to be made in canning fish but in the processing of fish by-products as well. With fish meal becoming widely used for poultry and livestock feed, as well as being in demand as fertilizer, the oil from the fish (which at one time was considered waste) was sought for use in the manufacture

of soap, paint mixer, vitamins, glycerin (for ammunition), shortening, salad oil, and the tanning of leather. By 1945, Monterey boasted 19 canneries and 20 reduction plants for the development of fish by-products, and a fishing fleet of over one hundred vessels. During this period, Monterey was known as the sardine capital of the world, and in total tonnage ranked third among the world's major fishing ports second only to Stavanger, Norway, and Hull, England.

During 1939, the catch was  $1.95 \times 10^6$  kg (215,000 tons or 430 million lbs) of sardines, which with an average of approximately three fish to the pound represented a staggering 1.2 billion individual sardines. If the total number of sardines caught were placed end to end, the row would stretch 327,592 km (203,600 mi) a distance nearly equal to that from the earth to the moon. The same row of fish if placed end to end around the equator would circle the earth eight times with over 5792 km (3600 mi) of fish left over.

Although 1945 was the high point of Monterey's sardine industry, 1946 marked the beginning of its decline. Fish continued to be caught and canneries continued to work, but the handwriting was on the wall. The 1946 catch was nearly  $9.1 \times 10^7$  kg (100,000 tons) under the 1945 mark, with the 1947 catch being over  $9.1 \times 10^7$  kg (100,000 tons) less than that. The 1948 catch plummeted to a disastrous  $1.3 \times 10^7$  kg (14,000 tons). Much of that amount was trucked to the Monterey canneries from more abundant fishing grounds to the south.

In 1949, the industry, for unknown reasons, received a most welcome shot in the arm as the catch jumped to  $37.2 \times 10^6$  kg (41,000 tons). During the 1950 season, the fleet recorded a catch of  $119 \times 10^6$  kg (132,000 tons). Even though the 1950 catch was over  $9.1 \times 10^7$  kg (100,000 tons) less than the catch of 1945, the industry's dollar turnover was the greatest in its history. As the 1950 season came to a close, for all intents and purposes, so did Monterey's sardine industry. The 1951 catch was embarrassingly small, and by 1952 canneries were closing at such a rapid rate that only a brief mention of their closing made the local papers.

As the canneries closed, many of the purse seiners found their way to various southern ports where sardines were still to be caught. With the harbor relatively empty of purse seiners and much of Cannery Row on the auction block, Monterey's sardine industry became little more than a memory.

The industry had gone from boom to bust in less than 50 years because of polluted water, warmer climates, changes in currents, recurring cycles, and, of course, the distinct possibility that the once abundant sardines were simply fished out.

## The haddock fishery

Compared with the cod fishery, which was centuries old, a substantial commercial haddock fishery was developed much later in New England. Cod were considered best for salting (haddock were unsuitable for that purpose), but use of ice made trade in fresh fish possible and haddock came into its own, growing quickly in public esteem. Haddock fillets cut and frozen at dockside soon found acceptance far inland.

On the haddock grounds, dory fishing with hook-and-line yielded slowly to trawling after the turn of the century. Beam trawls were supplanted by otter trawls, improved versions of which are now the main commercial gear. However, hook-and-line fishermen persisted alongside trawler men for a long time. In the late 1920s, roughly half the catch was still taken by longlines, and a small fraction still is.

Between 1891 and 1901, US haddock landings averaged nearly  $2.5 \times 10^7$  kg (27,500 tons) annually. Catches grew in size with an increasing number of trawlers through the 1920s until a peak of  $119 \times 10^6$  kg (132,000 tons) was reached in 1929. Operating under the mistaken notion that fish resources were infinite, there was an all-out effort to harvest as much as possible to meet the demands of the marketplace. After 1929, haddock resources showed signs of stress. Fishermen and fishery scientists worried as catches dropped sharply, and many fishermen were forced to switch to other species. In the 1930s, the US Bureau of Fisheries initiated biological studies of haddock and a new system of statistical reporting.

When fishermen stopped over fishing haddock, average US catches settled to about  $6.35 \times 10^7$  kg (70,000 tons) annually,  $4.7 \times 10^7$  kg (52,000 tons) of these from Georges Bank and the Gulf of Maine. These levels, close to the estimated long-term sustainable catch, prevailed from the mid-1930s to 1960.

In 1949, it was agreed by all countries concerned that scientific management of the fish resources in this region be carried out cooperatively, and a

treaty that year founded the International Commission for the Northwest Atlantic Fisheries (ICNAF). Haddock off the US coast were not a target of European fishermen in ICNAF's early years; nevertheless, haddock stocks soon benefited from ICNAF research and regulation. Investigations of the effects of trawl mesh size on catches showed that enlarged mesh openings would reduce waste of undersized groundfish. When new mesh regulations were issued in 1953, harvesting became more efficient and discards of small haddock were fewer.

During the 1960s, unprecedented numbers of foreign vessels, many from the Soviet Union, appeared on the principal haddock grounds off Georges Bank. At first, the Soviets mainly sought Atlantic herring and silver hake, but in the mid-1960s, their attention was drawn to large numbers of young haddock spawned in 1962 and 1963. At the same time, US and Canadian fishermen intensified their own efforts to catch haddock. The result was an all-time peak catch in 1965 of 165,000 tons, three times the estimated annual sustainable yield for Georges Bank. The collapse of the resource followed soon after.

ICNAF moved to reverse the disaster, making major spawning grounds off limits to trawlers in the spring and cutting the allowable catch for 1970 and 1971 to  $1.1 \times 10^7$  kg (12,000 tons) from Georges Bank and the Gulf of Maine. This number was halved during four of the five succeeding years; in 1974, it was set at zero, with a bycatch allowance of  $5.4 \times 10^6$  kg (6000 tons). Recovery of haddock stocks began, but too slowly for New England fishermen. They joined in support of a new law providing more direct control over exploitation of traditional resources. In this way, collapse of the Georges Bank haddock resource played a significant part in enactment of the present "200 mile-limit (322 km) law," the Magnuson Fishery Conservation and Management Act of 1976 (MFCMA).

Under MFCMA, the United States took unilateral control of most fish and shellfish within a 322 km (200 mi) zone off the coast, and management was required to be based on "optimum yield" (maximum sustainable yield modified by certain economic, social, and ecological considerations). Eight Regional Fishery Management Councils came into being. Management of the haddock stock fell to the New England Council, which gave it top priority. Optimum yield, in the council's judgment, would be the yield that would most effectively

speed recovery of the stocks. So, they set this limit at 5636 metric tons (6200 tons) to be taken only incidentally when fishing for other species. Of this total, 5454.5 metric tons (6000 tons) were designated for commercial harvest, and 181.8 metric tons (200 tons) for recreational fishermen.

The 322 km (200 mi) declaration gave the United States control over the destiny of its industry. With management authority over its coastal zone and the decision-making authority over the fish resources within it, the United States could take the steps necessary to ensure future resource supply through effective conservation measures.

As the new council took over, the haddock 1975 year class was the first good one in years. Assessments in 1977 showed it to be much stronger than the overall average, and many times stronger than those produced during the years of collapse. Haddock were so plentiful that fishermen on some grounds could avoid them only by keeping their nets out of the water. Catch limits had suddenly become quite impractical, but they were cumbersome to change under MFCMA. Massive discarding at sea was one result; misreporting of catches was another. Council managers could not change limits until November 1977, and by that time much damage had been done. Thousands of tons of haddock had been wasted and masses of data vital for management planning lost.

Thereafter, constraints on the fishery were progressively eased. By the 1979–1980 fishing year, optimum yield for Georges Bank and the Gulf of Maine had been raised to  $2.95 \times 10^7$  kg (32,500 tons) on the strength of the 1975 year class, and 1979 survey results revealed that still another good year class, from 1978, would recruit to the Georges Bank fishery in 1980. With two such year classes in the water, there was reason to hope for recovery of New England's haddock fishery. Unfortunately, recruitment did not continue to improve; subsequent year classes have been weak, adding little to the resource. Evidence shows stocks sinking again toward levels seen a decade ago. Recovery may require the kind of circumstances for recruitment success that occurs rarely.

## Early Pacific fisheries

Early fisheries on the Pacific did not affect US international relations to the same extent as the Atlantic



fisheries, because the development was much more recent and different in character. The difference, possibly, is because development occurred at a period when canning and refrigeration were replacing curing as the principal methods of preservation, and also when more fishing took place in clearly defined territorial waters.

Although there have been numerous disputes between Canada and the United States over Pacific fisheries, they have been minor compared with those in the Atlantic. In the 1930s, Japan moved into fishing grounds off the coast of Alaska and interfered with US vessels that were catching and salting cod. The cod fishermen threatened to shoot any Japanese obstructing their operations. Japanese fishing was a matter of great concern to the Pacific coast fishermen, but little notice was taken nationally until it was shown that the Japanese were catching salmon despite an understanding to the contrary. The controversy was still unsettled when Japan and the United States went to war in 1941.

Cured fish were the first manufactured products prepared on the Pacific coast, where for centuries Native Americans had an extensive dried salmon industry on the Columbia River. The fish were traded to the tribes in the plains of the interior. Native Americans still dry small amounts of salmon for their own use. The Russians operated a commercial salted-salmon industry in Alaska at the beginning of the nineteenth century, shipping products as far as St. Petersburg. Soon afterward, the Northwest Fur Company started a salmon salting business on the Columbia River. The Northwest Company merged with the Hudson Bay Company that shipped salted salmon to Hawaii, Australia, China, Japan, and the eastern United States. American fishermen salted salmon in Alaska while it was still under Russian possession. A number of the large salmon canneries of today began as salmon salteries.

The presence of cod off the coast of Alaska was discovered in the 1860s, and the possibility of building a prosperous salt cod industry was one argument for the purchase of Alaska. Recent, but still incomplete, studies have established that the Pacific banks are larger and of greater potential production than the Grand Banks off the coast of Newfoundland.

During World War II, the Pacific coast fish curing industry was much more adversely affected than its counterpart on the Atlantic coast. With the Alaskan

area considered a combat zone, almost all fishing and fish curing activities were stopped, and all but one of the cod salting vessels was requisitioned by the government. The loss of foreign markets and the effect of pricing regulations were other unfavorable factors.

## The menhaden fishery

Menhaden are herring-like fish that inhabit the coastal waters of the western Atlantic Ocean and Gulf of Mexico. The menhaden fishery is the largest of all fisheries in the United States and the basis of one of the leading fishing industries in the world.

Fishing for menhaden is one of the oldest industries in the United States. North American Native Indians taught early settlers to place a fish in each hill of Indian corn. Although menhaden probably were never widely used this way, the practice led to their use for enriching soils when crops along the New England coast and on Long Island began to fail in the late 1700s. By 1820, a fishery was organized for the purpose of supplying menhaden for fertilizer.

During the War of 1812, the use of fish oils in paints led to the utilization of menhaden for this purpose. The early menhaden oil industry was centered in New England where the large, oily fish were encountered in abundance along the coast during the summer. Despite the highly profitable market for menhaden oil, the industry grew rather slowly until about 1860 when the introduction of the mechanical screw press and the use of steam power made the oil recovery process practical using a factory operation. During the following decade, many new factories were built and improvements in the methods of catching and processing the fish followed. Development of suitable methods of preserving the fish press cake, accumulated from the oil extraction process, also provided the basis of another phase of the menhaden oil industry that was to continue for the next 50 years, the production of fish fertilizer. By 1870, more than 90 menhaden reduction plants had been established from Maine to North Carolina.

Prior to 1875, the New England states accounted for the greatest part of the annual menhaden production. In 1876, the catch amounted to approximately  $1.5 \times 10^8$  kg (170,000 tons) from which nearly  $11 \times 10^6$  L (3 million gal) of oil and over  $45.4 \times 10^3$  kg

(50,000 tons) of fertilizer were produced. Maine accounted for nearly half the total fish production in that year. Several years later, the fish failed to appear in the waters north of Cape Cod, and except for certain seasons, the fish have not been abundant in the coastal waters in that area since.

Following the collapse of the New England fishery, the industry expanded southward and by 1900 was centered in New Jersey and Virginia. Although menhaden were known to be in the Gulf of Mexico during the early years of the oil industry on the Atlantic coast, it was apparently the collapse of the New England fishery that motivated development of the Gulf fishery. Records show that menhaden were landed on the west coast of Florida and in Texas waters prior to 1902, but there are no records of further landings in those states until 1918. The first landings of menhaden in Mississippi waters were reported in 1939 and in Louisiana in 1948.

Records of menhaden landings in the first decade of the twentieth century are lacking, but in 1912 the catch amounted to  $3.2 \times 10^8$  kg (356,000 tons), the largest reported to that time, with Virginia accounting for more than half the total production in that year. Although incomplete, records show that, except for 2 or 3 years, the total annual menhaden catch from 1912 to the beginning of World War II remained relatively stable, fluctuating between  $1.1 \times 10^8$  kg (118,000 tons) and  $3.7 \times 10^8$  kg (406,000 tons) and averaging  $2.2 \times 10^8$  kg (243,000 tons). The discovery of vitamin B12 as an important constituent of the animal protein factor found in fish meal made menhaden even more valuable, and following World War II the catch increased markedly. Growth of the fishery catch during the 1950s more than doubled. In 1981, more than 25 reduction plants received and processed the fish into meal, oil, and condensed solubles. Today, after many years of industry consolidation, only six major plants exist.

Most of the fish meal is used as animal and fish feed. While historically most of the fish oil was sold to Europe for use in the production of margarine, today, that picture has dramatically changed. To use menhaden oil for human use in the United States, it needs Food and Drug Administration (FDA) approval. Through research that began in 1977 and a successful petitioning of the FDA, partially hydrogenated menhaden oil was approved in 1989, for specific use in margarine in 1995, and as refined oil in various food products in 1997.

**Table 1.1** Menhaden figures for 1997.

Product	Amount	Value
Menhaden landings	1.482 billion lb (672 tons)	\$1.25 million
Meal produced	563 million lb	\$ 218 million
Oil produced	12 million lb (20 million gal)	\$60 million

As a major source of the heart healthy omega-3 fatty acids, menhaden fish oil will continue to be in demand as will meal for aquaculture (Table 1.1).

## The whaling industry

Whaling, too, has its place in history. This industry was well established in Europe before the American colonists took up the work. There is also evidence that the Native Americans practiced offshore whaling. Whaling to some meant food, but more important was the use of whale oil for lamps and candles. These by-products stimulated the industry's growth.

Early in colonial history, Boston was the center of the whaling industry, then Nantucket, and finally New Bedford. Bigger, stronger ships were built that became factory, home, and storehouse, all in one. Expeditions for the sperm whale often lasted as long as 3 or 4 years.

The need for whale oil declined sharply after oil was discovered in Pennsylvania in 1859, and the East Coast industry suffered further decline when the New England whaling fleet was destroyed during the Civil War. The opening of the West shifted the focal point of the industry there. Bowhead whaling from California to Alaska replaced most of the East Coast fishery. By the end of the 1800s, whales in the Northern Hemisphere were becoming scarce. Therefore, world whalers turned their sights to the Antarctic. In 1931, there were 41 whaling factory ships operating with an annual catch of about 40,000 whales. With sailing restrictions during World War II, the industry declined again.

In 1946, the International Whaling Commission was established to place restrictions and quotas on the taking of certain species of whales that were becoming rare and were in danger of extinction.

In 1971, the US government, in support of the commission and yielding to public pressure,

ordered an end to whaling by US fishermen; the only exception was that Alaskan Eskimos could maintain a small catch for sustenance purposes only. To further discourage worldwide whaling, the United States forbids the sale of whale products.

## An overview of our heritage

Ports such as Gloucester, New Bedford, Boston, San Francisco, Monterey, San Pedro, San Diego, and Seattle were home to some of our earliest commercial companies.

Let your imagination wander back to the sights, sounds, and activities of such famous places as the Boston Fish Pier, New York's Fulton Market, Monterey's Cannery Row, or San Francisco's Fisherman's Wharf: two and three masted schooners pulling up to the wharf with sails down and holds open; baskets of fish being lifted ashore; carts filled to overflowing with fresh fish being pushed across the wharf to waiting fish skimmers in old, oak timbered market stands; teamsters whistling and cracking their whips over horse-drawn wagons piled high with barrels and wooden boxes of dried and salted fish.

Out of this profusion of activity grew many familiar seafood companies. The following names and dates are not all-inclusive but serve as examples of certain periods of early industry growth (Table 1.2). These names represent some of the many pioneers of our seafood heritage. Today's industry numbers more than 2500 companies engaged in the many facets of processing, selling, and distribution of some 350 varieties of fish and shellfish.

Consider the expressions borrowed from our sea heritage: a fish story, windfall, blubber, taut ship, salty tale, flounder around, he's a little shrimp, that's a whale of a story, and so on.

As the country expanded and developed, so did the industry. Gone are the days of running down to the wharf at dawn to choose dinnertime delicacies. Gone are days of the fishmonger calling, "Fresh fish! I got fre-e-e-esh fish!" Gone are those fish markets with sawdust on the floor. Gone are those early model trucks carting fish and seafood to hotels and hospitals.

Refrigeration, jet planes, modern processing methods, and supermarkets are the symbols of our age that find people eating fresh fish and seafood in inland cities far from the seven seas. Yet, just as

**Table 1.2** Names and start dates for some fishing companies.

Name	Year started
Booth	1848
Smith Brothers	1848
Gorton-Pew Fisheries	1849
Caleb Haley & Company	1859
New England Fish Company	1868
Paladini Inc.	1868
R.W. Claxton	1881
Isaac Fass	1883
Salasnek Fish House	1891
Crocker & Windsor	1895
Standard Fish Company	1895
Tilghman Packing Company	1897
San Juan Fishing & Packing Co.	1903
Mid-Central Fish	1905
Bumble Bee	1906
Marshall Smoked Fish	1908
Vita Food Products	1910
Los Angeles Smoking & Curing	1912
Lynch Foods	1912
Eacho Fish Company	1914
Farmers Seafood	1918
Burhops	1926
Slade Gorton	1929
Certi-Fresh	1932
Morley Sales	1933
J.J. Camillo	1934
J.W. Ferguson	1938

today's processors, producers, or distributors take pride in the advancement of their industry, so did yesterday's peddlers take pride in their trade. There is no business like the fish business . . . now or then.

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# 2

## Harvesting Techniques

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George J. Flick, Jr.

Fishing, born from the need to gather whatever food nature provided, was one of the earliest methods of obtaining food. Little is known about how early fishing tools developed. It is known that ancient man fashioned hand spears to hunt animals, and it is likely that these weapons also served as the first devices for capturing fish. Indeed, these simple spears served as a prototype for more advanced wounding gear.

A tool called the gorge is known to have been used in the Paleolithic era some half a million years ago. It was a short, straight, or curved piece of wood, bone, or other material sharpened at both ends that we speculate was baited and attached to the end of a fiber line. When struck by a fish, the gorge would wedge in its mouth. Although not documented, it is suspected that during this same period our ancestors also learned to entrap fish in small rivers, bays, and inlets.

Historically, much of the basic gear used by modern fishermen was developed in Neolithic times, roughly 10000 BC. Barbed hooks, nets, gaffs, sinkers, and fiber lines were used by the Egyptians, Greeks, and Romans during this period. The Mayan and Aztec tribes of Central and South America reportedly used the hook and line, net, harpoon, and trap, and as early as 1500 BC, Chinese fisher-

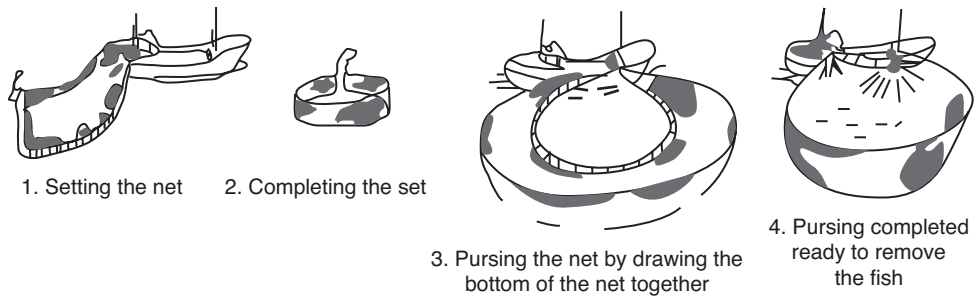
men of the period were known to use spun-silk fishing lines.

The pace at which we moved from ancient fishing methods and primitive gear to today's modern techniques has varied considerably. Two factors influencing this evolution were the need to catch fish in bulk rather than singularly, and the need to expand fisheries from shallow waters to greater depths. Today, many variations of the net, trap, and hook and line have evolved for specialized fisheries. The greatest changes have come in the materials and design of these nets and traps, in the methods of detecting fish, and in the boats rigged for fishing.

### Classification of harvesting techniques

Techniques for harvesting fish involve (1) fishing methods, the ways in which fish may be captured, and (2) fishing gear, the implements or tools used for that capture.

With the hundreds of fish and shellfish species of commercial importance, each with its own characteristic habits and environment, modern fishermen have to use a variety of fishing gear and methods. One common way to classify harvesting techniques is to group them by the gear employed. Fishing



**Figure 2.1** The operations are basically the same in both one-boat (above) and in two-boat purse seining. The net is set (far left); the set is completed in a one-boat operation (the second from left); the net is pursed by drawing the bottom of the net together; and the pursing is completed in preparation for removing the fish (far right).

gear used today may be grouped into the following categories:

- (1) Encircling or encompassing gear (seines)
- (2) Entrapment gear (pound nets, traps, and pots)
- (3) Lines (troll line and longline)
- (4) Scooping gear (reef net and fish wheel)
- (5) Impaling gear (harpoon and spear)
- (6) Shellfish gear (dredges, rakes, tongs, wrenching gear, and clamps)
- (7) Entanglement gear (gillnets or trammel nets)
- (8) Miscellaneous and experimental gear

Certain gear such as the harpoon, fish wheel, and some experimental devices are of little commercial significance in world of fisheries, so they will not be discussed in detail. Nets of all types are grouped together and discussed first, since fishnets collectively take most of the world's commercial fisheries catch.

## Nets

There are two main types of nets: nets that are used in motion that are drawn, hauled, or towed and nets that remain stationary or static. Nets are designed for the habits and environment of the fish they are intended to catch. Therefore, some are designed to work at the bottom, others at mid-water, or at the surface.

### Nets in motion

The purse seine is a motion net designed for and especially effective in the capture of schooling fish such as mackerel, tuna, sardines, salmon, herring,

and menhaden. All purse seines work on the same principle: a wall of net is used to encircle a school of fish. The top of the net is fitted with numerous corks or floats for support, and the bottom of the net is weighted to keep the wall of webbing in an upright position. A pursing cable (purse line) is threaded through rings sewn onto the bottom of the net to allow the fisherman to close off or purse the bottom of the net, thus trapping the fish in an inverted umbrella-shaped enclosure. The basic operation of the purse seine is similar to closing off the drawstrings of an old-fashioned purse.

There are essentially two techniques used to set and haul purse seines. The two-boat system is commonly used on the East and Gulf coasts of the United States in the menhaden fishery (Figure 2.1). This system utilizes two small seine boats that are lashed side by side and towed behind a larger carrier or mother ship when on the fishing grounds.

The seine boats are shallow-draft, open boats usually constructed of aluminum and vary in length from 9.7 to 10.9 m (32 to 36 ft). They are hung from the carrier vessel, one on each side. Half of the seine net is carried in each seine boat. The menhaden purse seines used in the two-boat system average 200 fathoms (365.8 m/1200 ft) in length and 10 fathoms (18.3 m/60 ft) in depth.

Spotter aircraft accompany the seine boats in the search for schools of menhaden. When a school is spotted, the two seine boats begin setting their respective ends of the net. This operation is directed from the spotter aircraft. The seine boats deploy in almost opposite directions, eventually forming a circle around the school. When the two boats meet to form the circle, the ends of the purse line are



run through pulleys on either side of the seine, which are attached to a heavy lead weight called a tom. The tom is sent overboard and the ends of the purse line are then hauled together with the aid of a hydraulic power block.

After pushing the seine, the tom is retrieved and the wings of the seine are hauled into the seine boats using power blocks. The fish are gradually concentrated in the bunt, a section of the net made of heavy twine, positioned between the two seine boats. Once the carrier vessel is alongside, the cork line is secured to its side to form a tight pocket from which the fish cannot escape. A flexible suction hose, attached to a centrifugal pump, is then lowered from the carrier into the net, and the fish are pumped into the hold.

One-boat seining is generally practiced on the Pacific Coast of the United States in the salmon, anchovy, mackerel, and tuna fisheries. The size and design of the West Coast seines differ depending on the species being harvested and local regulations. Seines carried on tuna boats are typically the largest, up to 10,973 m (3600 ft) long and 91 m (300 ft) in depth.

In one-boat seining, the net is carried aboard the carrier vessel (seiner), with an auxiliary boat assisting in setting and hauling it. When a school is sighted, the seiner is maneuvered into position to head off the school. The skiff is put down, and one end of the net, including the purse line, is put into the water and held in position by the skiff. To surround the school of fish, the skiff begins towing away from the seiner as the larger vessel encircles the fish. At the close of the net, the skiff and the seiner turn toward each other. After the skiff comes alongside, the seine is pursed from the seiner and then hauled aboard using a power block. Fish are then brailed (captured with dip nets) or pumped into the hold.

Drum seining is a version of purse seining used exclusively in the Pacific Northwest. The operation of drum seining is similar to the one-boat operation just described. It differs only in that a large drum, usually hydraulically powered, is mounted at the stern of the seiner, and the entire net is spooled during hauling.

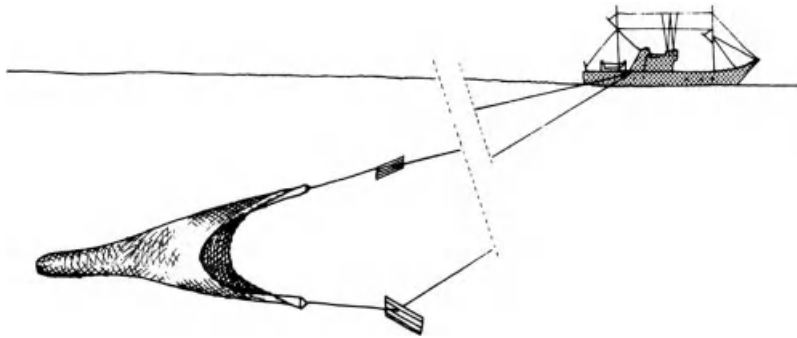
The lampara net is an encircling type net, which is considered the forerunner of the purse seine. The lampara was introduced by Italian fishermen in California in the late 1800s (Browning, 1974). It is shorter and shallower than the purse seine and

can be set and hauled in less time and with less power. It also lacks rings but has a relatively large, simple bunt area and comparatively short wings. The mesh in the wings is generally large; in the bunt, it is very small. The gear is set in a circular fashion, similar to the purse seine, and hauled by pulling both wings simultaneously. Lampara nets were used in the defunct California sardine fishery, along the West Coast to take bait for the tuna fishery, and throughout the West Coast mackerel and squid fishery.

Haul or beach seines are the simplest type of seining net. The haul seine, a long strip of netting with the head line (cork line) buoyed and the ground line weighted, is operated from shore. One end of the net is retained on land and the other is drawn through the water encircling the school of fish, and brought back to land. Smelts, shad, striped bass, croaker, bluefish, and weakfish can be caught with haul seines. Another form of setting and hauling a seine is to work with two boats. The bunt end is placed furthest from the beach and the boats proceed to shore with as wide a distance between them as possible. Once the boats are near shore, the net is drawn toward the shore and the fish are removed with hand nets. Some seine nets have a section (called the bunt or bag) more or less in the middle to hold the catch. Another type of seine has a pocket along the lower edge of the gear adjacent to the lead line.

Trawling is the most important fishing method used to harvest demersal (bottom fish) species such as cod, haddock, rockfish, flatfish, shrimp, which normally inhabit waters near the seabed. The trawl is a conical-shaped net with a wide mouth that tapers to a sock like or cod end in which the fish collect. Trawl nets consist of the upper and lower nets, joined together at the sides with the upper net extending over the lower net like a roof.

Trawls are subdivided into several categories depending on the method used to spread the net mouth open. In the United States, two trawling techniques are used, the beam trawl and the otter trawl, which is by far the more important (Figure 2.2). These nets range up to 30.5 m (100 ft) across the mouth with a depth of 6.1 m (20 ft) and length of 45.7 m (150 ft). The otter trawl uses two otter boards (or doors) attached by bridles to the wings of the trawl. The boards spread the trawl mouth horizontally. Towing warps (cables) are attached to the opposite side of the boards.



**Figure 2.2** Otter trawl net.

Floats give the headrope buoyancy, which together with a weighted line at the footrope or groundrope keeps the mouth of the trawl open. On rough fishing grounds, the groundrope may be fitted with wooden or steel rollers to assist the net in getting over rocks and debris.

On traditional East Coast or Atlantic otter trawlers, large trawl winches are placed just forward of the house. The trawl nets are shot (set) and hauled from blocks secured to two heavy A-frame gallows mounted on one side of the vessel, usually starboard. In operation, the cod end goes overboard first, followed by the mid-section, wings, and doors. When the doors are properly set and spaced, the warps are paid out rapidly and the vessel gains speed slightly. When the net sets on the bottom, the warps are drawn together near the stern. Trawling speed is usually between 2 and 5 knots (3.7–9.3 km/h) depending on which fish species is being targeted. Trawling time ranges from thirty minutes to three hours. The process is reversed in hauling back. When the net is alongside the vessel, the doors are hooked to the gallows frames and the bulk of the net is hauled in with the help of quarter ropes. When enough of the trawl is aboard, the cod end is hoisted over the rail by a haul line. Once the cod end

is aboard, the fish are released on deck by loosening its puckering strap.

On the West Coast, a somewhat different technique is used in operating otter trawl gear. With the possible exception of some halibut schooner vessels, which by design may still use the side trawl method, a large majority of the Pacific trawls are shot over the stern (Figure 2.3). Typically, trawling is carried out by Pacific combination vessels that operate both in the seining and trolling fisheries. When trawling, a pair of gallows frames are secured on each side of the stern with the winch mounted aft of the pilothouse. The combination boats may also use hydraulic drums to assist in setting and hauling the trawl, which is spooled onto the drum from the stern with only the cod end strapped over the side. On some modern vessels, stern ramps have been constructed so that the entire trawl can be hauled from the stern.

In the early 1900s, the shrimp industry switched from haul seines to trawls. Shrimp trawls are much like the East and West Coast otter trawl used for bottom fish, except they are generally smaller and lighter. Shrimp trawlers use double towing booms or outriggers secured to both the main mast and to a larger lifting boom. The towing booms can be



**Figure 2.3** Side trawling (left) and stern trawling (right).



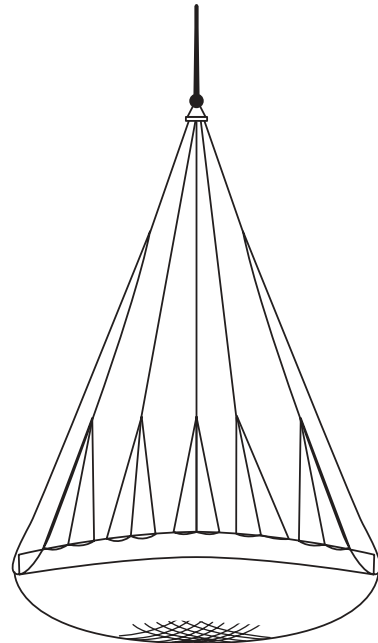
rigged to pull one or two nets. In operation, the net is towed from warps, which pass from a winch just behind the pilothouse through a block at the tip of the towing boom. In single rig towing (one net), the two warps pass through blocks on the same boom, and in double rig towing (two nets), a single warp for each net passes through blocks at the end of each boom.

Over the last few decades, the beam trawl has been replaced by the otter trawl, which is more efficient in handling and fishing. In beam trawling, a tapered wooden beam is used instead of otter boards to spread the mouth of the net. To the ends of the beam, U- or D-shaped runners are attached. The trawl, about 7.6 m (25 ft) long and tapering to a narrow pocket, is secured directly to the beam and runners. Beam trawls are operated similarly to other trawls, except they are always set from the ship's stern. Modern beam trawling is usually performed according to the double-rig system, one-beam trawl on each side of the vessel (sometimes called twin trawling or twin rig trawling).

Pair trawling involves the use of two equal vessels. There are several advantages to pair trawling: first, double towing power is available when two vessels cooperate, and second, the net size can be substantially increased so that increased yields can be achieved. One advantage of this fishing method is that the fish are not frightened since the vessel does not travel across the fish school nor do they tow their warps through the fish.

Many fish do not live directly on the bottom but near the surface or somewhere between the surface and the bottom. Trawling gear has been developed capable of fishing the entire water column above the bottom. One method used is to suspend the net by means of floats on the water's surface. The desired depth can be achieved by adjusting the connecting lines between the floats and the net. One disadvantage is that the depth of the net cannot be changed if the fish are descending or ascending. Another approach to mid-water trawling is to regulate the speed of the towing vessel and the length of the warps.

Cast nets are circular nets that are thrown by hand (Figure 2.4). The nets are best used on smooth bottoms that contain no vegetation or debris. The nets can have a diameter from 2 to 7 m (6 to 21 ft). The nets sink quickly due to weights around the circumference of the net. These weights are also important in keeping the net open when thrown. Once at the



**Figure 2.4** Cast net with central line connected with pockets.

bottom, a central line attached to several string lines close the net during its return to the surface.

### Stationary nets

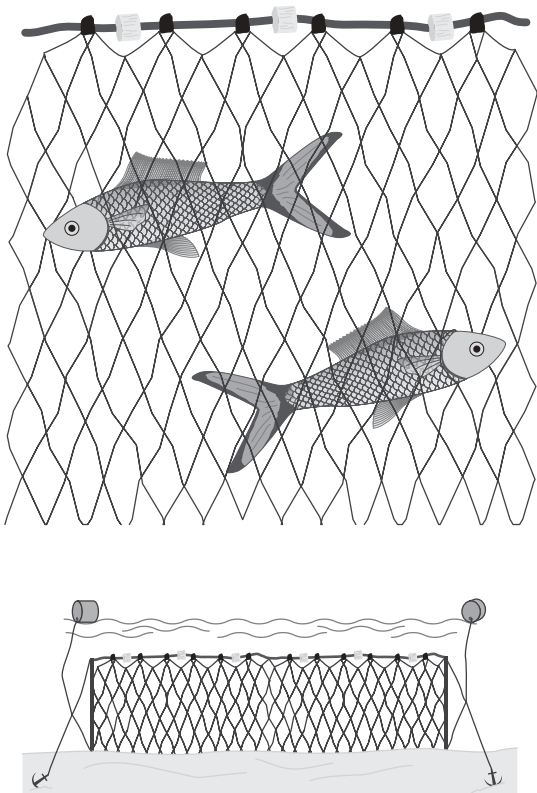
The gillnet is one of the oldest types of stationary nets. Browning (1974) observed that gillnets are apparently a logical, evolutionary development of the simple haul seine. As the name suggests, gillnets are designed to catch fish by the gills as they swim into it. The fish are held or become entangled in the net by their gills as they struggle to escape. The gillnet hangs vertically in the water, although some slack is built into the net to allow it to bulge. It is designed in this manner so fish swimming into a taut section of webbing do not bounce away from it but will entangle themselves.

Like seines, gillnets are vertical walls of webbing and are secured to a cork line and weighted lead line, which keep the net upright in the water column. The length, depth, and mesh size of gillnets vary with federal and state regulations as well as with the fish species being targeted. Two basic forms of gillnet are commercially important in the United States, the drift net in its several forms and the set or anchor net. Drift nets are typically used on the high seas; set nets are most often used for

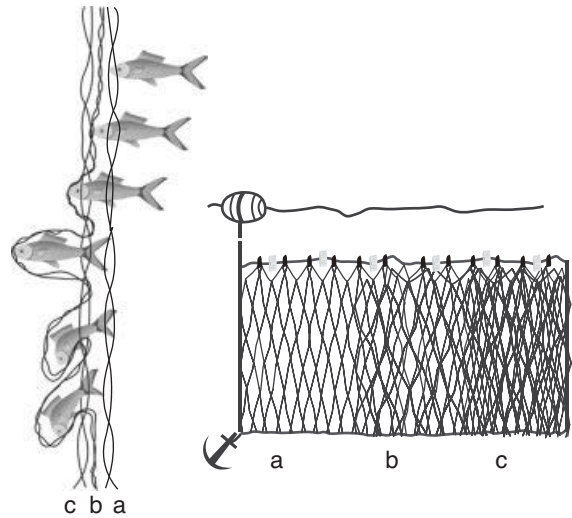
inshore fisheries. The drift gillnets, designed for pelagic (surface or mid-water) fish such as mackerel, salmon, and saithe, are rectangular and are usually fished in a straight line. Drift nets are commonly set at the surface but can also be fished at intermediate depths or near the bottom. Different sets are made by varying the float and weight rigging.

Since gillnets are typically hung and float from the surface, they are visible to the fish and, therefore, are usually fished at night. Once set, drift nets are allowed to drift anchored. Fishermen use marker buoys, or sometimes lanterns attached to floats to follow the drift of the net.

Set gillnets are put out along the seafloor to catch bottom living fish, such as mullet cod and flatfish. These nets can be held in place by anchors or stakes when the set nets are fished from shore or shallow water. Some gillnets are set so that they fish the middle water column. These nets are anchored to the bottom and supported by buoys (Figure 2.5).



**Figure 2.5** Gillnets.



**Figure 2.6** Trammel nets.

Trammel nets, sometimes called tangle nets, are derived from the gillnet (Figure 2.6). The nets have three sheets of netting suspended from a common cork line and attached to a lead line at the bottom. The middle net is of fine mesh, loosely hung; the mesh of the two outer sheets is usually three times larger than the center net mesh. Fish swimming against the trammel net draw the smaller inner mesh through one of the outer meshes and become trapped in the pocket that forms in the net. These nets are typically set in strings by one boat.

Gill and trammel nets usually remain set for 12–24 hours. They are hauled with the aid of a power roller, although the fisherman must manually assist to get a smooth winding of the net onto the reel. Most gillnet boats are rigged to work their nets from the stern. A noticeable exception exists in the Columbia River salmon gillnet fishery where small boats called bow pickers are rigged to haul their nets from the bow.

There is increasing public and government concern over the use of towed and static nets with respect to the capture of protected aquatic species and ghost fishing gear. The former concerns the incidental capture of certain animals, such as sea turtles and mammals. As a result, many nets are being developed with certain excluder devices. Ghost gear is lost fishing gear that continues to fish long after the gear has become lost. Large quantities of fish and some ocean birds can become permanently

impaled in the gear. Ghost traps have also become a problem in the crustacean fishery following the introduction of synthetic materials. Many pots can be lost during stormy weather, causing ghost pot fishing to approach 10%. Animals captured in a ghost pot have no chance of escape and eventually die. Their carcasses then become new bait and the traps continue to fish for an extended time period, even years. To prevent extended fishing by ghost pots, the nets are fitted with fibers that deteriorate after a short time and the net collapses ending its fishing ability.

### Trap and gear pot

A wide variety of traps and pots are used to capture fish and shellfish. Capture by trap gear generally depends on attracting fish or shellfish to pots by means of bait or by leading fish into an enclosure, which is the case with pound nets, trap nets, and weirs. Numerous variations in the form and construction of the trap nets are used in American fisheries, but we describe only a few of the more common. First, we cover weirs, as they are the primitive prototype of modern trap gears.

Weirs are usually set at a point of land that extends into the water for some distance or in channels, where the tide is strongest, to take advantage of the tendency of fish to stay in a strong current. The weir's main body is a large-circular or heart-shaped enclosure, constructed by driving long, heavy posts into the bottom, with smaller posts set closely between. In the traditional weir, fine brush is then interwoven between these smaller posts, horizontally on the lower portion and vertically in the upper part, which is visible at high tide. A lead of brush extends from the shore to the mouth of the trap. These leaders may be as much as 152.4 m (500 ft) long and extend inside the mouth 1.5 m (5 ft) or more. The openings at the mouth are made wide enough for a dory to enter and work the trap.

In most applications, netting has replaced the brush formerly used in the heart of the weirs. During harvesting, a dory enters the weir and the mouth is closed by dropping a net. In some weirs, seines are used to capture the fish; in others, the trap bottom is raised by means of pulleys, and fish are herded into one section where they can be brailled or pumped on board.

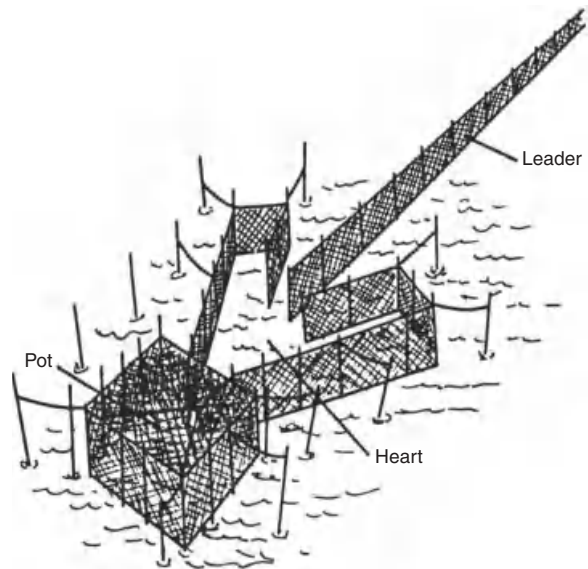
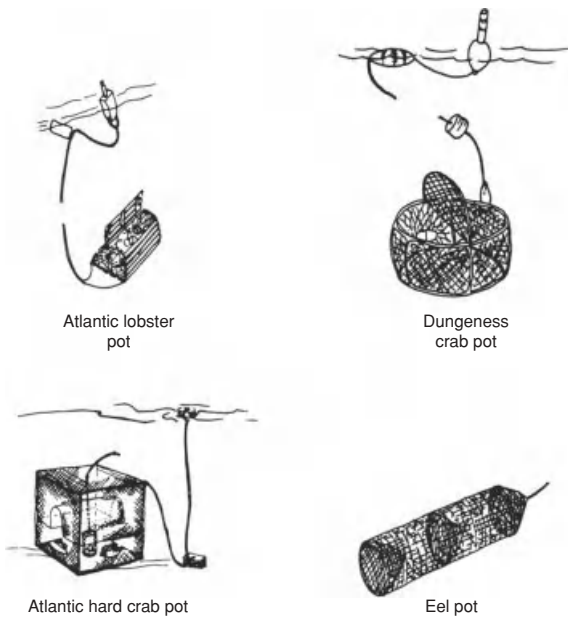


Figure 2.7 Pound net.

Pound nets, which still see limited use in the harvesting of sardine, salmon, and other fish, are slightly more complex than the fish weir. In its simplest form, a pound net consists of three parts: (1) the leader, extending from the shore or shallow water; (2) the heart or wings, a heart-shaped enclosure that deflects the fish; and (3) the pot (Figure 2.7). The fish are captured and removed from the pot, sometimes called the crib, pound, or pocket. Some pound nets are designed with two or more heart pockets.

Leaders used to guide fish through the series of progressively smaller compartments are up to 244 m (800 ft) long. The lead extends into the entrance of the heart, and fish move from the heart into the pot through an opening called a gate, situated directly in the center. The pound net's pot, which varies in size, is composed of small mesh netting supported by large, anchored poles. This section, like its equivalent in the weir, often has a net bottom secured to the sides. When harvested, the bottom is raised and the fish are brailled or pumped from the pot. In larger pound nets, the fish are seined from the inner pocket.

Trap nets are similar in construction to pound nets except the former are supported by floats instead of by poles or stakes. The lead, heart, and pot of a trap net may extend 12.2 m (40 ft) up from



**Figure 2.8** Various pots and traps used in harvesting seafood.

the bottom but are completely submerged with only marker buoys visible at the surface.

Fish and shellfish pots or basket traps are one of the primary pieces of harvesting gear used for several commercially important species of crab and lobster. Other species commonly captured by this gear are shrimp, eel, crawfish, sea bass, and octopus. Dozens of variations in pot design exist, but only the more common pots used in the US fisheries are discussed here.

### Crab pots

On the West Coast, an important type of pot is used in the Dungeness crab fishery (Figure 2.8). The Dungeness crab is harvested in estuaries, bays, and along coastal shorelines, usually where smooth, sandy bottoms are found.

The pot is a circular, stainless steel frame, covered with soft stainless steel wire. It ranges in size from 0.91 to 1.22 m (36 to 48 in.) across and weighs 34.1 to 72.6 kg (75 to 160 lb). Usually, two cone-shaped tunnels are placed at opposite sides of the pot's rounded surface. The tunnels are ramp-like structures leading crabs to the opening (eye) and into the pot. The opening is constructed of small-diameter stainless steel rods equipped with single or double

triggers, which are free swinging, gate-like devices extending from the top of the opening downward across the bottom.

As the crab enters the pot, the trigger closes, preventing escape. The lower flat portion of the pot is weighted so that the pot will sink to the bottom. The lid, one-half the top portion of the pot, is hinged and when closed is held in place with steel hooks attached to rubber bands. A small ring opening on the top or side gives undersized crabs an escape route.

Methods of fishing with pots are generally the same, with only the baits, time of season, and vessel size differing. Pots are typically baited with herring, squid, or shad and are set in rows, with varying lengths and number of pots. A single line and cylindrical plastic buoy attached to each pot marks the position.

When hauling, the crab vessel usually travels against the current, allowing time to gather in the buoys and start hauling the pot by the time the vessel is over it. Using a crab power block, the pots are taken aboard, emptied, and then baited before the next pot is hauled. An average boat can haul and reset about 300 pots a day.

Dungeness crab pots served, more or less, as the basis for the development of the Alaskan king crab and snow crab pot. The king crab pot is similar in construction but much larger and often rectangular rather than circular. The pots are 2.1–2.7 m (7–9 ft) square, 76.2–91.4 cm (34–36 in.) deep, and weigh 136.4–181.8 kg (300–400 lb). Like the Dungeness crab pots, king crab and snow crab pots are fished singularly from a buoy line.

Another important type of pot gear is used in the swimming blue crab fishery based on the East and Gulf Coasts of the United States as well as South America, Indonesia, China, Malaysia, and India. Blue crabs are smaller than Dungeness or king crabs so the pot size and design are substantially different. Blue crab pots, introduced to the Chesapeake Bay blue crab fishery in the 1930s, usually are cubical in shape, 61 cm (2 ft) square, and constructed of wire mesh or a rigid metal frame. The pots are divided into a lower chamber, which contains a bait holder and funnels or passageways from the outside, and an upper or trap chamber. Crabs enter the bait chamber through funnels located at the pot's lower edges and then after taking the bait, swim upward through an opening into the trap chamber. Crabs are removed by spreading an opening in one

seam at the top and shaking the crabs from the pot. Set singularly on buoy lines along the flat, sandy, or muddy edges of bays and channels in depths from 1 to 10 fathoms (1.8 to 18.3 m), the pots are usually lifted every day and are hauled by hand. While some pots are composed of various types of wood, the majority of the pots used today are constructed of plastic-coated steel wire, plastic, or galvanized wire. In order to extend the usable life of the pots, a metal bar is attached to prevent deterioration through electrolysis.

Other crabs caught in pots include the rock, stone, red, and Jonah crabs. Some crabs live in deepwater, the continental shelf, while others inhabit the inshore or estuarine waters.

### Lobster pots

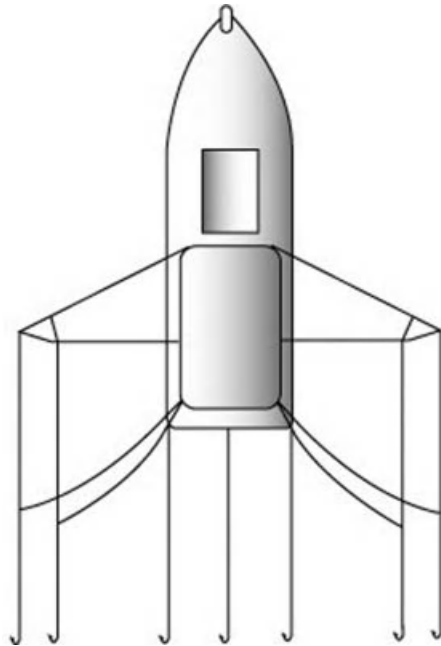
Three basic types of lobster pots used throughout the US fishery are recognized by their geometric shapes: the half round pot, the rectangular pot, and the square pot. These pots are usually constructed of wooden laths or wire. Nearly, all modern lobster pots consist of one or two funnels (heads) of coarse netting that slope upward toward the center of the net. The lobster enters through the funnel into the chamber compartment, or kitchen, in search of bait. After grabbing the bait, the lobster moves through a second funnel into another compartment, sometimes called a parlor, where it becomes trapped. It is removed through a door on top of the pot.

In the northern lobster fishery, pots are baited with fish like salted herring, menhaden, skate, and scup. The pots are either set on a single buoy or several may be attached to a long line called a trawl line and weighted so they rest flat on the bottom. Offshore lobster pots are set in trawl lines and are generally larger, heavier, and sturdier than those used in inshore waters.

Pots are hauled after soaking (fishing) one, two, or sometimes three nights, depending on the rate of deterioration of the bait and on the number of pots being fished. As with crabbers, lobster boats are rigged to store the catch live in seawater barrels or tanks.

### Hook-and-line fishing

Hook-and-line fishing has been used throughout the world for centuries. The objective of modern



**Figure 2.9** Example of the rigging of troll lines from Indonesia.

hook-and-line fishing, comments Alverson (1963), is to orient fishing lines to obtain maximum geographic coverage by the hooks while minimizing the effort needed to handle the gear.

Hook-and-line fishing can be divided into four categories: (1) hand lines, (2) pole and lines, (3) troll lines, and (4) longlines or setlines (Figure 2.9).)

Hand lines are important in the snapper, mackerel, sea bream fishery, and in some small inshore fisheries. In red snapper fishing, lines about 60 fathoms (110 m/360 ft) long, with two hooks at the end and a lead sinker placed about 1 fathom (2 m/6 ft) above, are set from the deck of the vessel when fish are located. The lines are forked at the end, providing room for two hooks, and are held apart by wire spreaders. Artificial spoons, or sometimes herring, are used as bait and the lines are retrieved using hand reels.

In major commercial fisheries, the pole and line method is most prominent in catching tuna- and mackerel-like fishes. The poles function to hold lines above deck level. A common rig has two or more poles set in sockets on each side of the boat, and two more lines are set from the stern. In the California tuna fishery, the ends of the poles are laced with a linen or nylon loop to which a 76–112 cm

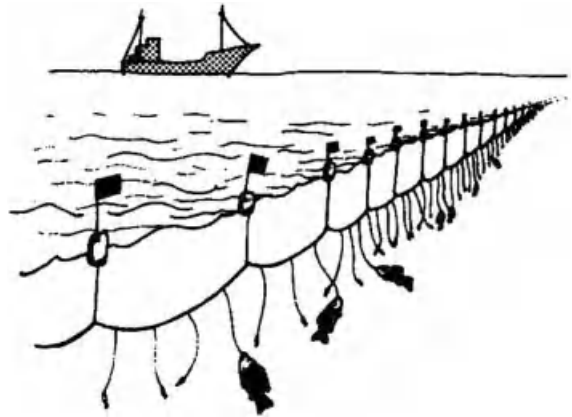


(30–48 in.) length of heavy cotton line is attached. From the cotton line, a wire leader is added, with a barbless hook baited with herring or a feather jig (two or more hooks embedded in a small metal fish-like lure) attached to the edge of the leader. In some fisheries, more than one line can be attached to one pole and one hook can be attached to more than one pole. Vessels involved in pole and line fishing vary in size and construction from small-motorized boats to larger diesel powered vessels. In the United States, yellowfin, skipjack, and albacore tuna are the principal species harvested by this method.

Trolling adds motion to the bait or lure being used. Simple trolling may be conducted by one line, although the modern troll fisheries, such as that for Pacific salmon, mackerel, tuna, and marlin use as many lines as possible. Large outriggers or spreader poles are used to space the lines, which are rigged with numerous lures or baited hooks. At the end of the trolling line, “cannonballs,” 4.5–22.7 kg (10–50 lb) weights, carry the lines to the desired depth and help prevent fouling. Several lines (normally up to 18 lines but sometimes greater than 20) can be fished from each outrigger, and as many as 15 lures or baited hooks are attached to each line. In addition to the use of one or more beams (outriggers) that can range from 5 to 22 m (15 to 66 ft), the lines may be set to varying depths by the use of weights, shearing boards (planers) or otter boards may be used to spread the lines over a wide area to prevent tangling. The number of lines and lures trolled varies with the species sought and is sometimes governed by conservation laws.

Depending on the target species, lures or baited hooks can be fished from the surface down to 80 fathoms (146 m/240 ft). During fishing, the trawler moves forward at the desired speed giving action to the lures. In the salmon fishery, lines are hauled by reels or spools known as gurdies. These gurdy assemblies can be worked by hand but are more often powered by motor or hydraulics.

Longline or setline fishing uses a main or groundline that has a number of short branch lines (droppers, gangens, or offshoots) where baited hooks are attached. Longlines, which may be fished on the bottom, at intermediate depths, or near the surface, have the advantage of needing fewer people to handle the large number of hooks that are fished over a wide area (Figure 2.10). The halibut fishery of the Pacific Northwest is one of the world’s principal longline fisheries. Here, the groundline consists of



**Figure 2.10** Longline sets.

a single string of ten skates (the primary unit of the longline) of 300 fathoms (549 m/1800 ft) each. Hooks are attached to gangens spaced along the groundline. Each skate, with 80–120 evenly spaced hooks, is coiled and baited prior to fishing. Some fishing boats may deploy from three to five branch lines with as many as 2000 hooks. Some longline boats may haul up to 3200 hooks a day. Setting 2000 hooks may require 4 hours while hauling 3200 hooks can require 15 hours.

When setting the gear, a flag connected to a pole with or without a light attached at the top buoy keg, and anchor are put over as the vessel runs ahead. As the vessel continues on course, the longline is played out through a chute on the stern.

A line vessel may set any number of skates to form a string of gear. When the complete string has been set, another anchor line and float marker are dropped.

After the gear has been adequately fished, one end of the longline is picked up and the gear retrieved using a power gurdy. As fish are brought to the surface, they are gaffed and lifted aboard. During the process, the lines are recoiled, baited with herring, octopus, or other baits and readied for the next set. Pelagic species can be fished with longline by rigging the groundline with floats.

Schooners and West Coast combination vessels are the most often used vessels in the halibut longline fishery. However, longline gear can be fished from almost any properly equipped vessel.

Cod, saithe, and squid are sometimes caught by jigging. Approximately 10–15 hooks are attached to a line that is operated by a machine. The machine

lets the line sink to a predetermined depth and then starts the up and down motion at a predetermined speed and range. When a fish becomes impaled on a hook, the line is brought to the surface and the fish removed from the hook. Normally, one person monitors two jigging machines and can land fish equally well as six individuals with a hand line.

### Shellfish dredging and scooping gear

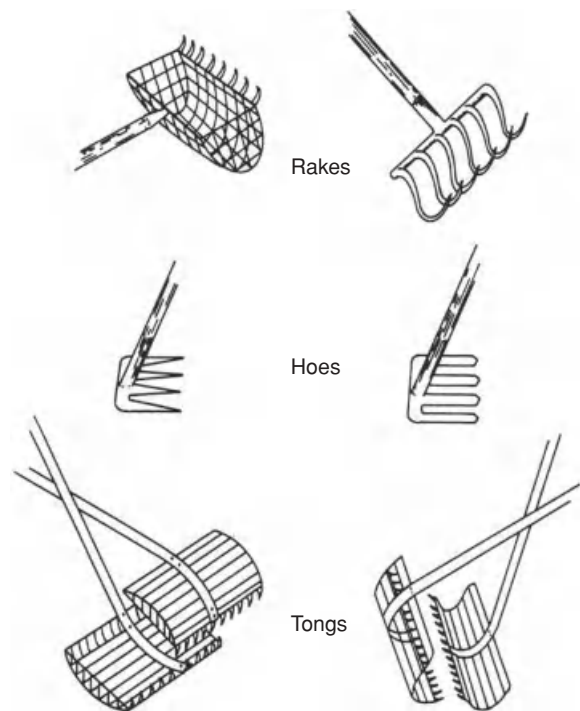
Shellfish such as oysters, clams, mussels, and scallops are sessile (not free-moving) marine animals and hence are harvested by different means than other marine species. Some simple devices popularly used for taking these shellfish include shovels, tongs, and rakes. A somewhat more sophisticated technique, which uses gear known as a dredge, is found in oyster, clam, and scallop fisheries.

Tongs consist of two rakes fixed to the ends of long wooden poles and hinged together with rake-like teeth facing each other. A basket-like frame is attached to each rake to collect the oysters. Oyster tongs typically fish oyster beds or reefs from small wooden, shallow draft boats usually powered by outboard motors.

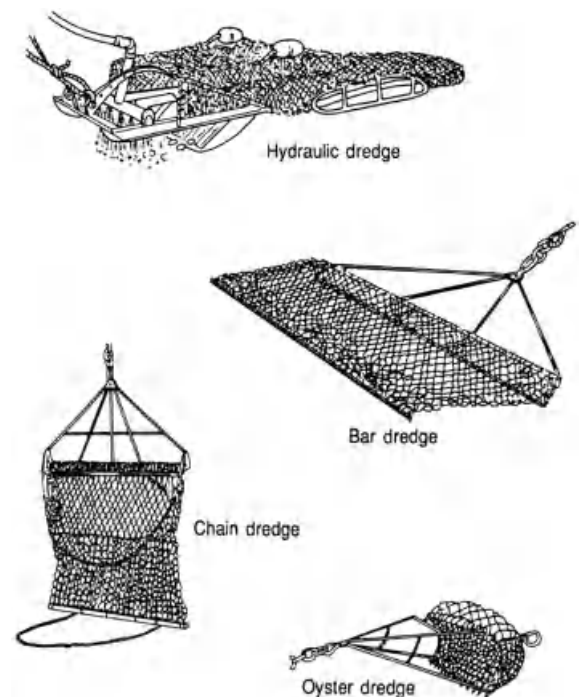
The fisherman stands on the deck of the boat, lowers the tongs to the bottom, and by opening and closing the handles, scoops up a quantity of oysters between the heads (Figure 2.11). The tongs are lifted and the oysters piled on deck. Although slow and laborious, this method is still practiced in many areas because of the limited investment in gear. In some areas, tonging is the only method available, as dredges are often considered destructive to natural reefs and are therefore prohibited on public reefs (Figure 2.12).

Oyster dredging boats tow a dredge or drag consisting of a metal frame that has a toothed “raking” bar across the front, which in turn is attached to a bag-shaped net made of metal rings. The frame is connected to a towing cable by a triangular A-frame. As the dredge is towed across the reef, the rake bar dislodges the oysters, and they roll back across the drag bag into the metal mesh bag. When the bag is full, the dredge is lifted and the contents dumped onto the deck.

Specialized suction and scoop dredges are also used in this fishery. A suction dredge creates suction at the head of the dredge. Oysters and water are suctioned up to a continuous conveyor located on the



**Figure 2.11** Hand-operated tongs and rakes used in seafood harvesting.



**Figure 2.12** Dredges.

deck. The scoop type harvester consists of a rake-like dredge with steel teeth. The dredge, which rests on runners to prevent excessive digging, is attached to a chain conveyor. In operation, oysters raked by the dredge are scooped by conveyor's loops and carried to the deck.

Clams and mussels are taken by various types of rakes or by dredge. A regular clam rake is similar to a common steel garden rake except it is heavier and has longer, sharper teeth that are spaced about an inch apart and are curved distinctly upward. Clam rakes varying in widths and handle lengths are designed for shallow water digging. A basket rake is one adapted for digging clams in deep water with a handle that may be 11 m (35 ft) long, much longer than the regular clam rake. The end of the basket rake handle is fitted with a crosspiece to aid in dragging it across the clam bed, and a basket of wire or netting is attached to the back of the rake to hold the clams. A third rake used in harvesting clams, the bull rake, has a long handle like the basket rake but does not have a mesh basket attached. The bull rake is designed much like the regular clam rake only it is wider and has more teeth. All clam rakes can be operated from small boats, but the regular clam rake can also be handled from shore. In either case, the teeth are worked into the sand or mud of the bottom, and the rake is then pulled in and lifted out of the water.

As in the oyster fishery, the majority of clams are taken by dredge. Clam dredges are operated with or without hydraulic equipment. The hydraulic or jet dredge is most often used for surf clams and ocean quahogs because of its effectiveness in extracting these mud burrowing clams. During operation, pressurized water supplied by a hydraulic pump on board the vessel is pumped through jets located in front of the toothed bar. The jets of water loosen the bottom, allowing the clam to be scooped more efficiently. The hydraulic dredge may collect the clams in a metal ring bag or deposit them directly on deck via a conveyor.

Essentially, all commercially harvested scallops are taken by dredge. The scallop dredge consists of an iron framework about 91–46 cm (3–1.5 ft), with an attached netting bag, which will hold one to two bushels of scallops. A single scallop boat often pulls several dredges across the scallop grounds.

Among the many scallop dredge styles, the scraper is one of most popular. It has a rigid, triangular iron frame; a raised crossbar connecting

the two arms; and a lower strip of iron, about 5 cm (2 in.) wide and set at an angle, for digging in the sand.

## Hand picking

The major types of seafood harvested by hand are sessile or slow-moving animals. These include mollusks (clams, oysters, and cockles), snails, some small crustaceans, and echinoderms. Other objects include plants (primarily seaweeds), turtles, alligators, and crocodiles.

Abalone, octopi, sea urchins, crawfish, sea cucumbers, sponges, and sometimes oysters are harvested by divers who use various hand tools to gather the shellfish. The catch is stored in a net bag until it is full, then it is raised to the surface and emptied by a second fisherman tending the vessel. Although tedious, this method is extremely selective. Depending on the water temperature, divers may use no protective outerwear, insulated suits, or have warm water pumped into an insulated suit. While some animals are taken by the barehand, some small tools are used such as pry bars, knives, hooks, tweezers, spears, and harpoons.

## Fishing optimization

Fish schools are customarily located by means of the fishing vessel's sonar. This identification enables the net to be deployed to the proper depth and also permits the success of the fishing operation to be evaluated. The use of acoustic detection not only determines the fish's position in the water column but also identifies the species and amount of the biomass. By identifying the species, it is possible to avoid unwanted species. Satellites have also been used to determine water temperatures and ocean upwelling so that a species specific directed fishery can be initiated.

## Miscellaneous and experimental gear

Here, we briefly describe some additional fishing methods, which either have a limited impact on commercial fisheries or are still in the experimental stage of development.



Jigging is a hook-and-line technique used most notably to harvest squid, although it is not used to any significant extent in US fisheries. Jigging involves setting a line with baited hooks or lures; then a jigging machine provides a constant jerking motion on the line to induce fish to take the hook.

Harpooning is of great historical but declining importance. It is still the major method for taking whales, but whaling has been banned by most nations including the United States. Swordfish, shark, and tuna are still taken by harpoon, although longline methods have all but replaced it. In practice, harpoons can be thrown by hand or shot from a gun.

Gigging is another method used primarily by sport fishermen. The fisherman, using a spear-like instrument called a gig, wades through shallow waters and spears or gigs the fish when it has been spotted. Flounder are often caught by this method.

A number of fishing techniques rely on physical or chemical stimuli such as light, electricity, and odors. Most of these methods are experimental, although lights already have practical application and are used in a variety of fisheries to attract fish into traps or to aggregate them so they may be netted. Lights are used to capture baitfish and are used extensively in the eel fishery. Although electricity for shocking or guiding fish has been used experimentally since World War II, it has not yet been employed extensively in marine fisheries.

Fish are sometimes harvested by poisoning (use of toxic plants or chemicals) and electricity. The

success of electrical fishing depends on the conductivity of the water and water temperature. Low conductivity increases the effect on fish while high conductivity decreases the effect. A low temperature increases the conductivity so that electrical fishing may not be successful in certain waters during the summer but would be successful in winter.

## Acknowledgment

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# 3

## Groundfish

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George J. Flick, Jr., and Laura S. Douglas

### Introduction

In commercial fishing, groundfish (or bottomfish) are defined as those species that feed or swim near or on the bottom of a body of water. Sometimes referred to as demersal organisms because they live close to the bottom of a body of water that is limited by the continental shelf. On the East Coast of the United States, this range extends out over 322 km (200 mi); the West Coast has a much narrower shelf extending only about 16 km (10 mi).

During the last 20 years, many groundfish stocks have been depleted due to overfishing and the groundfish fishery was declared a crisis in the 1990s. In the United States, the past century has witnessed overexploitation and subsequent collapse of one species after another. The East Coast groundfish like Atlantic cod, haddock, yellowtail flounder, Atlantic halibut, and ocean perch, which once fed millions and supported booming industries, are depleted and now regulated under fishery management plans (FMPs) in the hope of achieving some recovery (Northeast Fisheries Science Center, 2004; Mayo and O'Brien, 2006). The West Coast groundfish fisheries have fared no better non-whiting groundfish landings peaked in 1982 and declined every year from 1989 to 1999. In 2000,

landings fell by 50% from the previous year. The West Coast groundfish fisheries were declared an economic disaster on January 26, 2000, by the US Secretary of Commerce. In 2002, nine West Coast groundfish species were declared overfished (Conway and Shaw, 2008).

The US fisheries are not alone in these tumultuous changes. In Canada, conservation efforts came too late in some regions and certain Atlantic cod fisheries were shut down indefinitely and some species are now listed as endangered (Conservation Law Foundation, 2009). Despite these efforts, the stocks have yet to recover. In the North Sea, Irish Sea, and west of Scotland, similar concerns exist and there is a call for a complete ban on Atlantic cod fishing and for recovery plans to be developed (International Council for the Exploration of the Sea, 2003).

But there was some good news in 2008, groundfish species not only occupied the number one spot (based on weight) on a list of the major US species landed (this honor goes to pollock) but they also held four of the top ten spots on the same list. And, in a similar list ranking the top US species based on value, groundfish also held four of the top ten spots (Van Voorhees and Pritchard, 2009). In 2008, the Pacific trawl fishery landed a total of 1.8 million metric tons (mt) (4 billion lb) of fish (all groundfish

**Table 3.1** US commercial East Coast groundfish landings of top species in 2008.

Species	2008 Landings (metric tons)	Overfished?	Overfishing occurring?
Goosefish	10,937	Yes	Maybe
Atlantic pollock	9965	No	No
Atlantic cod	8652	Yes	Yes
Haddock	6350	Yes	No
Silver hake	6280	No	No
Summer flounder	4095	No	No

Source: Brodziak and Traver, 2006; Mayo, 2006; Mayo and O'Brien, 2006; Richards, 2007; Van Voorhees and Pritchard, 2009; National Marine Fisheries Service, 2009e.

species), which were worth \$815.2 million. The North Atlantic trawl fishery (mostly groundfish species) had landings of 44,271 mt (97.6 million lb) in 2008. The two sets of landings combined accounts for over 50% of the total commercial fishery landings in the United States in 2008 (Van Voorhees and Pritchard, 2009). So, in spite of declines in stock and more restrictive regulations, groundfish are still a valuable fishery.

Tables 3.1 and 3.2 list the major fish species caught on both the East and West coasts of the United States.

## Historical perspective

### East Coast fishing industry: a historical perspective

The fishing industry along the East Coast of the United States, particularly in the New England region, has been identified with and supported by groundfishing for the past 400 years. It is often

considered the first colonial industry in the United States, and it has supported numerous other industries during its ebbs and flows. However, 400 years of changes in technology, productivity, and demand combined with overexploitation and disregard for scientific advice ultimately led to the collapse of numerous species and the decline of many fisheries and associated industries (Northeast Fisheries Science Center, 2004).

Groundfish products like flounders, Atlantic cod (hereafter referred to as cod), haddock, pollock, hake, cusk, and ocean perch continue to play a major role in the US fresh fish industry, though the species are changing and the fish stocks are diminishing. In 1979, fresh and frozen groundfish fillets accounted for 68% of the quantity and 76% of the wholesale value for the fresh and frozen fillets from all species. Between 1998 and 2007, groundfish made up between one-fourth and almost one-half of the US supply of fillets and steaks (Van Voorhees and Pritchard, 2009).

The early 1970s were characterized as a period of stagnation for the groundfish industry in

**Table 3.2** US commercial West Coast groundfish landings of top species in 2008.

Species	2008 Landings (metric tons)	Overfished?	Overfishing occurring?
Alaska pollock	1,032,452	No	No
Pacific whiting	241,050	No	No
Pacific cod	224,055	No	No
Yellowfin sole	141,237	No	No
Atka mackerel	57,620		
Rock sole	52,979	No	No

Source: Van Voorhees and Pritchard, 2009; National Marine Fisheries Service, 2009g, 2009i, 2009m.

Massachusetts. Landings declined until 1977, averaging only about half of what they were in the early 1960s. Revitalization of the groundfish industry began in 1976 with the Fishery Conservation and Management Act (FCMA), later renamed as the Magnuson-Stevens Fishery Conservation and Management Act. By the end of the decade, landings, production, and wholesale value of processed products had increased by 44%, 50%, and 62%, respectively (Georgianna and Ibara, 1983). Since then, there have been fluctuations in landings and in the species caught, with many species experiencing further decline due to overfishing.

After steadily declining throughout the 1960s and early 1970s, the abundance of haddock roughly doubled on Georges Bank and in the Gulf of Maine between 1975 and 1979, matching the increase in cod abundance due to unusually large hatches for both species in 1975. While haddock saw significant landings from 1924 to 1966 (greater than 45.4 million mt or 100,000 million lb in total landings each year), there has been an ongoing decline since then (Georgianna and Ibara, 1983). The total haddock landings were down to 3039 mt (6.7 million lb) by 1987, and more recently, US landings of haddock were at 7542 mt (16.6 million lb) in 2005 and 6510 mt (14.4 million lb) in 2008. Atlantic cod has also experienced significant decline, going from 50,000 mt (110 million lb) in the early 1980s down to 6327 mt (13.9 million lb) in 2005 and 8425 mt (18.6 million lb) in 2008 (Fishery Statistics Office, 2009; National Marine Fisheries Service, 2009b, 2009e).

Yellowtail flounder, once the leading groundfish species, steadily declined in landings and production after 1972. It appears the fleet in Massachusetts, especially in New Bedford, increased concentration on cod and haddock as those stocks increased and the availability of yellowtail decreased (Georgianna and Ibara, 1983). In the mid-1990s, the yellowtail flounder stocks collapsed. For 2007, landings reached about 5000 mt (11 million lb) but current yellowtail flounder landings are down to 1789 mt (3.94 million lb) for 2008 (Fishery Statistics Office, 2009; National Marine Fisheries Service, 2009o).

Another formerly abundant Atlantic groundfish, pollock, saw harvest levels of less than 10,000 mt (22 million lb) in the 1960s but then increased to 26,000 mt (57.3 million lb) by 1986. These stocks were also overfished, and since 1999, harvests have only been between 4000 and 6500 mt

(8.8 and 14.3 million lb). The 2008 landings of Atlantic pollock were 9596 mt (21.2 million lb) (Fishery Statistics Office, 2009; National Marine Fisheries Service, 2009c).

These once-dominant groundfish species have been surpassed by monkfish (also known as goosefish). Monkfish brought in only 6000 mt (13.2 million lb) in 1978 but peaked at 28,300 mt (62.4 million lb) in 1997. They have since experienced a decline with landings of only 22,800 mt (50.3 million lb) annually between 2000 and 2004; 18,800 mt (41.4 million lb) in 2005; and 9279 mt (20.5 million lb) in 2008. Like the previously dominant species, monkfish seem to be experiencing overfishing that has led to a decline in available biomass.

In addition to overfishing and declining abundance, other factors that have lessened some groundfish landings include an aging fleet of large steamers built in the 1930s that were not replaced; the restriction of US vessels from the Canadian grounds starting in 1978; and changes in products and transportation facilities among others. A good example of this is ocean perch. From 1964 through 1970, ocean perch landings declined not due to declining abundance but rather due to the aforementioned issues. A 2268 mt (5 million lb) increase in Massachusetts ocean perch landings after 1974 was misleading, as landings in Maine dropped by 5897 mt (13 million lb) over the same period. Also, between 1970 and 1974, the quantity of ocean perch processed in Massachusetts was about double of what was landed there, with the difference made up of Canadian imports and Maine landings. The major products during that period (about 40% of the total) were frozen breaded fillets, which could be produced from imported Canadian fresh or frozen fillets. From 1975 through 1979, processed products roughly equaled landings in the Commonwealth as frozen breaded fillets dropped to 20% of the total and imported Canadian fresh and frozen fillets dropped from an average of 28,123 mt (62 million lb) from 1970 to 1974 to 21,319 mt (47 million lb) during the second half of the decade. These figures suggest that as landings of cod, haddock, pollock, and ocean perch increased and transportation facilities for fresh fillets improved, fresh fillets were substituted for frozen breaded ocean perch fillets (Georgianna and Ibara, 1983).

The pattern of landings by species throughout Massachusetts has also changed. Groundfish

landings decreased in Boston and New Bedford during the 1970s while landings more than doubled in Gloucester and other ports. However, Boston and New Bedford processing plants continued to dominate the processing sector. Boston processing plants increased their purchases of unprocessed cod, haddock, and pollock from Gloucester, and other ports in Massachusetts, Maine, and Canada, while New Bedford's primary dealers sold less unprocessed cod and haddock to Boston (Georgianna and Ibara, 1983).

The traditional specialization of landings and processing by species among Massachusetts major ports changed as well. New Bedford traditionally was very highly specialized, primarily landing and processing flounders. But as the landings of yellowtail flounder dropped from a high of 32,205 mt (71 million lb) in 1978, the New Bedford fleet and plants adjusted by landing and processing greater amounts of cod and haddock. Flounder production dropped by 3629 mt (8 million lb), while cod and haddock production increased by 10,433 mt (23 million lb) and 4990 mt (11 million lb) during the 1970s when processed products overtook landings for both species (Georgianna and Ibara, 1983).

As of the 2009–2010 harvest, the ports in Gloucester, and New Bedford, MA, seem to be the dominant ports, while ports in Portland, ME, Boston, MA, and Point Judith, RI, have significantly smaller landings. While all five ports have some landings for the top four groundfish species, pollock is the dominant groundfish landed for the Gloucester port with 4528 mt (10 million lb) in 2008. Cod comes in second at Gloucester with 3621 mt (8 million lb). This is where the majority of the cod are landed. Haddock is the dominant species at New Bedford with 3418 mt (7.5 million lb). Monkfish also sees most of its landings at the New Bedford port with 2608 mt (5.75 million lb) compared with 1318 mt (2.9 million lb) at Gloucester (Fishery Statistics Office, 2009).

These results indicate that when a favored traditional species became less available, the Massachusetts groundfish industry found it more profitable to turn to other traditional species rather than toward nontraditional species. Wholesale price increases during the 1970s help explain why processing firms were not anxious to turn toward nontraditional species. Also, developing markets for nontraditional species was costly and could not be recouped over a long period; once the market

was established, other processing firms would enter and bid down the high rates of return. The increasing prosperity of the traditional groundfish industry was much more appealing to established processing firms (Georgianna and Ibara, 1983).

The choice of a different traditional species over a nontraditional species is easy to understand once we consider the components of a switch to nontraditional species. Boats must change gear, work procedures, and trip patterns. Skippers must learn the location and habits of the new species. Unloading facilities and methods must be changed. Processing plant equipment and work must be adapted to the new species. And, most importantly, plant owners, managers, and salespeople must make new marketing arrangements with new customers in an initial atmosphere of apprehension between buyer and seller. Furthermore, all these changes require financing and must happen more or less simultaneously among participants who may not have been especially cooperative in the past.

However, the promotion of a nontraditional species succeeded when pollock was introduced in Boston. The Boston Fisheries Association and the US Bureau of Commercial Fisheries (predecessor to the NMFS) promoted pollock through advertising, supermarket displays, and subsidies for pollock landings during the 1960s in a successful campaign to encourage demand for and supply of pollock when haddock was becoming scarce. Boston processing plants were able to initiate and maintain their predominance in the pollock market throughout the 1970s. Anyone planning to utilize nontraditional species should consider the experience of the Boston pollock industry, although pollock may be a special case because it is a close substitute for cod and haddock in fishing, processing, and retailing (Georgianna and Ibara, 1983).

For 2008, the total US commercial landings on the East Coast were greatest for monkfish/goosefish (10,937 mt or 24.1 million lb), Atlantic pollock (9965 mt or 22 million lb), Atlantic cod (8652 mt or 19.1 million lb), and haddock (6350 mt or 14 million lb) (Van Voorhees and Pritchard, 2009).

### West Coast fishing industry: a historical perspective

The West Coast groundfish fishery includes two regions: the Pacific region (waters off of California,



Oregon, and Washington) and the North Pacific region (waters off of Alaska including the Bering Sea and Aleutian Islands (BSAI)). The North Pacific region accounts for over half of the wild fish caught in US waters and the groundfish resources of the eastern BSAI regions are among the world's largest. This region is home to the largest fishery in North America the Alaska pollock fishery. At the peak of foreign fishing (1971–1974), these regions produced animal catches in the range of  $2.0\text{--}2.3 \times 10^6$  mt (4.41–5.07 billion lb). Japanese and Soviet vessels took much of the catch during the 1960s and 1970s but with enactment of the 1976 FCMA, the Bering Sea resources within the 322 km (200 mi) limit came under domestic jurisdiction. Provisions of the FCMA mandated that management policies be set up to protect and conserve these resources and promote the development of domestic fisheries. During the 1980s, much of the Pacific groundfish fishery was executed via joint ventures. As of the first edition of this book in 1986, groundfish in the Bering Sea were harvested exclusively by foreign fisheries with the exception of US fisheries for Pacific halibut. However, by the late 1980s and early 1990s, the West Coast groundfish fishery became fully domestic (Witherell, 2000; Shaw and Conway, 2007).

The Bering Sea's unique geographic, climatic, and oceanographic conditions combine to create an environment favorable for supporting the very large populations of groundfish (in addition to some of the world's largest bird and marine mammal populations). Although the processes responsible for these large populations are not fully understood, they probably originate from the upwelling of nutrient-rich water along the south side of the Aleutian Islands and subsequent mixing of Pacific Ocean and Bering Sea waters. As well as the seasonal extremes in climate with a buildup of nutrients during winter months, and the expansive nature of the continental shelf in the eastern Bering Sea. The continental shelf and slope are prominent features of the eastern Bering Sea and the location of a majority of demersal fish resources; most of this shelf area lies within the United States—322 km (200 mi) fishery conservation zone (Bakkala et al., 1979).

A second major feature of the region is the Aleutian-Commander Islands arc, a chain of more than 150 islands that forms a partial barrier to the exchange of water between the Pacific Ocean and Bering Sea. Continental shelf areas throughout most

of the chain are narrow and frequently discontinuous between islands but broaden in the eastern Aleutians (Bakkala et al., 1979).

The Bering Sea climate is subarctic, except in the southernmost part that lies in the temperate zone. These climatic conditions produce subzero water temperatures and pack ice cover over extensive areas of the continental shelf in the northern and eastern Bering Sea in winter and spring. These conditions cause extensive offshore movement of groundfish to the deeper, warmer waters of the outer shelf and slope in winter. Pack ice begins to form in November, usually reaches maximum coverage in late March, and begins to retreat northward in April or May, making the Bering Sea generally ice free by early summer. The outer shelf between the Pribilof Islands and Unimak Island and the deeper waters of the Bering Sea are generally ice free throughout the year due to the influence of warmer Pacific Ocean waters (Bakkala et al., 1979).

The Bering Sea supports about 300 species of fish, the majority of which live on or near the bottom. Many of these have been targeted by both foreign and domestic groundfish fisheries over the years as abundance of one species has declined and that of another has increased (Bakkala et al., 1979).

Statistics for the total catches of groundfish have always been much greater in the eastern Bering Sea than in the Aleutians. Even during the period of the Aleutian area's peak catches (1964 and 1965), which coincided with relatively low catches in the eastern Bering Sea, the Aleutian Islands had only about a third of the catch taken in the eastern Bering Sea. In subsequent years as the fishery for walleye pollock in the eastern Bering Sea developed, the total groundfish catch in the Aleutians fell to 5% or less than that of the eastern Bering Sea (Bakkala et al., 1979).

In the eastern Bering Sea, total catches of groundfish have reached two peaks. The first and smaller peak occurred during 1960–1962, when Japan and the Soviet Union were intensively targeting yellowfin sole and other species that reached a maximum of 715,000 mt (1.58 billion lb) in 1961 (Bakkala et al., 1979). Catches declined from 1963 to 1965 because of reduced abundance of yellowfin sole. After the Japanese developed shipboard methods of producing surimi, their fishery for walleye pollock developed rapidly, and the total groundfish catches rose again to reach a second, much higher peak of over 2 million mt (4.41 billion lb) per year from

1971 to 1973. Since that time, catches have decreased because of restrictions stemming from evidence of declining abundance of pollock and other species. By 1977, catches had declined to about 1 million mt (2.2 billion lb) but catches were higher in 1978 at about 1.37 million mt (3 billion lb). Total Alaska pollock landings alone were just over 1 million mt (2.2 billion lb) in 2008 (Bakkala et al., 1979; Van Voorhees and Pritchard, 2009).

Flounders (primarily yellowfin sole) were the major species in eastern Bering Sea catches until 1963, after which walleye pollock predominated. The proportion of pollock in the total foreign catch of groundfish increased from about 44% in 1964 to about 72% in 1968 and, from 1971 to 1977, represented 81–85% of the total groundfish catch. As of 2008, pollock was the number one species landed in the United States. Pacific cod made up 13% of the total groundfish catch, while pollock accounted for 60%. These are currently the top two groundfish fisheries in Alaska (National Marine Fisheries Service, 2009g).

Landings in the Aleutian Islands region differ from those in the eastern Bering Sea in a number of respects. Overall, catches have been much lower, trends in catches and major species in catches have differed, and the Soviet Union rather than Japan used to take the greatest share of the catches. Total groundfish catches in this area reached a peak of 114,000 mt (251 million lb) in 1965, a few years after the fishery was initiated in 1962. Since then, total catches have fluctuated at a lower level, ranging from about 36,000–80,000 mt (79.4–176 million lb) annually (Bakkala et al., 1979). As of 2008, the total groundfish landings for the Aleutian Islands region were just over 78,000 mt (171.9 million lb) (National Marine Fisheries Service, 2009s).

Pacific Ocean perch and other rockfish were the primary target species in the Aleutians in the 1960s and 1970s. Rockfish catches reached their peak in 1971 with landings of 109,000 mt (240 million lb) but since then have shown an almost continual decline. Catches of other groundfish have increased since 1971 with walleye pollock and Atka mackerel accounting for most of this increase. Atka mackerel was the most abundant species in catches in the Aleutian area in 1976 and 1977 at 200,000–215,000 mt (441–474 million lb), respectively. Flounders have formed only a minor part of catches in the Aleutians with Greenland turbot and arrowtooth flounder the main species taken (Bakkala et al.,

1979). As of 2006, the species highest in abundance in the Aleutian Islands region were Atka mackerel and Pacific Ocean perch (Raring, 2008). Not surprisingly, Atka mackerel made up the greatest portion of the landings from the Aleutian Islands in 2008 with over 58,000 mt (127.9 million lb). Pacific Ocean perch landings were second for the region with almost 17,000 mt (37.5 million lb) in landings (National Marine Fisheries Service, 2009s).

Because of the need to rebuild populations of several groundfish species that are designated as overfished, all sectors of the groundfish fishery are currently limited. Because of this, the overall groundfish harvest has been significantly reduced due to the slow reproduction rate and small stock size of some species. However, some species stocks have recovered and their landings have been increasing since regulations were implemented. Many of these are managed and assessed by the Pacific Fishery Management Council's Groundfish FMP and the North Pacific Fishery Management Council's Groundfish FMPs for the Gulf of Alaska (GOA) and BSAI regions (National Marine Fisheries Service, 2009f).

## Species

### East Coast

The Northeast Fisheries Science Center (NEFSC) lists the primary groundfish for the northeastern US fishery resources as Atlantic cod, haddock, Acadian redfish, silver hake, red hake, and pollock. Flounders for this region include yellowtail, summer, witch, winter and windowpane flounder and also American plaice and Atlantic halibut. Other groundfish in the northeastern US fishery resources include goosfish, scup, black sea bass, ocean pout, white hake, cusk, tilefish, and Atlantic wolfish (Northeast Fisheries Science Center, 2009a).

Commercial US landings for the top East Coast groundfish species are listed in Table 3.1.

Gear used to catch East Coast groundfish includes otter trawls, gillnets, dredges, bottom trawls, high opening trawls, longlines, line trawls, hook and line, and pots and traps.

East Coast groundfish fisheries are managed by the New England Fishery Management Council's Multispecies FMP that covers 15 species of groundfish; the New England and Mid-Atlantic Fishery



Management Council's Monkfish FMP; the Summer Flounder, Scup, and Black Sea Bass FMP with input from the Atlantic States Marine Fisheries Commission and the Mid-Atlantic Fishery Management Council; the Atlantic States Marine Fisheries Commission's FMP for Inland Stocks of Winter Flounder; the Mid-Atlantic Fishery Management Council's Golden Tilefish FMP; and the South Atlantic Fishery Management Council's South Atlantic Snapper-Grouper FMP. Management tools include minimum size limits, time/area closures, gear restrictions, quotas, and seasons and are utilized in an effort to help species recover to minimum biomass thresholds (Northeast Fisheries Science Center, 2009).

### Goosefish

Goosefish (*Lophius americanus*), also known as monkfish, increased in commercial importance during the 1980s and 1990s. It became the highest valued finfish in the northeastern United States by the mid-1990s. Based on 2008 landings, monkfish is the most caught fish by weight in the US Atlantic groundfish fishery. Goosefish are notable for the modified first dorsal fin ray that resembles a lure on a fishing pole and which they utilize to attract prey. These fish inhabit waters from Cape Hatteras, NC, north to the Grand Banks and the northern Gulf of St. Lawrence.

For management purposes, the goosefish is divided into two stocks: the Gulf of Maine and northern Georges Bank stock and the southern Georges Bank and Mid-Atlantic stock. Commercial US landings were at 6000 mt (13.2 million lb) in 1978, peaked in 1997 at 28,300 mt (62.4 million lb), and were 10,937 mt (24.1 million lb) in 2008 (Van Voorhees and Pritchard, 2009).

Goosefish products include tails and livers and also the whole, gutted fish (Richards, 2007).

### Atlantic pollock

The Atlantic pollock (*Pollachius virens*), also known as pollock, shown in Figure 3.1, is dark greenish in color and usually olive or greenish gray with silver tints on the lower side. A light lateral line extends the length of the body and is in contrast to the dark sides. It has a spindle-shaped streamlined body with a forked tail. Only about 2% of the pollock landed in the United States is Atlantic pollock;

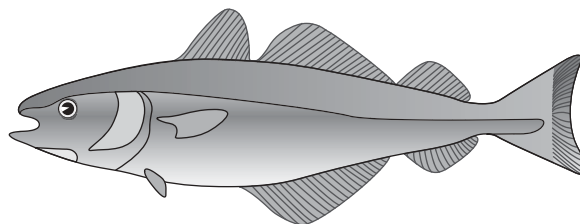


Figure 3.1 Atlantic pollock.

a different species, Alaska pollock, constitutes the rest of the pollock landings.

A close relative of the cod and haddock, pollock is found in the cool coastal waters from Cape Hatteras northward to Newfoundland, Greenland, and Iceland, and in European waters from the coast of France to the northern coast of Norway. This species, called saithe or coalfish in Europe, has been fished heavily in northern European waters for more than 50 years. On the North American side, the pollock is abundant only over a short part of its range. Being a cool water fish, rather than a coldwater species, it is most abundant off western Nova Scotia and in the Gulf of Maine. It is comparatively scarce south of Georges Bank or north of southern Newfoundland. Most of the pollock from this side of the Atlantic are taken in the Nova Scotia banks, with fishing effort centered in western Nova Scotia and eastern Georges Bank (National Marine Fisheries Service, 2009c).

One of the most active members of the cod family, it is found in large schools that may be found at any level between the surface and the bottom. Small pollock migrate into coastal waters in the spring, remain there all summer, and then move to deeper waters in the winter. Pollock often school at this time with 80% of the landings taken during October, November, and December.

Total landings of Atlantic pollock from Georges Bank and the Gulf of Maine rose from 1960 levels of less than 10,000 mt (22 million lb) to a peak in 1986 of more than 26,000 mt (57.3 million lb) (National Marine Fisheries Service, 2009c). This was followed by sharp declines in the following years, and 2008 levels were at 9965 mt (22 million lb) (Van Voorhees and Pritchard, 2009).

The pollock is similar in flavor, odor, and texture to cod and haddock. It makes a good, dry salt fish and some are smoked. Fresh US-caught pollock usually is marketed whole or as skinned or

unskinned fillets. The fillet size of the small pollock is similar to that of the haddock, and consumer acceptance is good. The long, thick slab fillets from large pollock, however, meet with sales resistance. Studies have shown that these thick fillets can be split into two or more thinner fillets, which then can be cut further into fillet-shaped pieces of acceptable size. Steaks and chunks are market forms most often used for the large pollock landed by the US fleet. They can be prepared from fresh, iced fish with special power-driven circular knives. However, it is more common to freeze the fish and then cut the steaks and chunks with a band saw. Superior flavor comes from the unfrozen fish or from fish frozen at sea.

### Atlantic cod

Spanish explorers came to the New World to find gold and precious stones, but the French and Portuguese, followed by the English, crossed the Atlantic to catch fish, especially the Atlantic cod (*Gadus morhua*). In the sixteenth century, French and Portuguese vessels fished the Grand Bank off Newfoundland. By the early seventeenth century, the New England colonists were fishing for cod in the local waters. In 1748, the first catch of cod from Georges Bank was landed.

Cod probably has influenced the course of American history more than any other marine fish. Its white flaky flesh was the foundation of power and wealth in colonial America. Cod was the first product shipped out of colonial Massachusetts. A large wooden codfish carving was hung in the Massachusetts State House in 1784 and still occupies an honored position there.

As a commercial fish, cod had no peer. It was abundant all year, and when split, salted, and dried, it kept almost indefinitely in any climate. Many long sea voyages would not have been possible without dried cod, as ships could carry no perishable food as staples (Ryan, 1979).

Codfish are found on both sides of the Atlantic Ocean, in the North Pacific Ocean, and in the Arctic Ocean down to about 457 m (1500 ft). The best cod fishing grounds are offshore banks including Georges Bank, 241 km (150 mi) off Boston, Massachusetts and Grand Bank off Newfoundland.

Based on 2008 landings, Atlantic cod is the third most caught fish by weight in the US Atlantic groundfish fishery.

The Atlantic cod includes several geographical subspecies. These are the Baltic cod (*Gadus morhua callarias*) found in the Baltic Sea and parts of the North Sea; the Kildin Island cod (*Gadus morhua kildinensis*), which lives in a salt pond, Lake Mogilno, on an island in the Baltic Sea; and the White Sea cod (*Gadus morhua marisalbi*), found in the Arctic Sea. The Greenland cod (*Gadus ogac*), often considered a separate species, is found mostly in inlets and in the shallow waters of the Arctic Ocean from west Greenland to Point Barrow, Alaska. Additionally, the Pacific cod (*Gadus macrocephalus*) is considered by most taxonomists as a separate species.

There are two Atlantic cod stocks for assessment and management purposes in US waters Gulf of Maine cod and Georges Bank and southward cod.

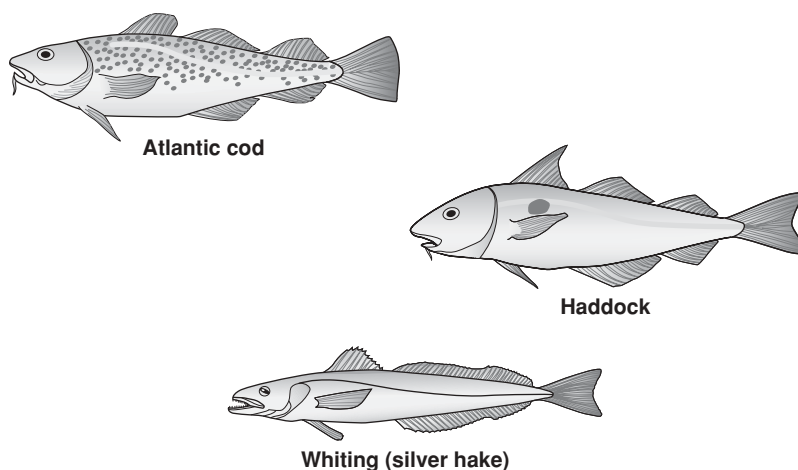
Cods are soft-finned fish lacking true spines, although in the whiting, the dorsal and anal fin rays are so stiff that they feel like spines. The cod family is distinguished from other soft-rayed fish by their large pelvic fins situated under or in front of the pectorals (not behind as in salmon and herring). Generally fishes of cold water, most cods live close to the bottom. In a side view, the Atlantic cod (Figure 3.2) is oval with three distinct dorsal fins, two anal fins, and a nearly square tail. Its color varies from olive green to reddish brown depending on its habitat. The lateral line is white, and the skin has many small scales.

Currently, the Georges Bank cod biomass is 12% below the target biomass, while the Gulf of Maine cod biomass is 58% below the target biomass. According to the most recent assessments, the Georges Bank stock biomass has not changed much since 2004 (the last assessment) while the Gulf of Maine stock biomass has experienced relatively large increases (National Marine Fisheries Service, 2009b).

The combined peak landings for stocks that occurred in the 1970s and 1980s were over 50,000 mt (110 million lb) in the early 1980s and today's catches remain well below these levels. Commercial US landings of Atlantic cod were 7697 mt (17 million lb) in 2007 and 8652 mt (19.1 million lb) in 2008 (Van Voorhees and Pritchard, 2009).

### Haddock

The haddock (*Melanogrammus aeglefinus*) (Figure 3.2) has as distinguishing marks a black



**Figure 3.2** Atlantic cod, haddock, and whiting (silver hake) are three of the more common groundfish.

lateral line; a sooty black shoulder blotch called the “Devil’s thumb print” or “St. Peter’s mark”; and a pointed first dorsal fin. Based on 2008 landings, haddock is the fourth most caught fish by weight in the US Atlantic groundfish fishery. Haddock are found in the North Atlantic Ocean along the coasts of Newfoundland, Nova Scotia, and the Gulf of Maine, and on Georges Bank. In the northeast Atlantic, it is found off the coast of northern Europe, the British Isles, and Iceland. Haddock are bottom-dwelling fish in areas where water temperatures range from 1.7°C to 8.9°C (35°F to 48°F). They are usually caught on an ocean bottom of hard, smooth sand, gravel, or broken shell. They like smooth areas between rocky patches. In US waters, there are two stocks of haddock for assessment and management purposes those in the Gulf of Maine and those in Georges Bank.

From 1924 to 1966, the haddock fishery never yielded less than 45,359 mt (100 million lb), but by 1976, the total catch was only 5805 mt (12.8 million lb). The record low was set in 1995 with landings of 2533 mt (5.6 million lb). The latest assessments show US commercial landings for haddock were 6350 mt (14 million lb) in 2008 (Van Voorhees and Pritchard, 2009).

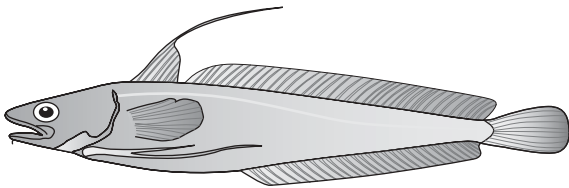
Caught, handled, and processed much in the same way as the Atlantic cod, haddock is used to make a number of smoked fish products, like finnan haddie and other cold smoked products such as the golden cutlet and the smoked single fillet. The chemical composition of haddock flesh is similar to that of cod.

## Hake

The origins of the word hake are not clear. According to the Oxford English Dictionary, the first usage was in the fourteenth or fifteenth century, and the word as presently understood refers in general to the genus *Merluccius* and several other genera of gadoid (codlike) fishes.

Fish species classified in the genus *Merluccius* as well as several other genera are often considered to be members of the family Merlucciidae, which, although related, are distinct from the Gadidae or cod family. The various named species of *Merluccius* are rather similar in appearance, and there is not at this time any good way to assign correct scientific names to *Merluccius* from many regions of the world. There may be as few as 4 or as many as 15 or more different biological species. Whatever the number and correct scientific names of *Merluccius* species, all are known in English-speaking countries as hake (Cohen, 1980). Other English language names, chiefly whiting, also are used for *Merluccius*. In South Africa, stockfish is another name for *Merluccius*.

Hake is used as a common name for a number of kinds of fish other than *Merluccius*. Among the Gadidae are seven species of *Urophycis* from the western Atlantic: *Urophycis chesteri*, longfin hake; *Urophycis chuss*, red or squirrel hake (Figure 3.3); *Urophycis cirrata*, Gulf hake; *Urophycis earlli*, Carolina hake; *Urophycis floridana*, southern hake; *Urophycis regia*, spotted hake (Figure 3.4); and *Urophycis tenuis*, white, black, mud, or Boston hake.



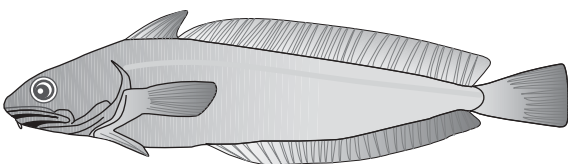
**Figure 3.3** Red hake.

As noted earlier, the name whiting is used interchangeably with hake for *Merluccius*; however, it is also used for fishes that are not called hakes. Among them are three species of European Gadidae: *Merlangius merlangus*, whiting; *Trisopterus luscus*, whiting pout, an alternate name for bib; and *Micromesistius poutassou*, blue whiting (caught rarely off the US East Coast where it has no common name). Whiting is also an alternate name for the eastern North Pacific gadid *Theragra chalcogramma*, often called walleye pollock. Members of the genus *Menticirrhus* of the croaker family Sciaenidae, not at all closely related to gadoids and with three Atlantic and one Pacific US species, are known collectively as whittings, although each also has other common names. Species belonging to several other families of fishes unrelated to gadids are known as whittings; among them are the spiny-rayed *Sillaginidae* of the Indian Ocean and western Pacific, and the *Odaciidae*, called rock whittings, wrasse-like (spiny-finned) fishes of Australia and New Zealand. Finally, sand whiting is listed as an alternate for the bothid flatfish, *Scophthalmus aquosus*, most commonly known as window-pane (Cohen, 1980).

Obviously, the nomenclature of hakes and whittings is complex. Positive identification of a species referred to under these names may require reference to a Latinized scientific name, although even some of these are subject to question. Yet, hakes are found worldwide.

#### Whiting or silver hake

Whiting or silver hake (*Merluccius bilinearis*) (Figure 3.1) are silvery over the whole body with brown



**Figure 3.4** Spotted hake.

or dark gray tints on the upper surface of the body. They have two dorsal fins and one anal fin with no barbel on the lower jaw. They are found on the continental shelf from Newfoundland to South Carolina. In winter, they move into deeper water and go further south. They are assessed as two stocks in the United States: the northern silver hake is found in waters from the Gulf of Maine to the northern Georges Bank and the southern silver hake is found in waters from the southern Georges Bank to the Mid-Atlantic Bight region (Col and Traver, 2006).

Northern silver hake commercial landings peaked in 1975 at 40,000 mt (81.2 million lb) but have declined ever since. Domestic landings of southern silver hake peaked in 1964 at 27,000 mt (59.5 million lb) but distant water fleet landings were much greater, reaching highs of 280,000 mt (617.3 million lb) in 1965 and 100,000 mt (220.5 million lb) in 1974. Total landings have declined since those peaks and in 2008 silver hake landings were 6280 mt (13.8 million lb) (Van Voorhees and Pritchard, 2009).

Whiting are lean, firm textured, flaky fish that are very tasty. Whiting is generally sold either round or dressed in fresh fish markets from New England south to Virginia, or frozen headed and gutted (H&G) and distributed throughout the nation with the majority of sales in the Northeast, Mid-Atlantic, and Midwest states. A small amount of the headed and eviscerated whiting is smoked.

#### Red hake

Red hake (*U. chuss*) (Figure 3.3) is reddish in color on the back and sides and white to yellowish on the belly. Red hake is abundant off the US East Coast and is assessed as two separate stocks: the northern red hake that inhabits the Gulf of Maine to the northern Georges Bank waters and the southern red hake that inhabits the southern Georges Bank to the Mid-Atlantic Bight waters.

The northern red hake stock reached a commercial landings peak in 1973 of 15,281 mt (36.7 million lb). The southern red hake stock experienced much greater landings from 1962 to 1976 compared with the northern stock. Commercial landings have steadily declined since that time and they reached a low of 300 mt (661,387 lb) in 2005 (Traver and Col, 2006). However, the fish are not currently overfished nor is overfishing occurring. In 2008,



commercial US landings of red hake were 587 mt (1,295,000 lb) (Van Voorhees and Pritchard, 2009).

Red hake is also a component of the mixed industrial fishery described for silver hake. As is the case for silver hake, use of red hake as food fish is economically preferable to increased industrial use. Several problems tend to limit red hake's marketability. It has softer flesh than whiting or cod, and the name "hake" is not as familiar to consumers as the "whiting" nomenclature used for silver hake. Fillet blocks prepared from red hake generally have been of unsatisfactory quality because the flesh develops a rubbery texture. Most red hake is white-fleshed although occasionally ruptured blood vessels can cause a pink hue. It is often prepared in the traditional New England method of corned hake with pork scraps and is also used for chowder and fish salad. Red hake is usually marketed as fresh or frozen fillets with smaller fish used for mink, cat, and poultry feed.

### White hake

White hake (*Urophycis tenuis*) is another elongated fish that inhabits waters from Newfoundland to southern New England. The species is common throughout the Gulf of Maine.

Landings of white hake have fluctuated over the decades with total landings in the late 1960s of about 1000 mt (2.2 million lb); a peak of 9600 mt (21.2 million lb) in 1992; and steady declines since then. The 2004 survey indicated that the white hake stock was both overfished and overfishing was occurring (Sosebee, 2006). In 2008, landings were 1367 mt (3.0 million lb) (Van Voorhees and Pritchard, 2009).

### Summer flounder

Summer flounder (*Paralichthys dentatus*), also known as fluke in some regions, is one of the most sought after recreational and commercial Atlantic coast species. They are laterally flattened fish with both eyes on the left side and are able to change their color to blend into backgrounds of varying colors and textures. These fish inhabit Atlantic waters from the northern Gulf of Mexico to Nova Scotia (National Marine Fisheries Service, 2009l).

The species is considered as one stock from Maine to North Carolina for management purposes. Commercial landings of summer flounder

were high in the late 1970s and early 1980s with levels around 17,000 mt (37.5 million lb). In 1990, when the FMP was implemented, landings had decreased to just over 4000 mt (8.8 million lb). In some years, commercial landings have been exceeded by recreational landings. In 1983, recreational landings peaked at 12,700 mt (28.0 million lb). More recently (1996–2007), recreational landings have ranged between 3800 and 7100 mt (8.4–15.7 million lb). The stock is expected to be rebuilt by 2013 (Terceiro, 2006b; National Marine Fisheries Service, 2009l). Commercial US landings of summer flounder were 4095 mt (9.0 million lb) in 2008 (Van Voorhees and Pritchard, 2009).

### Winter flounder

Winter flounder (*Pseudopleuronectes americanus*), also called blackback or lemon sole, are the darkest of the flounders, though their coloring varies with habitat. Their underside is white and their fins can be tinged with yellow, pink, or red on the top side. They are typical flatfish in shape, flattened and with their eyes on the right side, and they have small mouths. Winter flounder inhabit waters of the northwest Atlantic from the Chesapeake Bay to Labrador.

The species is currently at very low levels having suffered severe declines. Assessments as of 2008 indicate that the winter flounder is both overfished and that overfishing is occurring in the Georges Bank stock and in the southern New England/Mid-Atlantic stock. The status of the Gulf of Maine stock is considered unknown but the recent assessment suggests that it is likely overfished and that overfishing is occurring. Commercial landings of winter flounder are greatest in the southern New England/Mid-Atlantic region, with peaks in 1966 and again in 1981 between 11,000 and 12,000 mt (24.3–26.5 million lb). Landings from the Gulf of Maine and Georges Bank regions are significantly less with those from the Gulf of Maine peaking in 1982 at 2793 mt (6.2 million lb) and those from Georges Bank peaking in 1972 at 4509 mt (9.9 million lb). Declines occurred after the peaks, with the lowest levels being seen in 2005 (Hendrickson et al., 2006; National Marine Fisheries Service, 2009n). Commercial landings of winter flounder were 2355 mt (5.2 million lb) in 2008 (Van Voorhees and Pritchard, 2009).

Winter flounder are one of the five flounders most often found on dinner tables.

### Yellowtail flounder

Yellowtail flounder (*Limanda ferruginea*), also called sand dab, became a valuable flatfish in the mid-1930s as the stock of winter flounder declined and they are in high demand today. These fish are thin bodied with eyes on the right side as is typical of flounders. They have a highly arched lateral line and a small mouth. Yellowtail flounder are found in waters off the Atlantic Coast from the Chesapeake Bay north to the Gulf of St. Lawrence, Labrador, and Newfoundland.

The fishery is divided into three stocks for management purposes. The three stocks include one in Cape Cod/Gulf of Maine, one in Georges Bank, and one in southern New England/Mid-Atlantic. Currently, yellowtail flounder populations are low and overfishing is occurring. In the 1930s, landings were limited but began increasing as a demand developed for yellowtail. Landings of all three stocks have fluctuated over the years, with greater landings in the 1960s and 1970s followed by declines in the early 1980s and outright collapses in the 1990s. In the mid-1990s, the Georges Bank and southern New England stocks collapsed and the landings from the Cape Cod/Gulf of Maine stock, which had historically been only a small portion, became the majority. Total landings for the three stocks combined for 2007 reached about 1800 mt (4 million lb) with the most fish harvested from the Georges Bank stock and very little harvested from the other two stocks (National Marine Fisheries Service, 2009a). In 2008, commercial landings of yellowtail flounder were 1668 mt (3.7 million lb) (Van Voorhees and Pritchard, 2009).

### American plaice

American plaice (*Hippoglossoides platessoides*) or dab are large mouthed flatfish with the eyes on the right side. They inhabit deeper waters in the northwest Atlantic from Rhode Island to southern Labrador.

The species is considered as one stock in the Gulf of Maine/Georges Bank region. Commercial landings of American plaice peaked between 1979 and 1984 with an average of 12,700 mt (28.0 million lb). They have decreased in general since that time, and in 2004, landings were at a low of 1711 mt (3.8 mil-

lion lb). As of 2004, the stock was considered overfished but overfishing was not occurring (O'Brien, 2006a). Commercial US landings of American plaice were 1106 mt (2.4 million lb) in 2008 (Van Voorhees and Pritchard, 2009).

### Witch flounder

Witch flounder (*Glyptocephalus cynoglossus*) is another flatfish and inhabits waters on both sides of the North Atlantic. This fish ranges from Virginia to Labrador and is found in deeper US waters in the Gulf of Maine and Georges Bank and down toward Cape Hatteras.

Commercial landings of witch flounder peaked in 1971 at more than 6000 mt (13.2 million lb) and again in 1984 with commercial landings reaching 6700 mt (14.8 million lb). Declines occurred in between and landings reached a low of 1500 mt (3.3 million lb) in 1990. As of 2004, the witch flounder stock was not overfished nor was overfishing occurring (Wigley and Col, 2006b). US commercial landings of witch flounder were 1000 mt (2.2 million lb) in 2008 (Van Voorhees and Pritchard, 2009).

### Windowpane flounder

Windowpane flounder (*Scophthalmus aquosus*), also known as sand flounder, are thin-bodied and left-eyed flatfish. They inhabit waters from Florida to the Gulf of St. Lawrence in the northwest Atlantic.

As of the 2004 assessment, the Gulf of Maine Georges Bank windowpane flounder were not overfished nor was overfishing occurring. However, landings were at an all-time low from 2001 to 2005 with levels between 12 and 45 mt (26,455 and 99,208 lb). Commercial landings for the southern New England/Mid-Atlantic stock reached a record low of 25 mt (55,116 lb) in 2005. Based on the 2002–2004 assessments, this stock is overfished but overfishing is not occurring (Hendrickson, 2006). Data are not recorded for this species in the 2008 Fisheries of the US report (Van Voorhees and Pritchard, 2009).

### Scup

Scup (*Stenotomus chrysops*) are a deep-bodied fish that are dusky brown in color with a lighter underside and mottled or faintly barred fins. They have very spiny fins and narrow, almost conical front teeth with two rows of molars in the upper jaw.

They are sometimes confused with Southern porgy. Scup inhabit northwest Atlantic waters from South Carolina to Nova Scotia.

Scup were declared rebuilt in 2009 and current population levels are high. Overfishing is not occurring and the Mid-Atlantic stock is not overfished. It is unknown if the South Atlantic stock is overfished. Scup have been popular both commercially and recreationally for decades, though the current commercial harvest is a fraction of what it used to be. Commercial landings peaked in 1963 at 24,700 mt (54.5 million lb) but then declined significantly. Recreational landings peaked in 1986 at 5300 mt (1.2 million lb) (Terceiro, 2006a; National Marine Fisheries Service, 2009k). Commercial landings of scup were 2645 mt (5.8 million lb) in 2008 (Van Voorhees and Pritchard, 2009).

### Tilefish

Golden tilefish (*Lopholatilus chamaeleonticeps*) inhabit waters along the outer continental shelf of the northeast Atlantic from South America to Nova Scotia. They live in US waters from the Mid-Atlantic region to southern New England and occupy burrows in the substrate in and around ocean canyons.

Between 1967 and 1972, total commercial landings of golden tilefish were less than 125 mt (275,578 lb). This increased to more than 3900 mt (8.6 million lb) in 1979 and 1980. There was much fluctuation in the landings from the 1980s to 2001 and in November of 2001, the annual quota of 905 mt (2 million lb) was instituted. As of 2005, the stock was not overfished nor was overfishing occurring (Nitschke, 2006). In 2008, landings were 1339 mt (3 million lb) (Van Voorhees and Pritchard, 2009).

### Acadian redfish

Since the 1930s and the advent of freezing technology that permitted distribution of frozen products across the country, Acadian redfish (*Sebastes fasciatus*) have provided a substantial US commercial fishery in the Gulf of Maine and Georges Bank.

The Acadian redfish is extremely similar externally to the deepwater redfish (*Sebastes mentella*). Both species have a prominent tubercle on the anterior mandible that is usual in beaked redfish. Acadian redfish are orange to flame red on top and fade to a paler color underneath. Their large eyes

cause them to be perch-like in appearance and they are sometimes called ocean perch. Acadian redfish have a flattened body that is longer than it is deep and their mouths are large and lined with small teeth. They have one continuous dorsal fin from behind the head to the caudal peduncle and the tail fin is small (Department of Maine Resources, 2009).

The two species, Acadian and deepwater redfish both inhabit the Gulf of St. Lawrence, the Laurentian Channel, the Grand Banks, the Flemish Cap, and the Scotian Shelf and some hybridization of the species has occurred. The Acadian redfish also inhabits the Gulf of Maine, deeper portions of Georges Bank and the Great South Channel where they are managed as a unit stock in US waters.

Given the low biomass of Acadian redfish, a directed fishery has not really existed in the 1990s and 2000s (Mayo et al., 2006). Landings peaked at 56,000 mt (123.5 million lb) in 1942 and then began declining. A short resurgence occurred during the late 1970s, but landings have been declining ever since and are currently at the lowest levels ever experienced since their fishery began in the 1930s. From 1996 to 2005, the US commercial landings of Acadian redfish have been between 300 and 600 mt (661,387–1,322,774 lb). At these low levels, the stock is not overfished nor is it experiencing overfishing (Mayo et al., 2006). Commercial landings of redfish were at 1189 mt (2.6 million lb) in 2008 (Van Voorhees and Pritchard, 2009).

### Black sea bass

Black sea bass (*Centropristis striata*) vary in color from dusky brown for smaller fish to black for larger fish. They appear barred with some longitudinal dots and the belly is slightly pale compared to the sides. The dark fins have dusky spots and the dorsal fin has white dots and bands. During spawning season, the male black sea bass develop a hump on their heads that becomes bright blue in color. Black sea bass inhabit waters from the Gulf of Mexico to Florida and up the coast to the Gulf of Maine.

Commercial landings in the Mid-Atlantic peaked back in 1952 at 9900 mt (21.8 million lb) and have declined dramatically since then. By 1994, recreational landings (1300 mt or 2.9 million lb) surpassed commercial landings (925 mt or 2 million lb). Total black sea bass landings in this region have been relatively stable over the last decade with levels between 2000 and 3000 mt (4.4–6.6 million lb).



Commercial landings in the South Atlantic stock peaked in 1974 at 615 mt (1.4 million lb) while recreational landings peaked in 1984 at 1014 mt (2.2 million lb). Since these peaks, both commercial and recreational landings have declined and currently they fluctuate around 250–350 mt (5.5–7.7 million lb) each. The most recent assessments indicate that the Mid-Atlantic black sea bass stock is not overfished but is subject to overfishing, while the South Atlantic stock is overfished and overfishing is occurring (Shepherd, 2006; National Marine Fisheries Service, 2009d). Commercial landings in 2008 were 1036 mt (2.3 million lb) (Van Voorhees and Pritchard, 2009).

### Cusk

Cusk (*Brosme brosme*) is a deepwater, sedentary, and solitary groundfish species with an elongated, eel-like body. The species inhabits waters on both sides of the Atlantic with the greatest numbers from the central Gulf of Maine to the Western Scotian Shelf.

The US cusk fishery is not under management. The Canadian cusk fishery had a bycatch quota of 1000 mt (2.2 million lb) from 1999 to 2002 and of 750 mt (1.6 million lb) in 2003. From the 1960s to 1980, annual landings of cusk averaged about 2300 mt (5.1 million lb). Landings peaked in 1982 at 3700 mt (8.2 million lb) and then declined to a record low in 2005; the total US and Canadian landings of cusk were 623 mt (1.4 million lb). Cusk populations are at low biomass levels currently and exploitation of the species has declined (O'Brien, 2006b). In 2008, landings of cusk were 54 mt (118,000 lb) (Van Voorhees and Pritchard, 2009).

### Atlantic wolffish

Atlantic wolffish (*Anarhichas lupus*) are long, thin fish with blunted heads. They have darker, striped sides with lighter underbellies. They inhabit waters on both sides of the North Atlantic. In the northwest Atlantic, they exist from Davis Straits off of Greenland down to Cape Cod and sometimes into the waters of southern New England and New Jersey.

There is currently no management plan in effect for Atlantic wolffish in US waters. In 1970, total commercial Atlantic wolffish landings in the United States were only 270 mt (595,248 lb). This number increased to nearly 1200 mt (2.6 million lb) by 1983 but has since decreased. The biomass indices

for Atlantic wolffish from the NEFSC spring and fall surveys in 2005 indicate that the stock level is extremely low. Commercial landings are also experiencing record lows. However, there are currently no biological reference points for this species in US waters (Keith, 2006). In 2008, landings were 49 mt (109,000 lb) (Van Voorhees and Pritchard, 2009).

### Atlantic halibut

Atlantic halibut (*Hippoglossus hippoglossus*) is the largest flatfish in the northwest Atlantic. From the early 1800s to the 1880s, this species supported important commercial fisheries in the Georges Bank/Gulf of Maine waters. Massachusetts Bay had numerous halibut during this time and one vessel even harvested 6.8 mt in one trip. The inshore fishing grounds for halibut were gradually overfished and fleets had to move out to Georges Bank where the fish were still numerous. It was not unheard of for one vessel to harvest 23 mt of halibut in one 2-day trip during the 1840s. However, the population was heavily overfished in the nineteenth and early twentieth centuries, no recovery has occurred, and the stock remains depleted. There is presently no directed fishery for halibut in the Atlantic in federal waters, but some small harvests do occur off the coast of Maine in state waters.

Currently, there is a moratorium on directed harvests of Atlantic halibut with a bycatch limit of one fish per trip and a minimum size of 91 cm (36 in.). Between 2001 and 2005, the average US commercial Atlantic halibut landings were 29 mt (63,934 lb) (Brodziak and Col, 2006).

### Ocean pout

Ocean pout (*Zoarces americanus*) is eel-like in appearance and inhabits northwest Atlantic waters from Delaware to Labrador. Commercial interest in this species has had its ups and downs during World War II, pout was marketed as a food fish and landings increased. But then a parasite outbreak occurred that caused lesions on the fish and demand for pout as a food fish disappeared. Since then, an industrial fishery has developed and landings have increased somewhat.

Commercial landings peaked in 1944 at 2000 mt (4.4 million lb) and then declined precipitously in conjunction with the parasite outbreak. After the industrial fishery was developed in the mid-1960s,

US landings averaged 4700 mt (10.4 million lb). Total catches peaked in 1966 at 27,000 mt (59.5 million lb) when distant water fleets began harvesting, but foreign catches then declined and none have been reported after 1974. Commercial landings in the United States fluctuated with an average catch of 600 mt (1.3 million lb) between 1975 and 1983; increased catches in 1984 and 1985; and have experienced continuing declines since with a record low of 3.6 mt (7936 lb) in 2005. Recent estimates of discards of ocean pout often exceed the landings totals. In 2004, ocean pout stocks were overfished but overfishing was not occurring (Wigley and Col, 2006a).

At the peak harvest in 1984 and 1985, ocean pout was being sold to supply the fresh fillet market (Wigley and Col, 2006a).

## West Coast

The Pacific Coast Groundfish FMP includes over 82 species of groundfish according to the Pacific Fishery Management Council (Pacific Fishery Management Council, 2009). Included as groundfish are 64 species of rockfish; 12 species of flatfish (various soles, starry flounder, turbot, and sanddab); 6 species of roundfish (lingcod, cabezon, kelp greenling, Pacific cod, Pacific whiting (hake), and sablefish); 6 species of sharks and skates; and a few other species.

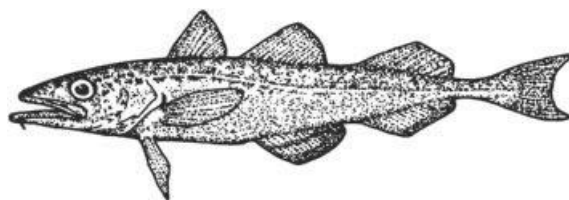
Alaska's groundfish are listed as walleye pollock, Pacific cod, Atka mackerel, sablefish, halibut, lingcod, and numerous species of rockfish and flatfish (Alaska Department of Fish and Game, 2009).

Commercial US landings of the top West Coast groundfish species are listed in Table 3.2.

Gear utilized to catch Pacific groundfish includes bottom and pelagic trawls; mid-water trawls; long-lines; set nets; setlines; hand lines; and pots or traps.

Pacific groundfish fisheries are managed by the Pacific Fishery Management Council's Groundfish FMP, the Groundfish FMPs for the GOA and for the BSAI, and the North Pacific Fishery Management Council's Groundfish FMP. Management methods utilized include permits, quotas, seasons, gear restrictions, guidelines, landing limits, seasonal closures, and limited entry to maintain populations at acceptable levels.

There are special measures in some of the Pacific groundfish fisheries that take into account the pro-



**Figure 3.5** Alaska (or walleye) pollock.

tection of endangered Steller sea lions that utilize fish like the Pacific pollock as a major food source.

## Alaska pollock

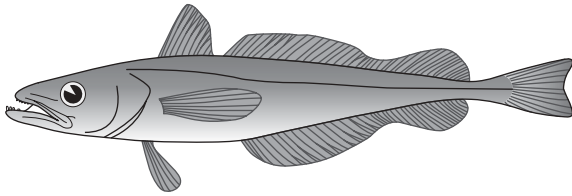
Alaska or walleye pollock (*T. chalcogramma*) (Figure 3.5), yet another member of the cod family, is an important food fish with almost all of the fish sold in the United States caught by US fishermen. The Alaska pollock fishery is the largest (by volume) fishery in the United States. It is also the largest whitefish fishery in the world. The fish are found in the North Pacific with the largest numbers in the Bering Sea (National Marine Fisheries Service, 2009m).

There are three stocks of Alaska pollock within the BSAI and two stocks within the GOA. The Alaska pollock fishery averages annual landings of 1.1 million mt (2.5 billion lb), which is valued at nearly \$1.0 billion. Safe harvest levels have been maintained for 30 years and the Alaska pollock is not currently overfished nor is overfishing occurring (Van Voorhees and Pritchard, 2009; National Marine Fisheries Service, 2009m).

## Pacific whiting

Pacific whiting or hake (*Merluccius productus*) (Figure 3.6) are a silvery color with black speckles on their backs and black inside their mouths. They are found from the Gulf of California to the GOA. There are three stocks recognized for fishery management including the offshore/coastal stock that ranges from southern Baja California to Queen Charlotte Sound; the central-south Puget Sound stock; and the Strait of Georgia stock (National Marine Fisheries Service, 2009i).

Populations are high and rebuilding of the stocks through various management measures was considered complete in 2004 after the fishery was declared depleted in 2002. US Pacific whiting



**Figure 3.6** Pacific hake.

landings saw a low of 90,000 mt (198.4 million lb) in 1980 and reached a peak of 360,000 mt (793.7 million lb) in 2006 (National Marine Fisheries Service, 2009i). Pacific whiting landings for 2008 were 241,050 mt (531.4 million lb) according to NMFS statistics (Van Voorhees and Pritchard, 2009).

Like whiting (silver hake) and other *Merluccius* species, Pacific whiting is a white fleshed, mild tasting fish. It is currently the most abundant commercial fish on the West Coast of the United States and it offers the largest (by volume) single species landings of the 90 species managed under the Pacific Coast Groundfish FMP. Historically, Pacific whiting was landed by US fishermen primarily for the industrial meal fishery with only small amounts being headed and gutted or filleted for human consumption. Today, Pacific whiting is most commonly used to manufacture surimi (processed fish flesh used to make artificial crab and shrimp), although the production of fillets has been increasing (National Marine Fisheries Service, 2009i).

### Pacific cod

The Pacific cod (*G. macrocephalus*) is also known as cod, true cod, and gray cod. In appearance and habits, it resembles its cousin, the Atlantic cod. The Pacific cod has a large head, three dorsal fins, and two anal fins. Its color is brown to gray on the upper surfaces and white on the anal and caudal fins with many brown spots on the back and sides.

Pacific cod are found in the North Pacific Ocean from California to northern Alaska and in a great arc to Korea. For US harvests, there are three stocks of interest those in the GOA, those in the BSAI, and those in waters off of Washington, Oregon and California.

The 5 year average (1982–1986) for Pacific cod landings was 47,174 mt (104.0 million lb) compared with 41,504 mt (91.5 million lb) of Atlantic cod. By 2005, domestic commercial Pacific cod land-

ings made up almost 12% of the total groundfish catch off Alaska (National Marine Fisheries Service, 2009g). The commercial landings of Pacific cod off the West Coast are much smaller (Gustafson et al., 2000). Pacific cod landings were 224,055 mt (494 million lb) in 2008, according to NMFS statistics (Van Voorhees and Pritchard, 2009).

The Pacific cod's white flesh has a mild flavor and flakes easily. It is marketed as fresh and frozen fillets with some of the catch sold as whole fresh fish.

### Yellowfin sole

Yellowfin sole (*Limanda aspera*) is a typical flatfish with a diamond shaped, flattened body with both eyes on the left side. It is one of the most abundant flatfish in the eastern Bering Sea. The species inhabits the eastern Bering Sea shelf from British Columbia to the Chukchi Sea and down the Asian coast to South Korea (Alaska Fisheries Science Center, 2009c).

After being overexploited in the early 1960s by foreign fisheries, yellowfin sole landings decreased significantly in the late 1960s and 1970s. During the 1980s, yellowfin sole began increasing in abundance and today the species supports the largest flatfish fishery in the United States (Alaska Fisheries Science Center, 2009c). Yellowfin sole landings were 141,237 mt (311.4 million lb) in 2008, according to NMFS statistics (Van Voorhees and Pritchard, 2009).

### Atka mackerel

Atka mackerel (*Pleurogrammus monopterygius*) is a semidemersal species with alternating dark and light vertical stripes along the body and into the fins. It inhabits waters from southeast Alaska to the GOA, around the Pribilof Islands, the Aleutian Islands, the Komandorskiye Islands, and off the Kamchatka Peninsula of Russia. The greatest number of these fish occur in the Aleutian Islands region (Alaska Fisheries Science Center, 2009a).

Atka mackerel typically accounts for around 3% of the groundfish catch off Alaska (Alaska Fisheries Science Center, 2009a). Atka mackerel landings were 57,620 mt (127 million lb) in 2008 according to NMFS statistics (Van Voorhees and Pritchard, 2009).

## Rock sole

Rock sole in Alaska are found as two different stocks, the northern and southern rock soles (*Lepidopsetta polyxystra* and *Lepidopsetta bilineata*), which are actually two different species. They are a typical flatfish with diamond shaped, flattened bodies and left-sided eyes. They inhabit waters from Baja California to the southeast Bering Sea (southern rock sole) and from Puget Sound through the BSAI and to the Kuril Islands (northern rock sole) (Alaska Fisheries Science Center, 2009b).

Commercial landings of rock sole were 52,979 mt (116.8 million lb) in 2008 according to the NMFS (Van Voorhees and Pritchard, 2009).

## Arrowtooth flounder

Arrowtooth flounder (*Atheresthes stomias*), also referred to as turbot on the West Coast, is another right-eyed flounder with a diamond-shaped body. They are brownish in color and have a large mouth. Although they are referred to as turbot, they are not related to the true turbot (*Psetta maxima*) that inhabit waters off the European coasts from the North Atlantic to the Black, Baltic, and Mediterranean Seas. Arrowtooth flounder inhabit waters off the West Coast of the United States from northern California through the Bering Sea. They are the most abundant fish in the GOA, and they are the dominant flounder from the Western GOA to Oregon (National Marine Fisheries Service, 2009a).

The arrowtooth fishery is limited by the bycatch limits for rockfish. In the waters off Alaska, arrowtooth were initially a bycatch of other species fisheries and, because of their low value, they were not retained. More recently, a direct arrowtooth flounder fishery has been developed in Alaska and there are no major bycatch concerns in these waters.

Currently, arrowtooth flounder are numerous and overfishing is not occurring. From the 1950s to the 1970s, arrowtooth flounder were caught as part of large, unselective flatfish trawls that were utilized for mink food but in the late 1970s a targeted fishery began to develop. Still, while the retention of fish caught has increased from 10% in the early 1990s to almost 70% in 2008, the low value of these fish leads to many being discarded. Landings for this fishery fluctuated at low levels in the late 1990s and early 2000s (National Marine Fisheries Service, 2009a). Arrowtooth flounder landings have since

increased and were 39,174 mt (86.4 million lb) in 2008 according to NMFS statistics (Van Voorhees and Pritchard, 2009).

Arrowtooth flounder are utilized for surimi and frozen fillets as well as kiriti (processed fish) and meal.

## Pacific halibut

Pacific halibut (*Hippoglossus stenolepis*) have flat diamond-shaped bodies and are found in coastal waters from northern California to the GOA and the Aleutian Island chain and into the Bering Sea. A majority of the fish are found off Alaska (National Marine Fisheries Service, 2009h).

They are currently not considered a groundfish (though they have been in the past) and are managed by the United States and Canada under the International Pacific Halibut Commission with input from the North Pacific Fishery Management Council, the Pacific Fishery Management Council, and the NMFS Northwest Regional Office. In addition to being an important commercial species, Pacific halibut are a popular recreational fish and also an important tribal fish. Because of its high price and large size, Pacific halibut is now one of the most valuable fisheries in the North Pacific (National Marine Fisheries Service, 2009h).

Pacific halibut are not currently overfished nor is overfishing occurring. Landings of Pacific halibut were low in the 1970s due to reduced catch limits. By the 1980s, the stock was rebuilt. Since the late 1980s, US landings have ranged from about 22,680 mt (50 million lb) to almost 40,823 mt (90 million lb) (National Marine Fisheries Service, 2009h). Total halibut landings, the majority of which are Pacific halibut, were 30,256 mt (66.9 million lb) in 2008 according to NMFS statistics (Van Voorhees and Pritchard, 2009).

## Pacific ocean perch

Pacific Ocean perch (*Sebastes alutus*) commonly known as POP are light red in color with some small areas along their back that are dark olive-green. They inhabit the Pacific waters from southern California to the Aleutian Archipelago along North America and also from the Bering Sea to Japan (National Marine Fisheries Service, 2009r).

For the West Coast fishery, catches peaked during the mid-1960s around 20,000 mt (44.1 million lb) but



then declined until the stocks were declared overfished in 1999 with landings of less than 600 mt (1.3 million lb). Between 2002 and 2006, landings declined even further, and currently, there is no directed fishery for Pacific Ocean perch on the West Coast. However, the POP fishery in the BSAI region has been more successful. Since 1990, BSAI Pacific Ocean perch catches have been between 12,000 and 20,000 mt (44.1 million lb) (National Marine Fisheries Service, 2009r). Total US commercial landings of Pacific Ocean perch for 2008 were 28,982 mt (63.9 million lb) (Van Voorhees and Pritchard, 2009).

### Flathead sole

Flathead sole (*Hippoglossoides elassodon*) are right-eyed flatfish similar to the Bering flounder. The species varies in color from a reddish gray-brown to dark olive brown with the blind side of the fish typically being white. They have pores under their eyes and one row of teeth on the upper jaw. Flathead sole occur along the Pacific Coast from the Bering Sea south to the GOA and down to the waters off of central California (National Marine Fisheries Service, 2009p).

Currently, flathead sole are neither overfished nor is overfishing occurring in Alaskan waters. Their status in the waters off of the West Coast is unknown as they are not assessed here (National Marine Fisheries Service, 2009p). The total US commercial landings for flathead sole were 25,274 mt (55.7 million lb) in 2008 (Van Voorhees and Pritchard, 2009).

### Sablefish or black cod

Sablefish (*Anoplopoma fimbria*), also known as black cod, are a roundfish that resemble cod but are not actually part of the cod family. On a per pound basis, sablefish are the highest valued finfish in the Pacific coast and Alaska fisheries. Their geographic range includes waters from Japan north to the Bering Sea and then south to Alaska and on down to the southern tip of Baja, California (National Marine Fisheries Service, 2009j).

There are two stocks of sablefish: the northern population that inhabits waters off of Alaska and the northern coast of British Columbia and the southern population that inhabits waters off of southern British Columbia, Washington, Oregon, and California (National Marine Fisheries Service,

2009j). Sablefish populations are currently high and no overfishing is occurring. Landings of sablefish peaked around 1988 at almost 40,000 mt (88.2 million lb) and have been steadily declining since that time (National Marine Fisheries Service, 2009j). Sablefish landings were 19,635 mt (43.3 million lb) in 2008 according to NMFS statistics (Van Voorhees and Pritchard, 2009).

The majority of sablefish is consumed as a smoked product (National Marine Fisheries Service, 2009j).

### Dover sole

Dover sole (*Microstomus pacificus*) is a typical flatfish with both eyes on one side and coloration that helps camouflage the fish when it rests on the bottom. The species can be found in waters off of Baja, California, and northward all the way to the Bering Sea and western Aleutian Islands (National Marine Fisheries Service, 2009q).

Dover sole populations are not overfished and no overfishing is occurring (National Marine Fisheries Service, 2009q). The total US commercial landings of Dover sole were 11,176 mt (24.6 million lb) in 2008 (Van Voorhees and Pritchard, 2009).

### Lingcod

Lingcod (*Ophiodon elongates*) are also called buckthead because of their enormous mouth and jaws that appear too large for their bodies. They are not a true cod but rather a member of the greenling family. They live in waters from Baja, California, to Kodiak Island in the GOA (National Marine Fisheries Service, 2009f).

Lingcod populations are rebuilt and overfishing is no longer occurring. Landings peaked in 1985 but then experienced a significant decline in the mid-1990s. By 1999, lingcod was declared overfished and stricter management rules were implemented. By 2005, the lingcod stocks had recovered and rebuilding restrictions were removed. However, landings are still low (National Marine Fisheries Service, 2009j). Lingcod landings for 2008 were 283 mt (625,000 lb), according to NMFS statistics (Van Voorhees and Pritchard, 2009).

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# 4 Pelagic Fish

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Laura S. Douglas

## Introduction

The term *pelagic* is derived from a Greek word meaning the sea or open ocean. When applied to fish, it generally means those species adapted to living not far from the ocean surface. The North East Fisheries Science Center defines pelagic fish as those that “spend most of their life swimming in the water column as opposed to resting on the bottom” of the body of water (Northeast Fisheries Science Center, 2004). The pelagic fish of commercial interest may be found from top surface waters to depths as great as 200 m (656.2 ft) or more.

Oddly, pelagic fish of commercial importance are found in just a few families, the most important of which are the herrings, *Clupeidae*; the anchovies, *Engraulidae*; the mackerel-tuna family, *Scombridae*; and the jacks, *Carangidae*. Other pelagic species that are sold in the United States include the swordfish, *Xiphiidae*, and the dolphinfish of the family *Coryphaenidae*, which is marketed under the Hawaiian name of mahi-mahi.

Statistics of the worldwide catch (FAO, 2006) of fish show a ratio of nearly four pelagic to about one nonpelagic (groundfish) (see Table 4.1) remarkable because we harvest far more species (and families) of groundfish than pelagic fish. In 1987, when this

book first came out, the one species of fish caught in the greatest abundance ( $6.7 \times 10^6$  metric tons (mt) or 14.8 billion lb) worldwide was Alaska pollock, a groundfish. By 2006, Alaska pollock had dropped to second place (2,860,487 mt or 6.3 billion lb) with a pelagic species (Peruvian anchovy) moving into first place in the world with 7,007,157 mt (15.4 billion lb) landed (FAO, 2006). In 1987, the next four species in total catch were all pelagic species: Japanese Pilchard,  $5.3 \times 10^6$  mt (11.7 billion lb); South American Pilchard,  $4.7 \times 10^6$  mt (10.4 billion lb); Chilean Jack Mackerel,  $2.68 \times 10^6$  mt (5.9 billion lb); and Peruvian Anchovy,  $2.1 \times 10^6$  mt (4.6 billion lb). By 2006, 8 of the top 11 species captured in the world were pelagic, with just two being groundfish, two Alaska pollock, and five blue whiting (Table 4.1) (FAO, 2006). In 2008, three of the top ten species that landed in the United States were pelagic fish, menhaden came in second to pollock while herring came in eighth and sardines came in tenth (Voorhees and Pritchard, 2009; Table 4.2).

The pelagic fishes caught worldwide and in the United States can be divided into three groups (1) the herrings, sardines, and anchovies; (2) the tunas, mackerels, bonitos, and billfishes; and (3) the miscellaneous pelagic fish that include the cobia, dolphinfish, wahoo, and opah (see Table 4.3). The

**Table 4.1** Top 11 worldwide capture for species for 2006.

Rank	Species	Amount landed (metric tons)
1	Anchovy (Peruvian anchovy)	7,007,157
2	Alaska Pollock	2,860,487
3	Skipjack tuna	2,480,812
4	Atlantic herring	2,244,595
5	Blue whiting	2,032,207
6	Chub mackerel	2,030,795
7	Chilean jack mackerel	1,828,999
8	Japanese anchovy	1,656,906
9	Large head hairtail	1,587,786
10	Yellowfin tuna	1,129,415
11	European pilchard (sardine)	944,012

Source: FAO, 2006. Reproduced with permission from the Food and Agriculture Organization of the United Nations.

**Table 4.2** Top ten US domestic species for 2008.

Rank	Species	Amount landed (metric tons)
1	Pollock	1,042,406
2	Menhaden	608,455
3	Flatfish	300,784
4	Salmon	298,619
5	Hakes	249,282
6	Cod	232,705
7	Crabs	147,501
8	Herring (sea)	117,678
9	Shrimp	116,390
10	Sardines	87,579

Source: Voorhees and Pritchard, 2009.

**Table 4.3** Worldwide capture for groups of pelagic species for 2000 and 2006.

Species group	Amount landed (metric tons)	
	2000	2006
Herrings, sardines, anchovies	24,936,012	19,105,699
Tunas, mackerels, bonitos, billfishes	5,847,856	6,465,810
Miscellaneous pelagic fishes	10,666,141	10,821,958

Source: FAO, 2006. Reproduced with permission from the Food and Agriculture Organization of the United Nations.

**Table 4.4** US domestic landings of pelagic species.

Species		Amount landed (metric tons)	
		Average (2003–2007)	2008
Menhaden	Gulf	444,223	420,719
	Atlantic	202,704	187,742
Sardines	Pacific	92,135	86,597
	Spanish	757	983
Herring (sea)	Atlantic	89,690	78,571
	Pacific	35,219	39,109
Mackerels	Atlantic	42,075	21,752
	Chub	4,729	3,578
	King & cero	2,599	3,012
	Spanish	2,290	1,879
Tuna	Albacore	13,367	11,535
	Bigeye	5,128	6,459
	Bluefin	695	329
	Little tunny	343	252
	Skipjack	682	416
	Yellowfin	3,860	2,720
	unclassified	40	18
	Anchovies	8,774	14,678
	Swordfish	3,366	3,662
Dolphin fish		1,102	1,054
Bonito		652	830
Jack Mackerel		711	283

Source: Voorhees and Pritchard, 2009.

herrings, sardines, and anchovies offer the largest catches by weight (both in the United States and worldwide) and in 2008 this group saw US landings of 828,399 mt (1.8 billion lb) (Voorhees and Pritchard, 2009). These account for a small percentage of the world landings that totaled 19,105,699 mt (42.1 billion lb) in 2006 (FAO, 2006). Menhaden (both Gulf and Atlantic) accounted for 73% of the US catch. The tuna group provided US landings of 56,442 mt (124.4 million lb) in 2008. The mackerels account for 54% and the tunas made up 38% (Voorhees and Pritchard, 2009; see Table 4.4).

## Species

### Herrings, sardines, and anchovies

This group includes the Atlantic herring, menhaden, Pacific sardines (or pilchard), and anchovies.

These species tend to be smaller fish (typically 7–15 in long) with very oily flesh. Like other pelagic fish, they tend to be darker on the top side (blue, green, or black) and lighter on the belly (white or silver). These fish are typically filter feeders who eat plankton. They are often found in large schools and, as such, are caught commercially using purse seines, mid-water trawl gear, and roundhaul gear. Commercial fisheries for Atlantic herring exist along the coasts of Maine and New Brunswick for young fish of one to 3 years, although the stocks are declining and the last Maine sardine processing plant closed in April 2010 (Seelye, 2010). Fisheries for adult herring have developed more recently and exist on the Scotian Shelf, Georges Bank, and the western Gulf of Maine. The menhaden fishery is second only to Alaska pollock in terms of quantity with US landings in 2008 of 608,455 mt (1.34 billion lb) valued at \$90.7 million. The fisheries for this group of species are managed by Fisheries Management Plan (FMPs) from the Atlantic States Marine Fisheries Commission and the New England Fishery Management Council, and by the Coastal Pelagic Species FMP. Management techniques for these fisheries include catch controls, total allowable catch (TAC), area management schemes, spawning area closures, quotas, limited entry, bycatch reduction requirements, and monitoring of landings. Landings of Atlantic herring reached 470,000 mt (1.03 billion lb) in 1968 but decreased to 36,000 mt (79.4 million lb) in 1983 after

the offshore fishery collapsed in 1977. Peak landings of Pacific sardines were greater than 700,000 mt (1.54 billion lb) in 1936 but declined during the late 1940s. By the 1970s, stock levels were extremely low and directed fishing was halted from 1974 to 1981 with landings of less than 50 mt (110,231 lb). California landings of Northern anchovy peaked in 1975 at 143,799 mt (317 million lb) but did not exceed 6000 mt (13.2 million lb) from 1983 to 1999. Menhaden and anchovies caught in the United States are not used for human consumption but instead for oil or fish meal, for poultry and pen-raised fish and also as baitfish. The US imports all of the anchovies eaten in the country (Table 4.5; Overholtz, 2006a; Voorhees and Pritchard, 2009; National Marine Fisheries Service, 2009g, 2009l, 2002; Wikipedia, 2010).

### Tunas, bonitos, and billfishes

Tunas are one of the fastest fish in the world with 20–30 mph speeds not uncommon. Some of these fish can swim up to 50 mph over large areas. They have streamlined bodies with large white muscle mass for long distance swimming and red muscle mass for bursts of speed and they also have physiological adaptations (circulatory heat exchange system) that allow them to inhabit warmer surface waters as well as deep, cold waters. Tuna species are found in subtropical, tropical, and

**Table 4.5** Herrings, sardines, and anchovies-summary table.

Species				
Trait	Atlantic herring <i>Clupea harengus</i>	Menhaden <i>Brevoortia</i> spp. and <i>Ethmidium</i> spp.	Pacific sardines <i>Sardinops sagax</i> <i>caerulea</i>	Northern anchovy <i>Engraulis mordax</i>
Location	Northeast Atlantic ocean from Cape Hatteras, NC to Labrador	Atlantic menhaden—Florida to Nova Scotia; Gulf menhaden—southern Florida to the Yucatán Peninsula	Southeastern Alaska to Baja California and the Gulf of California	Baja, California, and the Gulf of California to British Columbia
2008 US landings	78,571 mt	608,461 mt	86,597 mt	14,678 mt
Overfished?	No		No	Undefined
Overfishing occurring?	No		No	No/undefined

Source: Overholtz, 2006a; Voorhees and Pritchard, 2009; National Marine Fisheries Service, 2009g, 2009l, 2002; Wikipedia, 2010.

**Table 4.6** Tuna summary table.

Species	Albacore ( <i>Thunnus alalunga</i> )	Bigeye ( <i>Thunnus obesus</i> )	Yellowfin ( <i>Thunnus albacares</i> )	Atlantic Bluefin ( <i>Thunnus thynnus</i> )	Skipjack ( <i>Katsuwonus pelamis</i> )
Trait					
2008 US landings	11,535 mt	6,459 mt	2,720 mt	329 mt	416 mt
Overfished?	Atlantic: yes; S. Pacific: no; N. Pacific: unknown	Atlantic: no; Pacific: no	Atlantic: no; Pacific: no	Yes	No
Overfishing occurring?	Atlantic: yes; S. Pacific: no; N. Pacific: unknown	Atlantic: no; Pacific: yes	Atlantic: no; Pacific: yes	Yes	No

Source: National Marine Fisheries Service, 2010a, 2010b, 2010c, 2010d, 2010e, 2010j, 2010k, 2010m, 2010n.

temperate waters worldwide in the Atlantic, Pacific, and Indian Oceans and also in the Mediterranean Sea, the Gulf of Mexico, and the Caribbean. All of the tuna species, except for the Atlantic bluefin tuna, have an Atlantic stock and a Pacific stock. The western and central Pacific Ocean tuna fishery is one of the world's most productive fisheries and is also the largest with yearly catches nearing 1.02 mt (2.24 billion lb) that have a value of over \$1.7 billion. This is about one-third of the tuna landed worldwide, 30% of the sashimi-grade tuna imported by Japan, and 60% of the canned tuna. Skipjack tuna is the main species by volume while yellowfin is the main tropical tuna caught in the western North Atlantic by US fisheries. Atlantic bluefin tuna has the darkest and fattiest flesh of all tunas and is prized for sushi and sashimi but is not recommended for cooking. Tuna species such as the yellowfin, bigeye, albacore, and blackfin tunas are often difficult to distinguish from one another as they tend to be similar in shape and size and they are often caught together. Most tunas have torpedo-shaped bodies and are described as having metallic or dark blue (almost purple or black) backs and yellow, silver, or white bellies. Variations occur in the color and length of fins as well as in scales. Tunas are caught utilizing various gear including longlines, hand lines, rod and reel, purse seine, troll gear, pole and line, drift gill nets and baitboats. Tuna stocks are managed, depending on location, under the 2006 Consolidated Atlantic Highly Migratory Species FMP, the International Commission for the Conservation of Atlantic Tunas, the Pacific Fishery Management Council's Highly Migratory Species FMP, the Western Pacific Fishery Management Council's Pelagic Fisheries of the

Western Pacific Region FMP, the Inter-American Tropical Tuna Commission, the Western and Central Pacific Fisheries Commission, and the South Pacific Tuna Treaty. Management methods vary by species and location but include the use of quotas, gear restrictions, time and area closures, permits, logbook documentation, size restrictions, TACs, trade restrictions, monitoring and inspection programs, gear exclusion zones, limited access, retention or trip limits, and assessments (see Table 4.6; National Marine Fisheries Service, 2010a, 2010b, 2010c, 2010d, 2010e, 2009j, 2009k, 2009m, 2009n).

Mackerels are spindle-shaped fish that are tapered at both ends. They tend to be iridescent blue green or iron-gray above and silvery white underneath. Mackerels are found on both sides of the North Atlantic Ocean and from Brazil to Massachusetts in the western Atlantic and in the Gulf of Mexico. Commercial and recreational fisheries exist for mackerel and mid-water trawl gear is the primary means to harvest the species commercially while hook and line is the most common gear for recreational catches. Mackerels are managed under the Mid-Atlantic Fishery Management Council's Atlantic Mackerel, Squid, and Butterfish FMP and/or by the South Atlantic and Gulf of Mexico Fishery Management Councils' FMP for Coastal Migratory Pelagic Resources. Management tools include quotas, TAC, seasonal closures, size limits, trip and possession limits, gear restrictions, and permit requirements. Cero mackerel is included under an FMP but no regulations apply since it has no directed fishery and is mainly a bycatch or recreational species. At one time, the average landings for Atlantic mackerel were

**Table 4.7** Mackerel summary table.

Species Trait	Atlantic <i>Scomber scombrus</i>	Cero <i>Scomberomorus regalis</i>	King <i>Scomberomorus cavalla</i>	Spanish <i>Scomberomorus maculatus</i>
2008 US landings	21,752 mt	None available as not distinguished from King mackerel in reports	3012 mt	1879 mt
Overfished?	No	Unknown	No	No
Overfishing occurring?	No	Unknown	Little to none	No

Source: Overholtz, 2010; National Marine Fisheries Service, 2009g, 2009c, 2009e, 2009o.

350,000 mt (772.6 million lb) (between 1970 and 1976) but then the stock collapsed and landings were less than 50,000 mt (110.2 million lb) from 1978 to 1984. Spanish mackerel are often caught to use as bait in big game fishing (see Table 4.7; Overholtz, 2006b; National Marine Fisheries Service, 2009b, 2009c, 2009e, 2009o).

Swordfish (*Xiphias gladius*), a type of billfish, are one of the fastest fish on record at 55.6 mph (24.9 m/s) (Froese et al., 2010). There are two stocks of swordfish those in the North Pacific and those in the North Atlantic. They occur in tropical, subtropical, and temperate waters worldwide. This species is dark brown or black on the topside and fading to a lighter color on the underside. They have streamlined, round, elongated torpedo-shaped bodies with long, flattened bills and the adults lack teeth and scales. The North Pacific swordfish fishery off the west coast is managed by the Pacific Fishery Management Council's Highly Migratory Species FMP; the swordfish fishery in the US Exclusive Economic Zone (EEZ) off the Pacific Islands and on the high seas is managed by the Western Pacific Regional Fishery Management Council's Pelagic Fisheries of the Western Pacific Region FMP; and the North Atlantic stock is managed under Final Consolidated Atlantic Highly Migratory Species FMP. Management plans utilize quotas, size limits, time area closures, gear restrictions and modifications (especially concerned with marine mammal and turtle bycatch), retention limits, limited entry programs, permitting, and monitoring. Within the Hawaiian EEZ, swordfish are caught with hand lines and longlines; on the high seas, the species is caught with shallow-set longline

gear; and the North Atlantic swordfish is caught using pelagic longline gear. Commercial US landings increased steadily between 1970 and 1989 then increased sharply in the 1990s with a peak in Hawaiian landings in 1993 of 5942 mt (13.1 million lb). By 1995, the Hawaiian landings had dropped to 2726 mt (6.0 million lb) and the longline fishery for swordfish was closed in Hawaii from 2001 to 2004. In 2004, new regulations were enacted and swordfish landings increased sixfold in 2005. The North Pacific stock is not overfished nor is overfishing occurring, while the North Atlantic stock was rebuilt as of 2009 and the species is neither overfished nor is overfishing occurring. The US landings of swordfish in 2008 amounted to 3662 mt (8.1 million lb) (National Marine Fisheries Service, 2010f, 2009h).

### Miscellaneous pelagic fishes

Cobia (*Rachycentron canadum*) are found worldwide in tropical, subtropical, and temperate waters (except in the Eastern Pacific) and in US waters from the Gulf of Mexico to the Florida Keys and up to Massachusetts. They are relatively uncommon and are often mistaken for sharks or remoras. The adults of this species are dark brown with a single dorsal fin and they prefer to dwell near surface objects such as buoys, piers, boats, or platforms. Cobia are managed under the FMP for Coastal Migratory Pelagic Resources of the Gulf of Mexico and South Atlantic that utilizes permitting, gear restrictions, minimum size limits, and a daily per person limit. Recreational landings have been between 400 and



600 mt (881,849 and 1,322,774 lb) since 1980, while commercial landings have been between 351 and 627 mt (773,823 and 1,382,298 lb) since 1987. Cobia are not overfished and no overfishing is occurring (National Marine Fisheries Service, 2009d).

Dolphinfish (*Coryphaena hippurus*) also known as mahi-mahi occur in tropical and subtropical waters worldwide. They have torpedo shaped bodies with sharply forked tails and bright yellow, green and turquoise patterns. This species is managed by the Dolphin Wahoo Fishery of the Atlantic FMP and mentioned in the Coastal Migratory Pelagic Resources in the Gulf of Mexico and South Atlantic Region FMP; on the Pacific coast, the species is managed under the Highly Migratory Species FMP. Regulations include a cap on commercial landings, minimum size limits, gear restrictions, and permitting requirements. Currently, population estimates are high and there is no apparent overfishing. Commercial US landings have been increasing since the 1970s with a noticeable increase from 1989 (454 mt or 1 million lb) to 1995 (998 mt or 2.2 million lb). In 1999, the total US harvest was 91% recreational and 9% commercial. US commercial landings of dolphinfish were 1.05 mt (2324 lb) in 2008 (National Marine Fisheries Service, 2009f).

Opah (*Lampris guttatus*) are found in tropical and temperate waters worldwide. They are plate-like in shape (vertically flat and round) with a silver color and red fins and mouths. Very little is known about this species but it is being studied by the Pacific Islands Fisheries Science Center. Opah are not schooling fish so they are harvested in small numbers and are mainly caught as bycatch in tuna and billfish longline fisheries. Because they are particularly valued in Hawaiian restaurants, opah are highly marketable and are not discarded. There is no direct fishery for opah (National Marine Fisheries Service, 2009i).

Wahoo (*Acanthocybium solanderi*) occur in the Pacific, Atlantic, and Indian Oceans in tropical and subtropical waters. There are two stocks one in the Atlantic and one in the Gulf. Wahoo are typical pelagic fish in that they have dark, steel blue backs and pale blue bellies. Wahoo are caught using trolling surface lures and are managed by the Dolphin and Wahoo of the South Atlantic Region FMP through the use of permits, limits, and gear and area restrictions. It is unknown if Wahoo are overfished or if overfishing is occurring. Commercial landings range between 72.6 and 113.4 mt

(160,000 and 250,000 lb), while recreational landings have ranged between 136.1 and 816.5 mt (300,000 and 1.8 million lb) (National Marine Fisheries Service, 2009a).

## Physical adaptation

Fish have adapted to living in a dense medium (either fresh or saltwater) in many ways. In order to propel themselves in a watery world with minimum effort, most have streamlined bodies. The mackerel family, which includes the mackerels, bonitos, and tunas, has achieved the greatest degree of streamlining. These pelagic fish are rapid swimmers and have cigar-shaped bodies that are slightly thicker in front to facilitate the streamlining effect. Their fins can be folded back into depressions to reduce drag. They also have small finlets between the tail and the upper dorsal and lower anal fins that act like the slotted flaps on the wing of an airplane. These finlets help reduce the flow and reduce turbulence and resulting drag over the tail fin.

The ultrastreamlining of some pelagic fish enables them to attain remarkable speeds. Usually, speeds of fish are divided into three categories: cruising speeds are those used for ordinary travel; maximum sustainable speeds can be kept up for a considerable time; top speed is an explosive burst of speed for a short time only.

The top speed performers are often pelagic fish. When “fastest fish” is searched on the Internet, many sites and many speeds result. It should be noted that it is difficult to measure much less confirm the speed of a fish in the wild. Having said that, most sites indicate that the sailfish (*Istiophorus platypterus*) is the fastest fish on record with speeds of 68–70 mph (110 km/h) (Wyatt, 2009; Answers.com, 2010; Nationalgeographic.com, 2010).

Fishbase.org has compiled speed measurements of over 80 fish species. The top speed for some of the pelagic fishes of interest are presented in Table 4.8 (Froese et al., 2010).

One point often ignored in fish speeds is the chief propellant, the tail fin. All the piscatorial speed demons have either deeply forked tails like the mackerels, or lunate or crescent-shaped tails like the tunas, bonitos, and swordfish (see Figure 4.1). These two shapes are well adapted to high cruising speeds and top speeds when necessary.

**Table 4.8** Top speeds of some pelagic fishes.

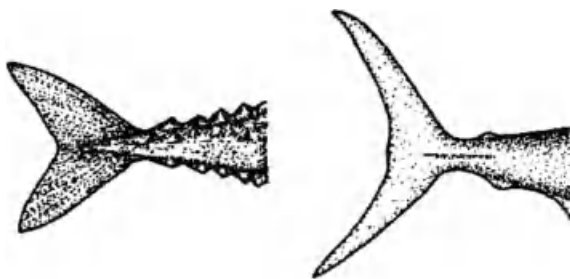
Common name	Species	Top speed	
		mph	m/s
Skipjack tuna	<i>Katsuwonus pelamis</i>	21.0	9.41
Yellowfin tuna	<i>Thunnus albacares</i>	45.8	20.5
Australian spotted mackerel	<i>Scomberomorus munroi</i>	46.5	20.8
Wahoo	<i>Acanthocybium solandri</i>	47.4	21.2
Swordfish	<i>Xiphias gladius</i>	55.6	24.9

Source: Froese et al., 2009.

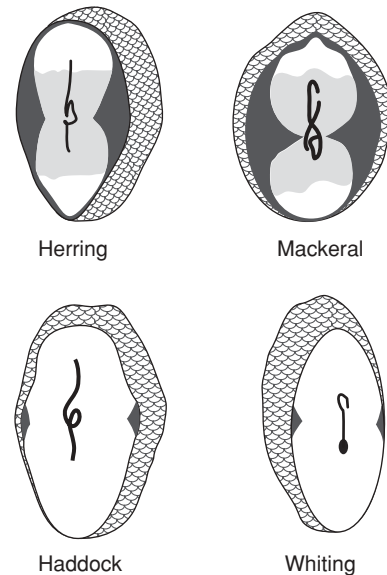
## Musculature

In nature, some animals are placid and slow-moving like cows, and others are as swift as greyhounds. Among fish, swimming muscles make the fundamental difference between the slow and the fast. Fish muscles are of two types white and red. Normally, the white muscle fibers make up the mass of muscle segments commonly called flakes. The red muscles are found as a layer on top of the white muscles. Mackerel is a fish with this two-toned musculature (Figure 4.2). The red muscles have much fat, a rich supply of blood, and contain a red oxygen-carrying protein called myoglobin that accounts for the dark color.

The red muscles of pelagic fish enable them to swim at a constant speed in order to obtain food or to accomplish spawning migrations, which may involve hundreds or even thousands of miles. They really are the cruisers of the fish world. Their nor-



**Figure 4.1** Forked tail, like that of the mackerel (left) or lunate tail, like that of the swordfish (right) are a sign of the sea's speed demons.



**Figure 4.2** Comparison of dark muscle size in active (top) and less active fish (bottom).

mal speed is higher than that of most fish, and, on average, they can swim for long periods of time at 6 knots (11.1 km/h). This speed is quite fast when compared with most members of the cod family that cruise at about 2 knots (3.7 km/h).

When danger threatens, pelagic fish can shift into high gear by calling on the white muscles that instantly go into powerful action. Instead of requiring oxygen, they rely on stored glycogen (called animal sugar) to energize muscles for movement. The only trouble is that once their glycogen supply is exhausted, it takes about a day or so to replenish it. If the danger has passed, the recovery is normal. However, some tunas can become so agitated when caught in nets that they actually die in a frenzied state.

## Preservation

Preservation of fish typically takes the forms of curing (drying, salting, or smoking), chilling or freezing, canning, and the making of mince or surimi (Hall, 1997). More recently, radiation and high pressure processing (HPP) have been added as possible preservation methods. Irradiation has been used on mackerel and may be used in combination with other preservation methods to, this should be to

**Table 4.9** Typical processing of some pelagic species.

Fish	Species	How processed?
Herring	<i>Clupea harengus</i>	Fried or grilled
Mackerel	<i>Scomber scombrus</i>	Fried, grilled, smoked, or canned
Sprat	<i>Sprattus sprattus</i>	Mostly cold or hot smoked or canned
Sardine	<i>Sardina pilchardus</i>	Canned in oil, grilled or fried
Tuna	<i>Thunnus thynnus</i>	Fried, roasted, smoked, or canned or used for sausage

Source: Venugopal, 2009.

enhance shelf-life and safety. HPP tends to be utilized for improved freezing and thawing as well as for creating textured surimi-based seafood analogs. HPP has also been used for shelf-life extension on some pelagic fish such as tuna (Venugopal, 2006).

Table 4.9 shows how some pelagic species are usually processed. The processing specifics of other pelagic species is explained in the text that follows.

### Maine sardines

Processing of Maine sardines has a long history that started in the 1870s when the Franco-Prussian War limited the supply of sardines from overseas. In the 1950s, there were nearly 50 sardine canneries in Maine but the numbers have since dwindled in 1970, there were only 21 canneries and by 1978 there were 15. In 2005, the only cannery left in operation was the one in Prospect Harbor. On April 18, 2010, the 100-year-old cannery was closed and Maine sardines are no longer produced. This decline has occurred due to overfishing and a decline in Atlantic herring stocks along with subsequent federal catch limits and quotas that have been decreasing recently (Ellis, 1997; Seelye, 2010; Wickenheiser, 2010).

However, given that many other sardines are processed in a similar way, Maine sardine processing will be covered in this chapter. Immature herring, *Clupea harengus harengus*, are usually held alive in the net for about a day to purge them of feed. This procedure is necessary because if the

fish are full of feed when they are brought to the cannery, enzymes in the gut will become activated, causing rapid deterioration and belly-blown fish. The fish are transferred to the carrier boat by suction pump, and as they are being put in the hold, salt is added for its preservative, firming, and flavoring action. Because of the demands of consumers for less salt in their diets, the practice of salting sardines aboard vessels is now being limited. Refrigerated seawater systems and chilled seawater, a mixture of ice and seawater, are being used to a larger extent in recent years.

The carrier boats discharge the fish by suction pumps at the cannery where the fish are flumed into holding tanks that also serve as brining tanks. At this point, the fish are salted to maintain a desired level of salt. The fish are then conveyed to the packing tables where packers using scissors cut the heads and tails from the fish and place them in open cans. Some of the larger canneries have installed automated cutting machinery to perform the trimming process. The cans are then placed on special wire racks on wheeled carts and rolled into a steam box for a preliminary cooking. Afterward, the racks are inverted to drain any water and oil resulting from the cooking process. The cans are then conveyed to a machine that fills each one with oil. Most Maine packs contain soybean oil, although cottonseed, olive, and peanut oils can also be used, or they may be filled with mustard, tomato, or pepper sauce. The oil or sauce is added hot to create a partial vacuum in the can. After filling, the cans are immediately sealed, placed in baskets, and sterilized by steaming at 121°C (250°F) under 6.8 kg (15 lb) of pressure in retorts (industrial pressure cookers). Upon cooling, the cans are washed, inspected for proper seals, and cased for shipping.

The Maine sardine industry also packed herring steaks from fish too large to be packed as sardines. For these packs the herring are sliced into approximately 1.9 cm (3/4 in.) slices after trimming and are then packed and processed in the same manner as the sardine packs. The Maine Sardine Council, which was funded by the industry, graded samples from every lot of sardines produced in Maine.

### Brisling and sild (formerly Norway sardines)

The processing of Brisling (small sprats) and Sild (small, immature herring), which were formerly

known collectively as Norway sardines, is similar to Maine processing except that two different species of fish are commonly canned in Norway. One is the same species as the Maine herring, *Clupea harengus harengus*. The other is a herring-like fish called sprat in English and termed *brisling* in Norwegian (*Sprattus sprattus sprattus*) (Hall, 1997). We make a distinction between the two Norway sardine packs later in this chapter in a section that also explains why these packs require different labels so as not to mislead the consumer.

An additional difference between Norway and Maine produced sardines is that a considerable portion of the Norway pack is smoked, and Maine packs are not.

### Portuguese sardines

Portuguese sardines seem to be going the way of Maine sardines. The FAO stated that "The canning industry and the drying industry are showing a decreasing trend in production, particularly sardine canning, due to decreasing sardine landings" (FAO, 2010). That being said, it is still an important industry. For the most part, about the only packs of true sardines found in the United States originate in Portugal and contain the fish whose scientific name is *Sardina pilchardus*. This sardine differs from the herring and sprat sardines in one very important respect: the viscera of sardines are much larger and must be removed, whereas with herring and sprats the temporary starving of the fish in nets (24 hours) is sufficient.

An additional difference is that despite the improvement in mechanization of processing equipment, there is still some extra hand labor required to prepare the skinless and boneless fancy packs. Although some variations in processing do occur, in general, the steps are the same for all sardines.

### Tuna

Tuna arrive at the canning factory having been frozen at sea. Once at the plant, they are thawed and mechanically conveyed to butchers who slit the belly wall and remove the viscera. They are then spray rinsed and placed in special baskets, which are tiered in wheeled racks. The racks of raw tuna

are rolled into large cookers for a precooking operation, where steam is introduced to raise the temperature to an average of 102.2°C (216°F). The length of cooking time varies depending on the size of the fish, with large fish requiring a cooking time of 8 hours or more.

After the precooking operation, the fish are cooled to make them firm. When cooled sufficiently, the heads are removed and the bodies are skinned and split into lengthwise quarters. The dark meat is separated from the light meat, which is all that is used for human consumption. The light meat quarters or loins are then mechanically cut and packed into cans. Salt is added to those packs requiring salt, although an increasing amount is now packed without added salt. The final step before sealing the cans is to add a packing medium such as vegetable broth, oil, or water. The cans are then sealed under vacuum and passed through a cleaning operation to remove any surface oil or other packing medium. The final step is to heat the cans in a retort or autoclave to a temperature that will kill all microbial life within the cans (Hall, 1997).

### Mackerel

Unlike tuna, mackerel are either delivered to the cannery fresh or as frozen blocks. They go to a cleaning or dressing station, where the fish are cut along the belly and the viscera are removed, including the kidney that lies lengthwise along the backbone. They are placed in a chemical bath and then water-jet sprayed to remove the skin. The next step is to remove any traces of blood. Then the fish are subjected to a brine soaking to firm the flesh, remove any remaining traces of blood, and to lend flavor. Some canneries omit the brining operation and simply add salt to each can before it is filled.

They are placed in slots on a conveyor that carries them to circular knives set to cut the fish to fit the can. A split and a whole body section of cut mackerel will fill a 1.0 lb (454 g) tall can solidly. After being filled, the open cans go to an exhaust box where they are subjected to a hot steam treatment to expel any trapped air. Upon leaving the exhaust box, the temperature of the open cans runs about 62.8°C (145°F).

From this point, the cans travel on a conveyor that tilts them to remove any liquid that has accumulated. The liquid is replaced by the desired packing

medium, which may be brine, oil, tomato sauce, or another flavoring. Next, the cans go to a seaming machine where the lids are sealed on the cans. From here the cans are rapidly moved through a mechanized washing operation that removes any packing medium, liquids, or particles of fish. The final operation consists of heating the cans in a retort or autoclave to the temperature that kills all microbial life within the can with the least damage to the sensory attributes of the final product (Hall, 1997).

### Anchovies, Mediterranean style

The only pack of anchovies now commonly found on store shelves is the Mediterranean style because it is canned and has a longer shelf life than Scandinavian anchovies. The processing of Scandinavian anchovies is not described here because they are not generally shipped to the United States due to their limited shelf life.

Genuine cured anchovies are made only from a European fish related to the herring family. Its scientific name is *Engraulis encrasicolus*, and it is the only member of the family Engraulidae in the European-Mediterranean waters. The preparation of this type of anchovy is more of an art than a science as we see in the following description of the process.

Freshly caught anchovies are beheaded by hand in a way that removes the entrails at the same time. The fish are placed in special barrels and then a layer of salt is added. Then a layer of fish is placed at right angles to the preceding layer, and alternate layers of fish and salt are made until the barrel is nearly full. At this point, the fish are topped with a layer of salt and a weighted cover to keep the fish pressed down. After a few days, the anchovies will sink somewhat and the cover and top layer of salt are removed. More fish are layered in the barrel, followed by a layer of salt, until the barrel is filled again and the weighted cover is replaced. The purpose of the weighted cover is to force out any air bubbles in the liquid extracted from the fish flesh and to prevent any entrance of air to the fish.

The curing process takes at least 6–7 months at a temperature between 15.6°C and 20°C (60°F and 68°F). The point at which the peak of perfection is reached is determined by an expert who judges by color (red) and flavor and odor. The changes that take place in the curing period are entirely enzymatic and not bacterial in origin. If the cure meets

the approval of the expert, the curing process is stopped by chilling the fish.

Once cured, the anchovies undergo a labor-intensive operation that accounts for their high price. First, they are given a brine wash and the skin is rubbed off; the tail is snipped and each tiny fish is filleted by hand; the backbone is removed in sections, and each fillet is blotted to remove moisture. The fillets are packed in cans by layering successively, and then the can is filled with olive oil. The cans are then hermetically sealed but not heat processed.

### Menhaden

Atlantic and Gulf menhaden (*Brevoortia tyrannus* and *Brevoortia patronis*) support one of the oldest fisheries in North America that is second only to Alaska pollock in terms of quantity. Menhaden are a very fatty species, ranging up to 18% fat, and are not consumed as fresh, frozen, or canned products. They do, however, represent one of the principal species for the fish meal industry of the United States (the other is pollock) (Miles and Chapman, 2006). Fish meal is used primarily for animal feed and fertilizer. Menhaden are also processed for their oil that is used in omega-3 supplements as well as in other products (Atlantic States Marine Fisheries Commission, 2007). The crude fish oil is also sold in Northern Europe where it is refined and manufactured into margarine. Small amounts of refined fish oils are used in a variety of industrial products because of their special properties (see Chapter 26 for a discussion of fish meal and oil processing).

### Nutritional value

All pelagic species have one thing in common: a high fat content. The unique composition of the fats or lipids in fish, and especially pelagic fish, has a special nutritional value to consumers. Many studies have shown a correlation with animal fat consumption and cardiovascular diseases (heart disease and stroke). Organizations such as the US Food and Drug Administration, the National Institutes of Health, and the American Heart Association have recommended that people reduce their consumption of saturated fats, which are derived primarily from meat products, and increase their



consumption of unsaturated fats, which are derived from fish and vegetable products. Studies on Greenland Eskimos and Japanese consumers have indicated that people with diets high in fish products also have lower death rates from coronary heart disease. The implication of these studies is that increasing the consumption of seafood that have high levels of polyunsaturated fats may reduce the risk of heart disease and stroke.

Fish lipids may also be important in the management of other human diseases. The effects of fish oil consumption on neurological disorders, headaches, diabetes, arthritis, depression, inflammatory diseases, colitis, asthma, and cancers have all been studied (Venugopal, 2006).

All pelagic species contain significant levels of polyunsaturated fatty acids (PUFAs) and are the prime source of omega-3 fatty acids that are those that reportedly have a major effect on reducing blood cholesterol levels. According to scientists from the National Marine Fisheries Service Gloucester Laboratory in Gloucester, Massachusetts, pelagic species can contain almost 3 g (0.11 oz) of omega-3 fatty acids per 100 g (3.5 oz) serving. Pacific mackerel, Pacific herring, bluefin tuna, and anchovies all have omega-3 fatty acid contents of greater than 1.0 g/100 g meat (Venugopal, 2006). The American Heart Association indicates that one 3 oz serving of canned, light tuna contains 0.17–0.24 g of omega-3 fatty acids (American Heart Association, 2010). Just one can of sardines will provide 2.7 g (0.1 oz) of omega-3s. The addition of pelagic species to diets can greatly increase intake of PUFAs and potentially reduce cardiovascular and other diseases.

In addition to their healthy lipids, pelagic fish are also a good source of vitamins A, D, and E as well as a variety of minerals (magnesium, calcium, phosphorus, sodium, and potassium) and trace elements (selenium, manganese, cobalt, iodine, and molybdenum) (Venugopal, 2006).

## Labeling

Many pelagic fish are important products in international trade and include such well-known canned foods as sardines, pilchards, anchovies, sprats, mackerel, tuna, and bonito. There is a complexity in national and international identification of both common names and scientific equivalents that is

mind-boggling. Following is a conservative listing of products you are likely to encounter.

## Sardines and sardine-like products

International standards (Codex Alimentarius Commission—Codex Stan 94-1981) state that the name “sardines” is to be reserved solely for that fish whose scientific name is *Sardina pilchardus*. If the sardines in question are not *Sardina pilchardus*, they must be labeled as “X sardines,” where “X” is the name of a country or geographic area or the species or common name as is customary and required by law in the country where the product is sold. Sardines (without any qualifiers) are canned almost exclusively in Portugal, Spain, and Morocco and do not occur anywhere in North American waters. They are usually labeled as “Imported Portuguese Skinless and Boneless Sardines.”

At present, American sardines are being eclipsed both because of a serious shortage of supply and by aggressive European marketing pressures. Because of the disastrous decline of the California sardine *Sardinops sagax*, no California sardines were allowed to be packed until fish stocks recovered. But as of 2009, California sardines are being landed again. More than 90% of these are exported and turned into fish meal, oil, pet food, and bait. However, there seems to be a slowly growing interest in California canned sardines as an omega-3 rich food and as a local product (Masala, 2009). On April 18, 2010, the only operating sardine cannery in the United States (in Maine) closed (Seelye, 2010). By law, sardines processed in Maine were permitted to be labeled as sardines but the word “Maine” had to qualify the word “sardines.” The labeling also had to list the brand name. The qualifier “Maine” was required because the fish that was canned was an immature herring and not a true sardine. Few people realize that much of the imported Norwegian pack of sardines comprise exactly the same herring whose scientific name is *Clupea harengus harengus*.

Norway packs two distinct species of fish, and each is usually labeled differently. The pack containing immature herring (the same as that which Maine packed) is labeled as “Sild” (formerly labeled as “Norway Sardines”) (Hall, 1997) followed by a declaration of the packing medium, such as sild sardine oil (herring oil), and will often list the number



of fish, such as “one layer 6–12 fish” or “two layers 16–24 fish.” The term *sild* is both the Norwegian and Danish name for herring.

The second species of fish packed in Norway as a sardine is the sprat whose scientific name is *Sprattus sprattus*. These fish are labeled as “Brisling” (formerly “Norway Sardines”) (Hall, 1997). Previously, some Norwegian packers had their labels declare “brisling sardines” in a very bold type. In Norwegian, brisling means that herring-like fish that is called sprat in English. Not found in waters outside the northern European Atlantic, it is generally considered superior to the herring. The difference in price between packs of sild and brisling sardines is appreciable.

## Anchovies

Anchovies are prepared almost exclusively in Europe and in two different styles involving several species of fish. The first is the Mediterranean style, which is descended from the type of cure once used by the ancient Greeks and Romans. Its perfection lies in a special process of salting and fermentation. The only fish permitted in this pack is the true anchovy, *E. encrasicolus*.

The second type of anchovy packed in Europe is produced in the Scandinavian countries of Sweden, Norway, and Denmark, with Sweden in the lead. Like the Mediterranean type, this product relies on a special salting and fermentation process. Unlike the Mediterranean style, it does not use the true anchovy but instead uses the same herring and sprats described under Brisling and Sild. Long usage has dictated that these two species of fish may properly be labeled as anchovies when prepared by salting and fermenting but must revert to the labeling of sild and brisling sardines when hermetically sealed and treated like sardine-type products.

## Tunas

Members of the family Scombridae constitute an important source of food worldwide. The customs governing the labeling of tuna are even more involved and complex than those for canned sardines. Biologists recognize 13 species scattered among four genera to be true tunas.

Tunas recognized as true tunas by scientists are not always recognized as tunas by different govern-

ments. For example, US laws prohibit the labeling of bonito as tuna, yet Canada permits it. Japan, on the other hand, considers about five species of what we call tunas to actually be bonitos. However, our main concern here is with labeling requirements in the United States where about a dozen species of the family Scombridae may properly be labeled as tuna. Only one tuna, the albacore *Thunnus alalunga*, can be labeled “white” tuna. All others are required to be labeled as “light” tuna.

Label declarations may vary as to the form of pack, whether solid pack, chunks, flakes, or grated. The solid pack and chunks of both white and light meat tuna predominate. Prominent label declarations are now evident for those packs with no added salt aimed at consumers who must limit their intake of sodium.

## Quality factors

### Brisling and sild (Norway sardines)

All other things being equal, the greater the number of fish in the can, the more chosen is the pack. When very small fish are packed (16–24 fish), the most attractive way to pack them is to make a double layer and cross pack them, that is, the fish lie parallel to the ends of the can. Normally, fish running 11–12 to the can (a desired size) are packed with the head end toward the ends of the can. The fish are alternated head and tail to present an even fill. The least number of fish permitted is four.

Head ends should be cut evenly and the fish packed belly side up to present a silvery appearance. All fish in each can should be of the same size. If the packing medium is oil, it should be clear and not turbid or cloudy. The flavor of the fish should be mild and without a strong salt flavor, which would indicate improper brining procedure. If other packing media are used, such as tomato sauce or mustard, they should be homogeneous and not curdled.

Processing was generally the same for Maine sardines as it is for brisling and sild.

### Portuguese sardines

The true Portuguese sardine grows larger than either the herring or sprat, but despite the difference in size, the ex-vessel price is much greater than that for herring or sprats. Quality factors to look for

are six or more skinless and boneless fish with no trace of visceral matter. Brisling and sild (formerly Norway sardines) do contain entire viscera but little or no food in the gut. Fish should be packed in the can head to tail and arranged to present white and dark portions of flesh evenly. The oil (usually, olive) should be clear and not cloudy or turbid. The flavor is milder than the herring sardines and sprat, and the flesh is firmer than either. The abundance of white meat has aptly led some to compare this true sardine to the position held by the white-meat albacore tuna among all the tunas.

## Tunas

Standards of identity, definitions, and standards of fill of container for tuna were announced by the Food and Drug Administration in 1959. In 1965, federal specifications for canned tuna were issued by the General Services Administration for the use of all federal agencies.

A primary factor is the color of the meat and whether it accords with the can label declaration as "white" or "light." Two other color designations, "dark" and "blended," are provided for in the definitions, but they are for limited or specialized markets. The label declaration of white applies only to the albacore tuna (*Thunnus alalunga*) whose reflectance value exceeds 6.3 Munsell units. Similarly, light meat tuna must have a reflectance value not lower than 5.3 Munsell units and it must not be cloudy or turbid. The values for free fatty acids, smoke point, and moisture content should fall in the range established by the manufacturer of the oil. Dark meat tuna is all tuna with Munsell values below 5.3 (CFR, 2009a).

Canned tuna is also classified in various forms. Solid or solid pack tuna is the designation for the fish loins that have been freed from any discolored surface tissue and cut into segments with no free fragments added and less than 18% flakes broken free during canning. Chunk or chunk style tuna designates a mixture of pieces of various sizes in which the original muscle structure is retained. No less than 50% of this product is retained when pressed through a one-half-inch mesh screen. Flake tuna is a mixture of various sizes in which the original muscle structure is retained, more than 50% of the product passes through a one-half-inch mesh screen. Grated tuna consists of tuna particles that

are of uniform size that passes through a one-half-inch mesh screen. These particles are discrete and do not form a paste (CFR, 2009a).

The more serious defects to look for are honeycombing of the flesh, lack of uniform color, extraneous foreign material, short flesh, short weight, and off-flavors caused by rancid oil, sour flesh, or scorched or overcooked cans.

The other labeling regulation linked to tuna is the dolphin-safe nomenclature. To utilize "dolphin-safe" on a tuna label, the tuna in the can must not have been caught using a purse seine net or a drift-net or by another fishery in such a way that dolphins were killed or seriously harmed. Documentation and observers are utilized to provide proof of this (CFR, 2009b).

## Mackerels

The Atlantic mackerel, *Scomber scombris*, is seldom packed now, but a close relative, the chub or Pacific mackerel, *Scomber japonicus*, enjoys a small annual pack. The jack mackerel, which is a carangid, *Trachurus symmetricus*, and not a true mackerel, is packed extensively.

The chief factor to look for here is broken body meat. If the mackerel are improperly brined before being placed in the cans, they do not attain the firmness that is desired for a good commercial pack. The liquid packing medium is usually a brine, which becomes quite turbid and cloudy after it is heated in a retort. True mackerels usually have a better flavor than jack mackerel.

## Anchovies, Mediterranean style

The Mediterranean-style anchovy is usually in one of two styles. The more common style is that of tiny, thin fillets packed flat in successive layers to fill the can. The other consists of anchovy fillets rolled around a caper, a cured olive, or other suitable small piece of vegetable that has been pickled in vinegar for preservation. Regardless of the type of pack, the anchovies should be red in color (due to fermentation process) and smoothly prepared without ragged edges. Some packs may contain mustard and vinegar as well as oil, making for a zesty packing medium.

Because of their high salt content, anchovies are never eaten as they come from the can but are freshened in water for about 15 to 20 minutes and then used with other foods as appetizers in salads, other fish products, quiches; and as anchovy paste, cream, and butter.

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# 5

## Major Cultured Species

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Lori S. Marsh

### Importance of aquaculture

Aquaculture is the farming of fresh or saltwater organisms including fish, crustaceans, mollusks, and aquatic plants such as algae. Aquaculture has been practiced for centuries; in the Far East, the practice dates back over a thousand years (Swift, 1993).

Increases in population and standards of living, accompanied by an increasing understanding of the health benefits of eating seafood, have resulted in a steadily increasing demand for seafood. Unfortunately, it is widely agreed that the world's major fishing grounds have either reached or exceeded their natural limits for producing fish. Therefore, any increase in per capita seafood consumption must come from aquacultured products, and not wild catch.

Worldwide, from 1970 through 2002, aquaculture grew at an annual rate of 8.9% (Leung et al. 2007). The number of species being farmed has also increased dramatically. The Food and Agriculture Organization (FAO) of the United Nations reported that 314 aquatic species were farmed in 2003. An average of five farmed species was added each year from 1950 to 2000 (FAO, 2006). In 2006, FAO reported 29 species being produced at the level of

210,000 metric tons (mt) or more and that aquaculture supplied approximately 36% of the worldwide demand for seafood (FAO, 2006). Approximately 90% of this production occurred in Asia, with China topping the list at 67% of the world aquaculture production.

This chapter provides some statistics on aquacultural production worldwide. In addition, the most common aquaculture methods are described in a general fashion and a bit more detail are provided for the six most aquacultured species groups.

### Production environments and systems

Production environments for aquaculture are classified as freshwater, brackish, or marine. If aquatic plants are excluded from consideration, then freshwater aquaculture produces the maximum amount of products worldwide (57.8%) compared with 34.2% for the marine environment and 8.0% for brackish waters (FAO, 2006). When aquatic plants are included in aquacultured production, the marine environment produces the maximum amount of products due to the large production of seaweeds.



There are a great variety of aquaculture production systems and management strategies. Generally, systems can be classified as pond, enclosure, cage, flow-through, or recirculating. Management strategies range from ranching, where fish spend a portion of their lifecycle in the wild and a portion in captivity, to systems that are intensively managed from breeding of brood stock to final harvest. Examples of ranching include rearing juvenile salmon and trout for release in the wild and capturing of young bluefin tuna at sea and rearing them in cages until they reach marketable size.

Management intensity varies greatly with different systems. Extremes range from high-input, highly intensive, indoor recirculating aquaculture systems (RAS), where water quality and water temperatures are controlled, to low-input, seasonal ponds, where feeding is limited to fertilization to promote phytoplankton and zooplankton production, which serves to feed the fish. In some countries, it is common to integrate fish culture with agricultural crops such as rice (in Vietnam) and ducks in Thailand. System specifics are highly dependent upon the water resources, technologies, and capital resources available to the fish farmer.

## Pond systems

Ponds are the most common aquaculture system, based on both area and yield. Pond farms can be inland or coastal; inland ponds are the most common. Prior to constructing a farm pond, it is necessary to understand the soil quality, topography, and water resources available. Pond management ranges from extensive, low-density systems with very low inputs where feeding is limited to the addition of fertilizers to intensive, high-density production that requires intensive feeding, water quality monitoring, and aeration. Ponds may be monocultured (one fish species) or polycultured.

Pond systems can create environmental problems. Probably of greatest concern is the discharge of nutrients (e.g., nitrogen and phosphorus) and sediment to nearby water bodies. The release of disease organisms from a pond to nearby waters is also a possibility. Discharges are most likely to occur from intensively managed ponds because of water exchange (to improve the water quality in a pond) or if the pond is drained for harvesting.

Another negative environmental consequence of ponds resulting from shrimp farming has taken a toll on coastal habitats. Mangrove swamps in Africa and Southeast Asia have been cleared at an alarming rate to make room for shrimp ponds. In just 6 years, from 1987 to 1993, Thailand lost more than 17% of its mangrove forests to shrimp ponds (Holmes, 1996). Destruction of mangroves leaves coastal areas exposed to erosion and flooding, alters natural drainage patterns, increases salt intrusion, and removes critical habitat for many aquatic species.

## Enclosure and cage systems

Enclosure and cage systems are designed to rear aquatic organisms by restricting them to a small area within a larger body of water. Enclosures and cages can be set up in a large variety of water environments including dug ponds, embankments, reservoirs, catchments, lakes, rivers, channels, paddy fields; in protected large water bodies such as bays and fjords; and in open waters and high seas.

Generally, if at least one side of the containment is formed by a naturally occurring barrier such as a shoreline, the containment is considered an enclosure. A simple and efficient example of an enclosure used for aquaculture is one formed by damming a bay, cove, fjord, or arm of the sea. Another example of an enclosure is that which is formed by employing nets to partition off areas of an open-water body, while using the shoreline to form one side of the barrier.

Cages and pens are more self-contained than enclosures and may be partially or completely submerged. Large net pens typically consist of a floating unit with a flexible mesh-net suspended under it. Both cage and enclosure systems rely on natural water currents to remove waste and uneaten feed and to provide fresh, oxygenated water for the fish.

Offshore or open-ocean aquaculture generally refers to marine farming systems located several miles offshore. These systems require special designs to withstand storms in open-ocean settings. New technologies generally involve submersible cages that are anchored to the ocean floor and can be moved within the water column. Because of the difficulty in accessing offshore cages, they generally contain an equipment room and feeding



mechanisms, with robotics used for cage maintenance, inspection, cleaning, and monitoring (Naylor and Burke, 2005). The next-generation technology includes a gigantic cage that will roam the seas rather than remain at a fixed location.

Large-scale production of salmon, tunas, and other commercially valuable fishes in net pens has become common. Unfortunately, cages and pens are not without environmental consequences, which include the following:

- (1) Uneaten feed, fish feces, and chemicals used to control net fouling and disease outbreaks can effect local waters and damage bottom-dwelling biota, hence reducing natural biodiversity in the area.
- (2) Interbreeding of escaped fish with the wild population may reduce the fitness of wild fish.
- (3) Concentrating large amounts of fish in small areas may lead to disease outbreaks. Viral, bacterial, or parasite outbreaks could be transmitted to wild fish. For example, data from Ireland, Scotland, Norway, and Canada suggest that net-pen rearing is linked to outbreaks of deadly sea lice in wild salmon (Naylor and Burke, 2005). To control outbreaks, some farmers use antibiotics and parasiticides, which could lead to development of resistant strains of infectious organisms.
- (4) Net-pen operators often kill or aggressively deter predators such as herons, seals, sea lions, and killer whales through tactics such as sirens.

### Flow-through systems

Flow-through systems generally consist of raceways or long tanks, where water is introduced at one end and flows out at the other. These systems require large quantities of oxygenated water, which tends to limit the number of applicable sites. Trout is probably the most common species reared in raceways.

Environmental concerns with raceways generally involve discharge of nutrients and suspended solids into natural water bodies. Because of the flowing nature of the water, treatment to remove nutrients and solids is often difficult and expensive. Release of nonnative species from flow-through systems to the natural environment is also a concern.

### Recirculating aquaculture systems

RAS employ treatment devices to clean and reuse water within the production system. Recirculating systems can be either indoors (allowing for temperature control in cooler climates) or outdoors. Advantages of RAS include a high degree of environmental control; ease of inventory control, grading, and harvesting; control over escapement, hence no concerns for releasing nonnative species; the ability to optimize feed and chemical use; faster growth rates and higher density production resulting in very high production per square meter per year; the ability to implement biosecurity programs to restrict entry of disease organisms; and increased disease diagnosis and treatment options. Disadvantages of RAS systems include initial high capital costs and high operating costs due to large feed, labor, and energy inputs.

### Common aquacultured species

The FAO of the United Nations tracks fisheries and aquaculture worldwide, maintaining statistics on production, utilization, and trade (FAO, 2006). Table 5.1 presents the ten largest species groups in terms of quantity of aquaculture product produced in 2006 and shows both their total value and the value per unit weight. The top three species groups in terms of total quantity are among the least expensive in terms of cost per unit weight. However, the fourth, sixth, and tenth most aquacultured species groups (shrimps, salmons, and freshwater crustaceans) are among the most expensive per unit weight.

Table 5.2 presents the five species groups with the greatest percentage increase in aquaculture production between 1997 and 2006. It should be noted that none of these species groups are currently in the top ten in terms of quantity produced. The group containing cods, hakes, and haddocks ranks 10th in terms of value per unit weight, and the groups containing sea urchin and sturgeon rank 11th and 12th, respectively.

A brief discussion of the six largest aquacultured species groups (based on quantity of production worldwide) follows. Pillay and Kutty (2005) and Leung et al. (2007) provide a much more detailed description of aquaculture systems for various species.

**Table 5.1** Top ten aquacultured species by quantity in 2006.

Species group	Quantity produced (ton)	Total value (US\$'000)	Value in 2006 (US\$/kg)
Carp, barbells, and other cyprinids	20,525,641	18,837,954	0.92
Oysters	4,714,215	3,188,289	0.68
Clams, cockles, and arkshells	4,310,488	4,054,145	0.94
Shrimps and prawns	3,164,384	12,485,824	3.95
Tilapias and other cichlids	2,326,413	2,777,464	1.19
Salmonids, trouts, and smelts	2,143,271	9,891,798	4.62
Mussels	1,890,131	1,200,446	0.64
Scallops and pectens	1,408,153	2,158,732	1.53
Misc. marine molluscs	1,255,888	729,084	0.58
Freshwater crustaceans	1,065,790	4,714,823	4.43

Source: FAO [ftp://ftp.fao.org/fi/stat/summary/b-1.pdf](http://ftp.fao.org/fi/stat/summary/b-1.pdf).

## Carp

Fish in the family Cyprinidae represent the largest aquacultured species group, both in terms of quantity (20,525,641 mt in 2006) and market value (US\$18.8 billion). The common carp (*Cyprinus carpio*), which is cultured throughout Asia, in most parts of Europe including the former USSR, some countries in Africa, and Latin America, is one of the only fish species that is considered domesticated. Just over 3 million mt of *C. carpio* were aquacultured in 2006. This fish is an omnivore in nature, and in ponds, it feeds on a wide variety of plant and animal matter.

Another group of five species collectively known as Chinese carps represents even greater aquacultural production than the common carp. Within this group, in 2006, the silver carp (*Hypophthalmichthys molitrix*) was the second most aquacultured species worldwide in terms of quantity (4.4 million mt) and first in terms of value (US \$3.7 billion). The grass carp (*Ctenopharyngodon idella*), also in the Chinese

carp group, was in 2006 the third most aquacultured species in terms of quantity and second in terms of value. The remaining species in the Chinese carp group include the bighead (*Aristichthys nobilis*), the black carp (*Mylopharyngodon piceus*), and the mud carp (*Cirrhina molitorella*). In China, the Chinese carps, along with the common carps are often reared together (polycultured) in ponds. The various species feed on different materials within the pond. For example, the grass carp is herbivorous and feeds on macrovegetation including grass and aquatic plants; the silver carp feeds on plankton; the bighead consumes macroplankton; the black carp feeds on snails and mollusks at the pond bottom; and the mud carp feeds primarily on detritus in the water column. The common carp, which are omnivores, are considered scavengers in the pond. The strategy of polyculture is believed to have originated from collection of carp larvae and fry from natural spawning grounds in rivers, which was necessary because Chinese carp do not spawn naturally in ponds. Separation of larvae and fry by species

**Table 5.2** Aquacultured species groups showing the greatest percentage increase in production from 1997 to 2006.

Species group	Quantity produced in 2006 (ton)	Value produced in 2006 (US\$/kg)	Percentage increase in production from 1997 to 2006
Sea urchins and other echinoderms	85,601	3.39	115,577
Abalones, winkles, and conchs	367,503	1.37	9,340
Cods, hakes, and haddocks	13,274	3.82	4,266
Freshwater mollusks	154,235	0.59	1,087
Sturgeons and paddlefishes	21,319	3.34	953

Source: FAO [ftp://ftp.fao.org/fi/stat/summary/b-1.pdf](http://ftp.fao.org/fi/stat/summary/b-1.pdf).

was difficult, and rearing of mixed species proved both compatible and efficient.

A third group of carps, the Indian carps include catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhina mrigala*), and calbasu (*Labeo calbasu*). In India, these species are collectively referred to as the major carp, which distinguishes them from other cyprinids, known as minor carp, which do not grow as large. The Indian carps are often polycultured in ponds in India, along with Chinese carps because it has been observed that this combination results in higher yields than polyculture of Indian carps alone. This combination is referred to as composite carp culture in India (Pillay and Kutty, 2005). In both China and India, there is a trend toward increasing the number of species within a pond polyculture system to increase production.

Carps are primarily produced in stagnant or semistagnant ponds and were traditionally fed by fertilization of the pond plus supplementary feeds consisting of green fodders, freshwater mollusks, and by-products from agricultural activities (e.g., grain processing and slaughterhouses). This keeps feed costs low and in addition, using organic manures as fertilizers, further boosts agricultural economies (Pillay and Kutty, 2005). More recently, however, there has been a trend toward more intensive culture systems, which are monocultured and rely on commercially manufactured formulated pellet feeds (Miao and Yuan, 2007a).

## Oysters

Oysters (family Ostreidae) are the second most aquacultured species group in the world in terms of quantity produced, exceeded only by the carps. Several species of oysters are cultured in many parts of the world. Oysters cultured for food (as opposed to pearl oysters) belong to two genera: *Crassostrea* (cupped oysters) and *Ostrea* (flat oysters). While cupped oysters are more common in aquaculture production, flat oysters are more desired for serving on the half-shell and command a much higher price in many countries.

Cupped oysters tolerate a wide range of temperatures and grow well between 10°C and 30°C. Some tropical species can tolerate even higher temperatures, up to 34°C. The flat oyster is less tolerant of high temperatures, with a growth range of 10–24°C;

temperatures above 26°C are often lethal (Pillay and Kutty, 2005).

Most oysters attach to a hard substrate. They typically tolerate salinities between 5 and 32 ppt, but some can tolerate higher salinities. They are filter-feeders, drawing their food through an inhalant. Culturing oysters generally involves collecting spat, placing it on suitable substrate and in a location with suitable temperatures and available feed sources for grow out, grading and replanting as needed, providing protection from predators and pests, and fattening for market.

One-culture system, known as bottom culture, involves providing some material (typically molluscan shells) to stiffen the sea bottom and provides a surface for oyster attachment. The off-bottom culture method can employ various substrates that sit off the water bottom; off-bottom culture is particularly useful in areas where the bottom consists of soft mud. Off-bottom systems include stakes, sticks, or racks and suspended systems. In stake and stick systems, the stakes may be driven into the bottom or set out horizontally on racks. In rack systems, trays or ropes are suspended from racks in or near intertidal zones. In suspended systems, ropes or trays are suspended from floating rafts or longlines. Many tray designs and tray materials are employed in rack and raft systems.

Spat may be collected and grown in the same location or spat may be collected in one area and then moved to another area for grow out. Spat collection is generally accomplished by placing a substrate material (such as sticks or mesh bags containing shell cultch) in areas of abundant spat fall.

Most oysters are grown from collection of wild spat; however, hatchery production of seed oysters is possible. Many wild spat fall in locations of low water velocity that are not optimum for grow out due to relatively low food sources (plankton). Hence, the collection, transport, and sale of oyster spat have developed into a separate industry. Likewise, hatchery production of oyster spat is a specialized industry.

## Clams, cockles, and arkshells

This species group is the third most aquacultured in terms of total quantity produced worldwide. Simple methods of clam cultivation have been practiced for centuries in Japan and China. While

considerable research on both hatchery production of clam seed and grow out systems has been conducted (primarily in the United States and the United Kingdom), the majority of clam production is still from simplified methods that have existed for a very long time.

Clam culture is very similar to oyster culture, with the simplest systems involving transfer of seed from spawning areas to growing beds, which are typically located in intertidal areas that remain covered with water most of the time. Much more intensive systems can be found in the United States, involving hatchery production of seed and grow out in recirculating systems.

## Shrimps and prawns

Shrimps and prawns are the fourth most aquacultured species group in terms of quantity produced; however, when measured in terms of total monetary value of annual worldwide production, it is the second highest species group. It is third highest of the aquacultured species groups on a value-per-unit-of-production basis (US\$3.95/kg), exceeded by the trout and salmon species group (value US\$4.62/kg) and the freshwater crustaceans (value US\$4.42/kg) (FAO, 2006). The relatively high value of shrimp, accompanied by high market demand from economically advantaged countries such as the United States and Japan, led to the rapid development of shrimp aquaculture. Major shrimp producing countries include China, Thailand, Indonesia, and Vietnam.

The terms shrimp and prawns are generally used to denote crustaceans of the families Penaeidae and Palamonidae (Pillay and Kutty, 2005). In the current aquaculture literature, it appears that the term prawn is generally applied to freshwater forms of the Palamonidae family, while shrimp is used for the other marine species. Some of the major cultivated species of marine shrimp include *Penaeus monodon*, *Penaeus chinensis*, and *Penaeus vannamei*. The most important aquacultured freshwater prawn is *Macrobrachium rosenbergii*.

Shrimps have been farmed as a subsidiary species in saltwater ponds and impoundments and in extensive pond systems for hundreds of years; however, semi-intensive shrimp production is a relatively new enterprise, driven by the export market. As is true with all aquacultured species, develop-

ment of hatchery technologies that assure a year-round adequate supply of seed is necessary to support the development of an intensive grow out industry.

Grow out of shrimp is generally accomplished with pond culture and semi-intensive systems are becoming more and more common. Traditional coastal shrimp ponds in Asia that were originally stocked with wild seed stock that arrive with tidal water exchange are more and more commonly being stocked with sorted fry that are either wild caught or hatchery reared (Pillay and Kutty, 2005). Specially designed ponds are the norm for modern, large-scale shrimp farming. Many of these farms employ pumps to provide for controlled water exchanges. Intensive systems often employ concrete tanks with controlled water inlets and outlets and harvest basins. In addition, aeration and substrates to provide for habitat are often provided. Stocking densities in these systems often reach 200–250 fry/m<sup>2</sup> and yield as high as 2.8 kg/m<sup>2</sup>. However, intensive stocking densities and heavy feeding can cause environmental problems and result in disease issues accompanied by large-scale mortalities.

China is the largest producer of cultured shrimp in the world (Miao and Yuan, 2007b) and hence is representative of culture trends. Shrimp aquaculture in China developed rapidly beginning in the late 1970s and continued to expand until 1992, when the industry was plagued with disease problems. In the early 1990s, most major shrimp producers in Asia experienced an outbreak of shrimp viral diseases including white spot syndrome virus and Taura syndrome virus. It was not until about 2000 that China's shrimp industry recovered to its 1992 levels and began to experience another rapid increase in cultured shrimp production. A great deal of the recovery is attributed to a shift to production of *Litopenaeus vannamei*, which is an exotic species that can be produced in very low salinity conditions and which has not experienced the same virus pressures that *P. monodon* and *Fraxinus chinensis* experienced. Unfortunately, disease outbreaks remain an unpredictable threat to the industry.

## Tilapias

Tilapias (family Cichlidae) are native to Africa. Tilapias are herbivores or omnivores, tolerate a

wide range of salinities from fresh to seawater, and require warm temperatures (optimal range 27–30°C, lethal range 10–12°C). They are a very hardy fish and, hence, are considered a good species for aquaculture. Popularity of tilapia has increased significantly in the United States, with total imports of tilapia (primarily as frozen filets) rising from 27.8 million kg in 1998 to 179.4 million kg in 2008, a 545% increase in two decades.

Tilapias are prolific breeders, which have introduced challenges in their culture. First, there are valid concerns that the escape of tilapias into non-native waters could devastate the local fish populations. Also, because tilapias mature early and breed frequently, especially in tropical climates, producing fish of marketable size proved to be challenging (Pillay and Kutty, 2005). However, through applied research and species selection, tilapia has become the fifth leading aquacultured species group in the world.

Even though tilapias are prolific breeders, a great deal of work has gone in to developing methods of spawning to produce large numbers of consistent sized fry for use in aquaculture. Because males grow more rapidly and tend to reach a larger size than females, considerable effort has also been directed to producing monosex populations. Techniques used to produce male fry include use of interspecific hybrids known to produce predominantly male offspring, sex-reversal using steroid hormones, and size grading of fry to select males. The use of hybridization to produce male fry has proved limited in commercial practice due to the difficulty in maintaining the pure genetic lines necessary to obtain consistent results.

Grow out of tilapia is typically accomplished in ponds. If the grow out is based on unsorted seed stock, it is necessary to stock at very low densities (on the order of 1 kg/m<sup>3</sup> or 0.009 lb/gal) to achieve a fish of market size before it starts breeding. After harvest, these ponds are typically drained completely to destroy fry that resulted from inadvertent spawning. If these fry are not destroyed, they tend to be stunted and breed before reaching an acceptable market weight.

The use of all male stock can alleviate the problem of spawning and not reaching market weight. With all-male stock, much higher stocking densities are possible and densities become limited by the level of inputs and management. In RAS with intensive water treatment and inputs of food and oxygen,

densities as high as 238 kg/m<sup>3</sup> (2 lb/gal) have been reported.

## Salmons and trouts

Salmons and trouts, in the family *Salmonidae*, while having a shorter aquacultured history than carps, do have a long history in Europe and North America. A great deal of scientific and laboratory research has been carried out on salmonids, with the initial emphasis placed on hatchery production for enhancement of wild populations to improve or maintain sport fisheries and for ranching. However, the salmonids are currently in the top ten most aquacultured species groups worldwide in terms of quantity produced.

The typically anadromous salmons require a freshwater nursery period followed by a saltwater grow out. Atlantic salmon (*Salmo salar*) is the most common species used for large-scale sea farming, but some Pacific salmons, primarily coho (*Oncorhynchus kisutch*) and chinook or king salmon (*Oncorhynchus tshawytscha*) are also cultured in net pens (Pillay and Kutty, 2005). Norway, Chile, the United Kingdom, and Canada are the four leading producers of aquacultured salmon. Norway and the United Kingdom were the first countries to develop net-pen salmon operations. Ownership within the salmon industry has become highly concentrated and is a vertically integrated industry, with a multinational company owning subsidiaries that include feed, hatchery, grow out, distribution, and value added processing. In 2001, 30 companies controlled approximately two-thirds of the world's farmed salmon and trout production (Naylor and Burke, 2005).

Unfortunately, the salmon industry faces obstacles to further expansion. For example, in Chile, an ongoing outbreak of Infectious Salmon Anemia (ISA), a highly contagious virus that first appeared in 2007, has forced the closure of numerous salmon farms. As a result of ISA, Chilean salmon production is forecasted to drop between 40% and 50% in 2009 (MercoPress: South Atlantic News Agency, 2009). Another challenge that all carnivorous aquaculture ventures face is their dependency on fish meal and fish oil in the production diet. Because of this dependency and declining natural harvests, the sustainability of carnivorous aquaculture production is being questioned (Naylor and Burke,



2005). Finally, Liu and Sumaila (2008) analyzed both salmon and finfish aquaculture data and concluded that the 5-year moving average of year-on-year growth rate of aquacultured production in Norway, the United Kingdom, Canada, Chile, and globally have all been declining for more than 20 years. Hence, they conclude that the expectation that fish from aquaculture will continue increasing into the future at recent rates to compensate for declining capture fisheries production is not realistic.

Rainbow trout (*Oncorhynchus mykiss*) is a native of the Pacific Coast drainages of North America. Because it is the fastest growing of the trouts and tolerates higher temperatures than the others, it is the most commonly aquacultured trout. The two main varieties of rainbows consist of the sea-going steelhead and the land locked form, which is the more commonly used trout in commercial aquaculture. It has been introduced to waters of all continents except Antarctica. A cool water species requiring relatively cool water temperatures (optimal range 10–18°C, lethal limit range 25–27°C), rainbow trout is found in upland areas of many tropical and subtropical countries of Asia, east Africa, and South America.

Trout are cultured in a variety of systems including ponds, cages (both fresh and saltwater environments), raceways, tanks, and recirculating systems. Raceways, which were originally used for trout production in North America, are probably the most widely used system. Recirculating systems are more common for brood stock and fry production.

## Conclusions

Aquaculture, which has existed for centuries, continues to advance in terms of culture techniques and species raised. As the worldwide demand for seafood increases, the need for aquacultured products will also increase due to the finite production capacity of the world's oceans. Care must be taken to assure that expansion of aquaculture industries

does not occur at the expense of wild stocks or the environment.

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# 6

## Shellfish—Mollusks

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### Mollusk farms and fisheries

Mollusk farms and fisheries are an important industry in the United States, with a value of approximately \$2.3 billion annually. Both fisheries and mariculture are based primarily on the production and harvest of bivalves (two-shelled mollusks) such as clams, oysters, and mussels, but gastropods such as abalone are also farmed as well as harvested in the wild. Conchs and cephalopods such as squid or octopus are only wild harvested. Mollusks are harvested along the entire coast of the United States, from coastal bays and estuaries to the edge of the continental shelf.

The earliest settlers harvested shellfish. Midden heaps (piles of shell) found in many areas along the coast show that native tribes also consumed oysters, clams, and conchs. Tribes used shells for tools, decorations, and barter. The quahog, or hard clam, bears the scientific name of *Mercenaria* in reference to its use as a kind of currency by the tribes.

### Natural history

Most of the mollusks such as clams, oysters, and abalone have a similar life history. As water tem-

peratures warm up in the spring or early summer, and/or the right combination of algae is present in the water, mollusks spawn. Most bivalves release eggs and sperms into the water, and external fertilization takes place as the eggs and the sperms meet. The fertilized eggs develop into free-swimming planktonic larvae that drift within the water mass at the whim of wind and tides. This process disperses the larvae to populate areas away from the parents. After approximately 2–4 weeks the larvae develop into seed, also known as spat, which sink to the bottom, or, in the case of oysters and mussels, attach themselves to a substrate, where they settle and grow. However, brooding takes place entirely inside the mantle cavity for the smaller native West Coast oyster (*Ostrea conchaphila*), popularly known as the Olympia oyster. Eggs are fertilized in the mantle where the larvae develop until they can survive on their own, at which time they exit the protection of the mother oyster and settle nearby.

Gastropods and cephalopods generally also reproduce via internal fertilization and lay their eggs inside of capsules, which are attached to the bottom or other suitable substrates. These offspring hatch from the eggs as completely formed juveniles instead of larvae.

Most commercial species of mollusks become sexually mature at about 1 year of age. Later, typically in their second or third year, about half change sex and become female. Some shellfish can change sexes periodically, but many others change sex only once.

Many commercially harvested shellfish are prolific, provided the environmental conditions are conducive to reproduction and larval survival. It is estimated that a clam is capable of spawning up to 60 million eggs per year; an oyster might yield approximately five times that number per year. Increasingly, however, most shellfish farmed on the East and West Coasts are propagated in hatcheries using broodstock. Even the Gulf Coast, which still largely relies on wild-set oyster seed, has recently turned to hatchery production in some instances to offset losses to the wild fishery from hurricanes Katrina and Rita.

## Feeding

Most commercial bivalves are filter feeders, obtaining their food by pumping water through their gills, a sophisticated sorting method whereby they select certain food particles that are passed to the mouth and into the stomach. A single adult oyster can filter up to 120 L of water per day. Gastropods often graze along the bottom for food. Some are specialized feeders seeking live prey or are scavengers of dead fish or shellfish. Cephalopods, the squid, and octopus, are usually hunters, capturing fish or crabs to eat.

## The mollusk and public health

Shellfish are sometimes eaten raw or lightly cooked. With this potential lack of thorough cooking, it is important that shellfish come from unpolluted waters. The Food and Drug Administration has oversight of the National Shellfish Sanitation Program (NSSP) that establishes minimum water quality standards and specific harvest requirements for all growing waters. Each shellfish producing state has a designated authority that oversees this program at the local level, including water monitoring, sanitation surveys, and oversight of all processing facilities. Growing areas are classified by the state authority as “approved,” “conditional,”

“restricted,” or “prohibited.” Oversight of harvest to prevent product from being taken from an unclassified or prohibited area is a critical component of the NSSP.

## Conservation regulations

Most mollusk aquaculture and fisheries currently take place near shore, in bays, lagoons, and estuaries. Nearshore activities are regulated under a variety of laws that may differ significantly from state to state. Fisheries regulations generally stipulate types of harvesting gear that can be used, seasonality of harvest, size of animals taken, and quotas on size of harvest.

All US shellfish mariculture operations that commenced prior to March 2007 are regulated by the US Army Corps of Engineers under Nation Wide Permit 48 and, where applicable, may include the requirement to undergo Endangered Species Act and Magnuson–Stevens Fisheries Management and Conservation Act (Essential Fish Habitat Rule). Individual states regulate aquaculture operations under a variety of environmental and zoning laws, and at the local level, further regulations may be imposed.

A large body of research on the interactions between cultivated shellfish and the natural marine environment already exists, and further research into various aspects of shellfish farming are currently being conducted or are slated for future studies.

Molluscan shellfish are widely recognized as a keystone species that perform functions critical to the overall health of nearshore marine environments. Shellfish feed on phytoplankton and detrital matter and, as they do so, perform a vital filtering function that clarifies the water, allowing sunlight to penetrate to seagrasses. Also, both in the wild and in cultivated assemblages, shellfish create three-dimensional structure that serves as essential habitat for several species of benthic and epibenthic marine flora and fauna. Increasingly, oysters are being used throughout the United States to mitigate marine waters that are polluted due to increasing development along the shorelines.

Fisheries, mariculture, and harvest practices differ significantly from coast to coast, as described later.

**Table 6.1** Estimated annual production and value of farmed West Coast shellfish as of 2005.

Type of shellfish	Pounds (£)	Value (US dollars)
Oysters	94,206,010	84,832,500
Manila clams	8,554,726	17,143,038
Mussels	2,728,361	3,498,419
Geoduck	1,090,000	11,990,000

## West Coast

On the West Coast of the United States only a small proportion of mollusks are still commercially harvested from the wild, and most of this is fished by native tribal harvesters for subsistence purposes. Native littleneck clams, naturalized Manila clams, and Pacific oysters make up most of the wild fishery.

The vast majority of commercially harvested mollusks from the West Coast are farmed, with seed produced from select broodstock in hatcheries, and often grown out in nursery systems prior to planting. The annual farm gate value of West Coast shellfish is \$111 million (as of 2005), including Alaska, Washington, Oregon, and California. Estimated annual production and value of farmed West Coast shellfish is shown in Table 6.1. Currently, Hawaii is not producing product ready for market, but hatchery and nursery operations there are an important component of the shellfish mariculture infrastructure, providing much of the seed used by producers in the other West Coast states.

## Clam culture operations

Although there is minor commercial production of butter (*Saxidomus gigantea*) and littleneck (*Protothaca staminea*) clams, Manila (*Tapes philippinarum*) clams are the predominant clam species farmed along the West Coast. In Alaska, however, the only clam currently farmed is the native littleneck. Methods of cultivation include ground culture, where clams are grown directly in the substrate of the beach at the intertidal range, and bag culture, where clams are grown in bags that are set on the beach in the intertidal zone, or in bags suspended from racks or trays either subtidally or intertidally.

## Seeding

Typically, clam seed is planted in the spring and early summer. Most of the clam seed used comes from West Coast hatchery and nursery facilities, although in some areas natural sets of clams occur. Clam seed sizes and methods of seeding vary, depending on site specific factors such as predators present and weather conditions.

## Harvesting

Harvesting crews typically hand dig clams using a clam rake. Each digger is responsible for going back and smoothing over the beach upon completion of the dig. Market size clams are selectively harvested, put in buckets, bagged, tagged, and transported to processing plants. Undersized clams are left in beds for future harvests. Mechanized harvest is a new method being evaluated for use in a few areas. Beds may be dug annually, or as infrequently as once every 4 years.

## Geoduck (giant clam) culture operations

Native geoduck (*Panopea abrupta*), the largest known clam, is a relatively new species for culture, and aquaculture techniques are rapidly evolving and changing. At the present time, Washington and Alaska are the only US states actively farming geoducks. In Canada, British Columbia is very actively involved in substantial geoduck cultivation. Farms are typically located low in intertidal zones, although subtidal farming of geoducks is in an initial experimental phase.

The most common culture system currently used in farming geoduck consists of setting sections of open-ended polyvinyl chloride (PVC) pipe, approximately 10–12 in. in length and 4–6 in. in diameter, into the substrate, leaving about 3 in. of pipe exposed. Three to four seeds are then placed in each tube where they burrow into the substrate. To protect against predation, nets are then placed individually over the top of each pipe, or a large net is used to cover the entire field of tubes. These tubes are kept in place for 1–2 years, or until the geoduck have burrowed down far enough to avoid predation, usually 18 in. to 3 ft below the surface. Removed tubes are reused in future plantings.

## Harvesting

Once the clams reach market size, approximately 2 lb in 5 years, the crop is harvested. Clams are carefully extracted using a high-volume, low-pressure hose that pumps seawater beside the clam, loosening the beach substrate, and allowing the clam to be lifted out. Within one or two tidal cycles, the disrupted areas have been observed to fill back in. To date, studies have confirmed this observation, and further long-term studies are currently being conducted.

## Wild geoduck fishery

Both Alaska and Washington have wild geoduck fisheries. In Washington, the Department of Natural Resources, Department of Fish and Wildlife and Washington State Treaty Tribes comanage the resource through an auction system that limits entry and allows for only a small percentage of total estimated biomass to be fished each year. In Alaska, the Department of Fish and Game and the Alaska Commercial Fisheries Entry Commission sets quotas to assure that overharvest does not occur.

## Mussel culture operations

Two species of mussels are farmed on the West Coast, *Mytilus trossulus*, commonly known as the blue mussel, and *Mytilus galloprovincialis*, commonly known as the Mediterranean or gallo mussel. Most mussels on the West Coast are grown suspended from rafts or surface longlines in the subtidal zone and anchored in place. Rafts may be periodically wrapped with nets to exclude predators. Surface longlines are typically made of heavy polypropylene or nylon rope suspended by floats or buoys attached at intervals along the lines and anchored in place at each end.

## Seeding

Typically, naturally spawned mussel seed sets on lines or metal screen frames in net cages are suspended in the water during the late spring spawning season. Hatchery seed is set on lines or screen frames at the nursery, and then transported to the mussel farm for planting. Once the seed reaches a manageable size of 6–12 mm (0.25–0.5 in.) long,

which can take several months in winter or several weeks in summer, it is scraped from the frames or stripped from the lines and sluiced into polyethylene net sausage shaped tubes, called “socks,” each with a strand of line threaded down the length of the sock for strength. Concrete weights with stainless steel wire hooks are hung on the bottom end of each mussel sock for tension. The socks are then lashed to the raft, longlines or stakes, and suspended under the water.

When the mussels reach about 2.5 mm (1 in.) in length, the weights are often removed from the socks and saved for reuse. If the predator exclusion nets become excessively fouled, blocking the flow of microalgae to the mussels, the nets may be removed, and shell or other debris cleaned off.

## Harvesting

When the mussels reach market size, socks or lines of mussels are freed from the longline, stake, or raft structure for cleaning and grading. The mussels are stripped from the socks, bulk bagged, and tagged for transport to shore and the processing plant. Weights are reclaimed for reuse, and used socking and lines are recycled or disposed of at an appropriate waste facility.

## Oyster culture operations

Several species of oysters are cultured on the West Coast including the Pacific oyster (*Crassostrea gigas*), Olympia oyster (*O. conchaphila*), Kumamoto oyster (*Crassostrea sikamea*), Eastern oyster, also known as American oyster (*Crassostrea virginica*), and the European flat oyster (*Ostrea edulis*).

Productive oyster ground is dependent on a number of variables including salinity, temperature, substrate quality, water quality, and types of predators present. Oyster ground is often classified or referred to by its use, such as seed ground, grow out ground, or fattening ground.

Different approaches can be taken to oyster grow out, depending upon target market, beach characteristics, and environmental conditions. For instance, bag, rack and bag, and suspended culture methods are typically employed to supply single oysters destined for the half-shell market. For the shucked meat market, oysters can be grown in clusters, so the method used is determined primarily

by environmental conditions, such as substrate composition and the presence or absence of certain predators. Suspended cultures, such as longline and stake culture, are primarily used in areas that are not suitable for bottom culture.

### Seeding

Seed oysters attached to cultch shell may be sprayed from the deck of barges or cast by hand onto marked beds at an even rate to achieve optimum densities. Seed may also be placed into grow out bags or racks, or placed on cultch hung from longlines or stakes. For suspended culture, oysters may be placed in lantern nets supported by buoys or off rafts. In some cases, farms rely solely on natural set of oyster seed on existing beds. Oysters may be transplanted from one site to another at some point during grow out. For example, oysters may be moved from an initial growing area to “fattening” grounds where higher levels of nutrients are found, allowing the oysters to grow more rapidly for market. Growers must abide by all transfer permits, regulations, and requirements when transplanting oysters from one area to another to assure pests (such as oyster drills) are not accidentally introduced into growing areas.

### Harvesting

Bottom culture oysters are most commonly harvested by hand or in some cases with a mechanical harvester. In the case of hand harvesting, workers hand pick oysters into large containers or baskets. Large containers are sometimes equipped with ropes and buoys so they can be lifted with a boom crane onto the deck of a barge at high tide. Smaller baskets are hand carried off the beach. For mechanical harvesting, a harvest bag is lowered from a barge or boat by boom crane or hydraulic winch at high tide and pulled along the bottom to scoop up the oysters. This type of harvest apparatus is arranged to provide for adjustment so that minimal negative impact occurs on sensitive bottom substrate layers as tidal levels change. Where feasible, the area may be hand harvested at low tide afterward to obtain any remaining oysters.

### Scallop culture operations

Scallop culture for any of several commercially important species is still in its infancy on the

West Coast. Commercial aquaculture is currently practiced only in British Columbia and Alaska, although experimental culture trials are being conducted in California and Washington. Aquaculture development in Alaska, Washington, and California is focused on the purple-hinged rock scallop, (*Crassadoma gigantea*). Ongoing research on different types of harvesting gear conducted in Alaska are expected to help launch more formal growth studies under the direction of the Alaska Marine Advisory Program in the near future. In Washington, research is underway on the use of submerged offshore tray-based systems to raise rock scallops in open waters off the northwest coast, near Neah Bay.

The economic viability of scallop cultivation is still being investigated, as culture methods for scallops tend to be labor intensive. Several factors constrain the development of the US aquaculture scallop industry to date, including the high cost and relative scarcity of hatchery produced seed, fouling of bags and equipment during grow out, lack of established suspended aquaculture facilities and farm locations, and regulatory restrictions regarding the utilization of wild broodstock for hatchery production of juveniles or collection of wild spat.

### Abalone

The abalone is a gastropod, or snail, although it does not look like most snails. There are a number of species found on rocky outcrops and bottoms, where they graze on the encrusting organisms that grow on the hard surfaces. Wild abalone are found along the West Coast and, where allowed, are harvested almost exclusively by divers. In the early days of the fishery, sufficient numbers could be found in shallow waters so that diving was not required. Divers now seek out the abalone on submerged rocky ledges and pry them loose with a small prying bar. Both commercial divers and sport divers are licensed, and there are strict regulations governing number and size of the abalone captured.

California has a relatively small but thriving abalone farming industry with both onshore and inshore facilities. Since cultivated abalone must be fed, abalone farmers must obtain permits for harvesting wild kelp. Strict requirements exist to avoid overharvest of kelp.



Abalone are usually sold fresh at the local market where they command a high price, often as high as \$66/kg (\$30/lb). They are sometimes dried for export to Japan and China, where they are considered to be medicinal and the price increases accordingly.

## Atlantic and Gulf Coasts

On the Atlantic Coast, several different species of shellfish are harvested, both from the wild and increasingly through mariculture. On the Gulf Coast, the Atlantic oyster (*Crassostrea virginica*), is the primary shellfish commercially produced.

### Surf clams

Surf clams (*Spisula solidissima*) (Figure 6.1), also known as hen clams or skimmer clams, are found on the Atlantic Coast from Newfoundland to North Carolina, in depths up to 61 m (200 ft). Currently, commercial concentrations are primarily found off of the New Jersey shore, the Delmarva Peninsula, and on Georges Bank (NMFS, 2009a). However, the Georges Bank region has been closed to harvesting

of surf clams since 1990 due to the risk of paralytic shellfish poisoning.

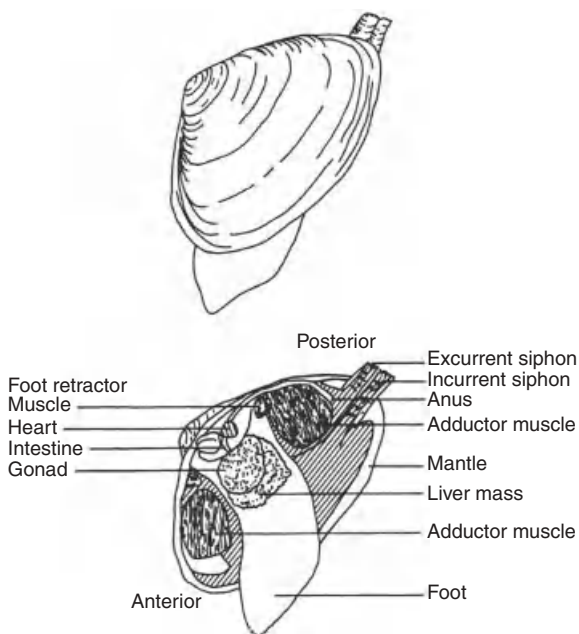
Surf clams reach a maximum size of about 22.5 cm (8.9 in.) shell length, but surf clams larger than 20 cm (7.9 in.) are rare. Maximum age exceeds 30 years; surf clams of age 15–20 years are common in many areas. Surf clams are harvested when they reach 10 cm (4 in.), which occurs at about 5 years of age. Most of the surf clams landed in recent years were 8–12 years old. (Jacobson and Weinberg, 2006a). In 2007,  $25.3 \times 10^6$  kg (55.8 million lb) of surf clams were landed (NMFS; 2007). New Jersey, New York, and Massachusetts accounted for more than 99% of the total harvest in 2007.

Population levels of Atlantic surf clam are high and no overfishing is occurring. This is due in large part to the Surf Clam-Ocean Quahog Fishery Management Plan of the Mid-Atlantic Fishery Management Council, which was put into effect in 1990. The management plan is based on an individual transferable quota (ITQ) system that provide individual fishermen or corporations the exclusive privilege to harvest a certain percentage of the total allowable catch. The program allows individual licenses or “shares” to be bought and sold in the marketplace.

There has been a significant consolidation of the commercial surf clam fishery over the last several decades. In 1990, prior to adoption of the management plan, 128 vessels participated in the fishery. When the ITQ management plan went into effect, the number of vessels dropped to 75. In 2005, only 50 vessels were active in the fishery (Jacobson and Weinberg, 2006a).

The first surf clam fisheries were established in New England around 1918 and relied on harvesting inshore from a boat using rakes. Hand tongs were also used in the early days of the industry. As power boats became more common in the 1920s, scraper-type dredges, which would scoop 15–23 cm (6–9 in.) into the bottom, came into use. These dredges allowed harvesting in deeper water.

No significant advancements took place in the surf clam fishery until World War II brought a large increase in the demand for food. A hydraulic jet dredge was developed that pumped a jet of water into the bottom ahead of the cutting bar of the dredge. This method was so much more efficient that abandoned fishing areas, where clams were no longer dense enough to harvest by conventional scrape-type dredges, could be successfully



**Figure 6.1** Surf clam.



harvested. Hydraulic dredges also resulted in a great reduction in broken clams and could harvest hard bottom areas that scrape-type dredges could not. The hydraulic dredge, considerably modified, improved, and enlarged from the early models, is now the mainstay of the surf clam industry. The commercial clam dredges have bars that are spaced several inches apart so as not to collect anything but the targeted surf clams.

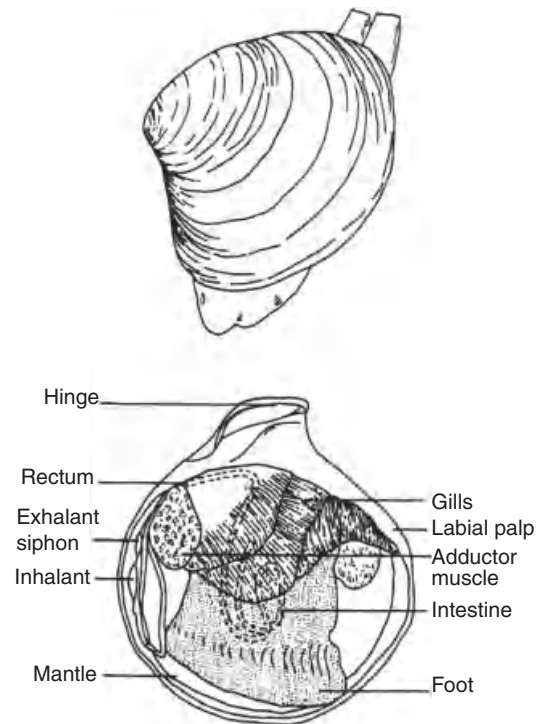
## Processing

After the harvest, the clams are placed in metal-mesh cages, which hold 1057 L (30 bushels) each. These are mechanically unloaded at the dock and stored, if necessary, in a refrigerated room. They are then dumped onto a conveyor belt that moves the clams through a gas flame to open the shell. Some processors use a steam or hot water bath to open the shells. After opening, the clams are carried to a table where the meats are extracted from the shell by shuckers, and the viscera, referred to as the sand-bag, is removed. These two steps are often still done by hand, but mechanical shakers and eviscerators are also being used. The meats are then washed and cut or diced for packing and freezing. Surf clam meats are frozen in 10.2 cm (4 in.) thick sheets, called blankets, for sale and shipment to food processors and restaurants. Surf clams are usually served in chowders, soups, or as fried clam strips.

## Ocean quahog

The ocean quahog (*Arctica islandica*), or mahogany clam (Figure 6.2), is found on both sides of the North Atlantic Ocean. In the northeast Atlantic, quahogs are found from southern Newfoundland to just north of Cape Hatteras, North Carolina. Although its range overlaps that of the surf clam, it is usually found in deeper water. While found in depths ranging from 8 to 400 m (26 to 1300 ft), the heaviest concentrations of ocean quahogs in US waters are found from 20 to 80 m (65 to 260 ft deep) buried in sand and mud bottoms.

Ocean quahogs are among the longest lived and slowest-growing marine organisms in the world, they can live to be more than 200 years old. Their growth rate is slow after the age of 20 years, which is about the age when most are harvested. Ocean



**Figure 6.2** Quahog clam.

quahogs are relatively unproductive and can only support low levels of fishing.

## Present status

In the United States, the ocean quahog fishery, like the surf clam fishery, is regulated under an ITQ system. The ITQ management was established by the Mid-Atlantic Fishery Management Council in 1990 under Amendment 8 to the Surf Clam-Ocean Quahog Fishery Management Plan. The latest amendment (13), approved in 2002, implemented various measures to facilitate efficient management, including multiyear quotas and provisions for use of automatic vessel monitoring systems aboard fishing vessels (Jacobson and Weinberg, 2006b).

Total ocean quahog biomass has been gradually decreasing since the late 1970s. However, the allowable quota in the Surf Clam-Ocean Quahog Fishery Management Plan has held relatively steady over the past decade at approximately  $20 \times 10^6$  kg (44 million lb). Ocean quahog stock is not overfished, nor is overfishing occurring (Jacobson and Weinberg, 2006b).

## Processing

The ocean quahog is prepared and marketed in the same manner as surf clams.

### Hard clam

Hard clams (*Mercenaria mercenaria*), or northern quahogs, are found from the Gulf of St. Lawrence in Canada, along the East Coast of the United States, around the Florida peninsula and into the Gulf Coast of Texas. It has been introduced to the West Coast of the United States (Washington and California), Puerto Rico, the United Kingdom, France, Holland, Belgium, and Taiwan Province of China. They inhabit shallow areas where they burrow into sand or mud bottoms.

The hard clam industry is the largest of all the clam species and represents more than 50% of the dockside value of all clams harvested (Lorio and Malone, 1995). These clams are sold in the shell by size. They are graded for increasing size as littleneck, cherrystone, and chowder. Littlenecks and cherrystones bring the highest prices and are almost always in demand. There is a large variability in the growth rate of hard clams, they reach commercial size sometime between 2 and 5 years; clams in southern waters grow more rapidly.

The annual catch of clams landed in the United States from the Atlantic Ocean was  $3.33 \times 10^6$  kg (7.3 million lb) in 2007, with an estimated value of \$52 million (NMFS, 2007).

### Aquaculture of hard clams

Hard clams are harvested by several hand and mechanical methods: raked from the bottom; hand tonged; and patent tonged with tongs that are raised and lowered by a power winch. In shallow areas, hard clams are collected by wading or treading (feeling for the clams with moccasin covered ft). In intertidal areas, clams are often harvested by clam signing. The harvester looks for the siphon holes, or sign, and then digs up the clams with a clam pick, which resembles an 45.7 cm (18 in.) two-pronged fork with the prongs bent at right angles to the handle. Since the mid-1950s, a more efficient device called a hydraulic dredge has been used for harvesting shallow water mollusks. The hydraulic dredge, suspended from a vessel, jets water into the

bottom ahead of the dredge blade, making a solution of the sand, mud, shells, and clams. The clams are washed back into the dredge by water pressure and onto a chain link conveyor belt that carries them to the surface.

Hard clams are the most commonly aquacultured of all of the bivalve species. They are different from most bivalves, in that large quantities of seed are not typically found in nature. Hence, hard clam culture relies on hatchery technology for a seed source. In the hatchery, broodstock clams are spawn and larval clams raised through the postset stage to juveniles or seed clams. The first successful rearing of larval hard clams in the United States occurred in the early 1920s (Lorio and Malone, 1995), but significant commercial production did not begin in the United States until the middle-to-late 1970s (FAO, 2004).

The hatchery phase is followed by a nursery phase, where the seed clams are nurtured to a size that is less vulnerable to the stresses imposed in the grow out phase. Nurseries typically rely on natural seawater, which provides the food source for the juvenile clams. Various methods of nursery culture are employed including land-based upflow systems that pump seawater to reservoir tanks providing a vertical upflow current for the seed clams, which rest on a fine-mesh screen. Alternatively, land-based raceways consisting of long, shallow trays with a thin layer of sand on the bottom provide a horizontal flow of seawater across the seed clams. A third method is the field-based system, this method involves placing seed clams in trays that contain a layer of gravel or sand and have a protective cover. These trays are then submerged in subtidal and intertidal areas. Another field-based nursery technique involves using floating nursery trays or a series of bags held together in long belts to hold seed clams. All of the field-based nursery methods are conducted in shallow water areas to minimize the threat of poaching.

There are several different systems employed for the final grow out stage. Most of these systems use some form of pen, tray, or net. All three systems are used in intertidal zones; nets are also used in subtidal zones. Harvesting of pens is generally accomplished by hand raking, or mechanical means where legal. Nets, which are placed around a seed clam planted area and staked down to prevent predation, are generally removed prior to harvest, which is accomplished by legal bottom harvest methods.

Trays are harvested by lifting them out of the water. Due to their weight, this generally requires a lifting apparatus. The grow out phase typically requires 18–36 months.

The 2005 Census of Aquaculture (USDA National Agricultural Statistics Service, 2007) reported 434 hard clam farms in the United States in 2005. Of this number, all but 12 were located on the Atlantic Coast. The census does not report production in weight, but the value of all hard clam aquaculture in the United States was reported as \$60 million in 2005.

### Processing

The smaller hard clams are usually sold live and in the shell and are consumed raw, steamed, or as specialty items such as clams casino. Chowder clams are either sold in the shell or fresh shucked for further processing. Surf clam processors occasionally process chowder clams in the same manner as surf clams.

### Soft shell clam

The soft-shell clam (*Mya arenaria*), or steamer clam (Figure 6.3), is an inshore species found in brackish waters, estuaries, and marine habitats. They are found in sand–mud bottoms in intertidal to subtidal inshore areas and are even found in deep waters, up to 190 m (625 ft). Soft-shell clams are tolerant of a wide range of salinities and temperatures and have been known to survive in oxygen depleted environments for up to 8 days (Cohen, 2005). It is native to the North American East Coast from Labrador, Canada south to North Carolina, but due to its tolerance for a wide range of conditions it has been introduced along the Pacific Coast from Alaska to California. It has also been reported in many parts of Europe including the Baltic Sea, Denmark, Estonia, Finland, Germany, Iceland, Latvia, Lithuania, Norway, Poland, and Sweden (National Biological Information Infrastructure, 2007). Except for its native regions, it is considered invasive. The market for soft-shell clams is primarily in the eastern United States and Canada. It is not commonly eaten in Europe, the United Kingdom, or in the West Coast of the United States.

Like most clams, soft-shell clams grow faster in warmer waters. It takes them about 6 years to reach

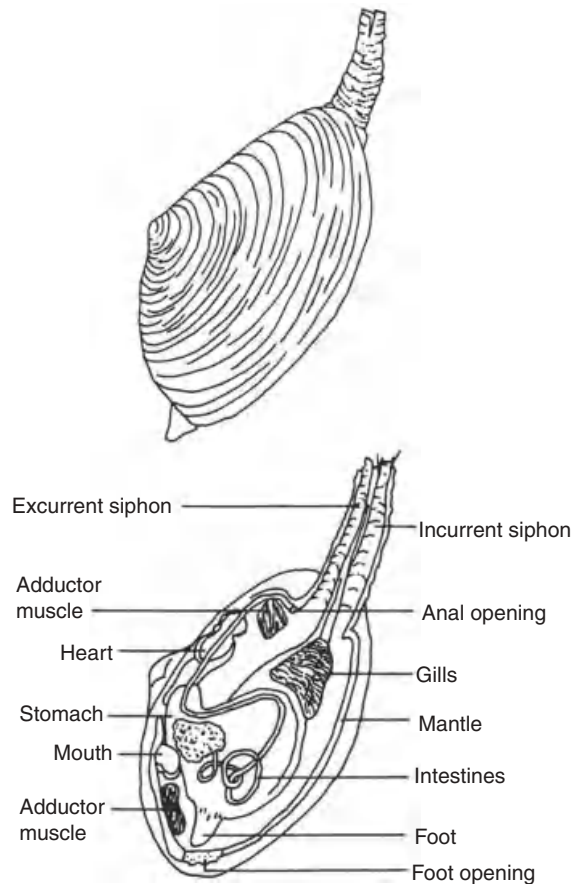


Figure 6.3 Soft shell clam.

market size in Maine, 4 years in Massachusetts, but only 18 months in Maryland. Soft-shell clams in the Chesapeake Bay grow rapidly but are subject to heavy predation and massive die-offs can occur due to oxygen deficiencies and periods of low salinity caused by heavy rains.

In 1980, the US catch was almost  $4.4 \times 10^6$  kg (10 million lb). In 2007, the catch had dropped to  $1.7 \times 10^6$  kg (3.7 million lb). Maine is currently the leading state in landings with  $8.8 \times 10^5$  kg (1.9 million lb) followed closely by Massachusetts with  $5.9 \times 10^5$  kg (1.3 million lb). Lesser amounts of  $8.9 \times 10^4$  kg and  $1.2 \times 10^5$  kg (0.19 and 0.27 million lb) were landed from New York and Rhode Island respectively in 2008 (NOAA, 2007). The soft-shell clam fishery was originally based in Maine and Massachusetts and supplemented by imports from Canada. The clams were dug by hand from

extensive intertidal flats using a clam hack. In the 1950s, the hydraulic dredge was introduced into the Chesapeake Bay, opening a significant new area for soft clam harvesting. The Chesapeake Bay has a relatively low-tidal fluctuation and few intertidal areas for clamming. The newly introduced hydraulic dredge made practical the harvest of deeper subtidal areas.

## Processing

Soft clams are sold in the shell for steamed clams or as a shucked and frozen product used in restaurants as breaded and fried clams. They also are sold fresh shucked in cans or frozen.

## Scallops

Two scallops are harvested commercially from the Atlantic Coast, the Atlantic sea scallop (*Placopecten magellanicus*) and the bay scallop (*Argopecten irradians*). Of these two, the sea scallop dominates the market. The Atlantic sea scallop is found in the northwest Atlantic Ocean from Labrador to North Carolina. This species takes from 3 to 6 years to reach market size. In 2007,  $26.5 \times 10^6$  kg (58.5 million lb) of sea scallop meat, valued at \$386 million, were harvested (NOAA, 2007). Massachusetts, New Jersey, and Virginia accounted for just less than 93% of the landings with 32.5, 11.8, and 10.0 million lb each, respectively.

Sea scallops are fished commercially year round; the primary harvest method involves dredging, especially in the Northeast. Trawl net gear is used by some in the Mid-Atlantic. The fishery is managed under the Atlantic Sea Scallop Fisheries Management Plan, which was implemented in 1982. In 1994, a limited access program was implemented for scallop vessels (NMFS, 2009b). The sea scallop population has been rebuilt to sustainable levels since 2001 and is currently supporting the largest amount of landings in its history.

Bay scallops are harvested in eastern North America from the East Coast in shallow bays from Massachusetts through Long Island, New York, and in North Carolina. They grow to market size in about 12 months. Bay scallop was an important fishery from the 1870s to the 1980s. However, it has declined significantly since 1985 due to a sharp

decline in abundance after 1985 (MacKenzie, 2008). In 2007, 0.18 million lb, valued at \$1.56 million, were harvested off the coast of Massachusetts and New York.

The scallops are usually harvested using a wide shallow dredge similar to an oyster dredge, except the rock scallop, which is harvested by divers.

## Processing

Scallops are usually shucked by hand. The adductor muscle, referred to as the heart, is saved and the rest of the viscera discarded. The Atlantic sea scallop is usually shucked and iced aboard ship. The meats are sold fresh or frozen. Recently, some bay scallop meats have been sold whole (viscera and adductor together) either fresh or frozen.

## Oysters

Oysters (Figure 6.4) are found on all US coasts in shallow waters. Their range often extends into brackish water, such as in tidal creeks and estuaries. Along the Atlantic and Gulf Coasts, the commercial oyster is the Virginia oyster (*C. virginica*).

On the East and Gulf coasts, the oyster fishery involves more than just harvesting wild oysters. Natural oyster populations are enhanced by management of oyster beds. Management strategies designed to create an environment that is more conducive for oyster larval settlement include (1) improving the available substrate for larval metamorphosis by placement of "clutch," that is, oyster shells, clam shells, or limestone and (2) silt removal from existing shell beds by towing boards across the bottom to scour silt from shells present

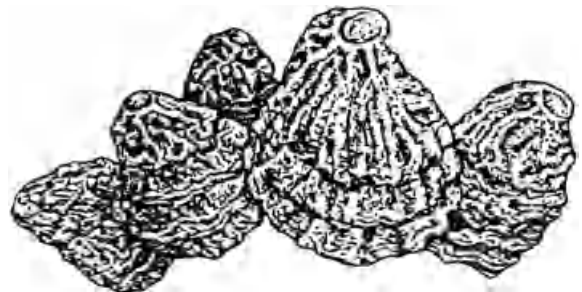


Figure 6.4 Oysters.



on the ocean bottom (MacKenzie, 1996). Control of predators such as boring gastropods and starfish has also been practiced. Management varies by locality. For example, in some localities (e.g., Prince Edward Island, parts of Chesapeake Bay, Florida, and Texas) oysters are usually left where they are set until harvest. In other localities, such as Connecticut, Delaware Bay, Virginia's portion of the Chesapeake, and Louisiana, oystermen often move oysters during the fall after seed is set to other areas where they can grow more rapidly. Once moved, the oysters are broadcast over the bottom so they are not too crowded and can be harvested easily when they reach market size. This method frees the original area so that more cultch can be placed on the bottom to collect spat the next spring.

When oysters reach maturity, they are harvested using an oyster dredge, which is a rectangular steel frame with a series of teeth. The dredge, which is towed by a boat, digs the oysters from the bottom mud. Once filled, the dredge is usually hauled aboard with a winch and the catch is dumped and sorted by hand.

The oyster fishery is one of the oldest shellfish industries, and since it is inshore with the oyster grounds often spanning more than one municipality or extending over state boundaries, it is encumbered with more regulations than any other fishery. For instance, in many areas, oysters can only be harvested with tongs. In certain areas of the Chesapeake Bay they must be harvested by sail driven dredge boats: the famous skipjack oyster schooners. Because they are inshore, beds are often subject to closure due to pollution.

### Present status

The oyster industry on the East Coast used to be the most important shellfishery in the United States, but since 1980, the overall production of oysters from Maine to eastern Florida has greatly declined; however, their inflation corrected annual landed value has remained about level. Production from the Gulf of Mexico has remained essentially level over the long term. The decline along the East Coast was due primarily to disease (MacKenzie, 1996) In 2007, the harvest off the East Coast totaled  $1.13 \times 10^6$  kg (2.49 million lb). However, the Gulf Coast harvest accounted for an additional  $10.2 \times 10^6$  kg (22.5 million lb).

### Processing

Oysters are processed and sold in several ways. Many smaller sized oysters are steamed open, the meat removed by mechanical shakers, and then canned or frozen for use in chowders, soups, or processed in cakes or sticks. Others are served raw, on the half-shell, or packed fresh in cans and sold to retailers.

### Blue mussel

The Atlantic Coast blue mussel (*Mytilus edulis*) fishery peaked with landings of approximately 10 million lb annually in the late 1980s. In the 2000s, annual landings have averaged approximately 3 million lb. The wild harvest is usually done by hand raking, tonging, or using an oyster dredge.

In addition to wild harvest, a mussel culture industry is starting in the Northeast. The Census of Aquaculture reported 11 mussel farms (8 in Maine and 3 in Massachusetts) in 2005. Production from the Maine farms was valued at \$1.24 million. Because of the small number of farms in Massachusetts, value of production was not reported to protect confidential information regarding individual farms.

For cultured mussels, natural mussel set is collected on plastic ropes or plastic mesh tubes hanging from rafts. When the mussels reach market size of 6.4 cm (2.1 in.) in about 18 months to 2 years, they are harvested.

### Processing

Most mussels are sold in the shell. However, some are steamed, and the meats that are removed from the shell are canned either plain or in special sauces.

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# 7

## Shellfish—Crustaceans

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Michael J. Oesterling

Crustaceans are members of the phylum Arthropoda, which also includes insects, spiders, centipedes, and millipedes. Among the 26,000 known species of crustaceans are some of the most popular and valuable seafood products: crabs, shrimp, and lobsters.

Man's interest in crustaceans dates back thousands of years. Drawings of crabs have been found on Egyptian temple walls. The early Romans placed the crab in the zodiac about 2100 BC, and the ancient Greeks included the crab constellation and crab in their mythology. One myth explains the origin of the crab constellation: while Hercules was battling the Hydra, a jealous Juno had a crab nip at Hercules's ankles to distract him. When Hercules crushed the crab, Juno raised it to a place among the stars as a reward for its sacrifice.

The name crustacean is derived from the Latin word for shell. Indeed, the hard exoskeleton is such a prominent anatomical feature that crustaceans are often referred to as shellfish. Crustaceans have several other characteristic features: they have mandibles as mouth parts, possess two pairs of antennae, and breathe through gills derived from leg appendages. Crustaceans are found in great variety in both freshwater and saltwater habitats.

Among the crustaceans, the animals of the order Decapoda are of primary economic interest. The 8500 plus species of decapods represent about one-third of all crustaceans. The name decapod means ten feet; all decapods have five pairs of thoracic appendages. In many decapods, the first pair of legs is modified into claws or pinchers used for prey capture and defense. Many decapods qualify as important food resources; they are abundant, wholesome, and accessible. Of particular interest are the true crabs, the shrimp (penaeid and pandalid), and lobsters (American and spiny).

One feature that all crustaceans have in common is their hard outer shell and the need to shed this shell in order to grow. This shedding process, termed molting or ecdysis, is an important event in the lives of all crustaceans. In many cases, a critical phase of reproduction occurs at molting.

The actual process of molting and growth is complex. Prior to shedding, a new shell begins forming underneath the old one. In some species, there are visible indications that molting is about to occur. As the time approaches, the crustacean resorbs some carbohydrates, proteins, and calcium from the old shell. These substances are stored within the body and used to help form the new shell. Muscle attachments to the old shell are loosened and reattached

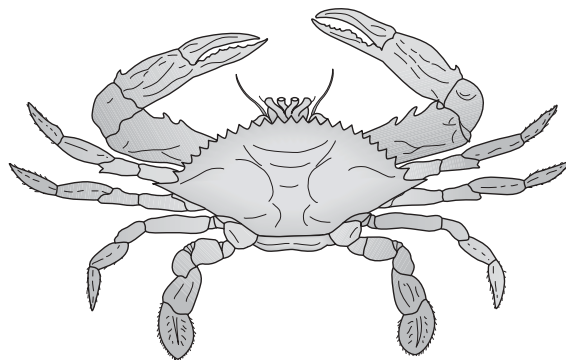
to the forming shell. In most instances, a portion of the stomach lining is lost; hence, all feeding ceases. Finally, the old shell splits open along predetermined fracture lines and the animal simply backs out of the old shell. At this time, the crustacean is very soft and defenseless. For this reason, molting takes place in hiding. Just before and immediately after molting, large quantities of water may be absorbed to aid in expanding the new shell to a larger size than the old shell. The amount of size increase is probably controlled by both genetics and environmental conditions. After a period of hours or days, the new shell hardens completely. The interval between molts depends on the size of the individual, with younger individuals molting more frequently than older ones.

## Crabs

No other group of decapods is so diverse in terms of habitat and lifestyle as the crabs. They are found in freshwater and saltwater, in warm and cold temperatures, and range in size from giant to almost microscopic. Some crawl, and some swim.

Many regions of the United States have its locally caught crab that finds favor with the residents of the area. Some crab species, such as the blue crab and king crab, have been heavily exploited and are regular items in many seafood restaurants. The figures on commercial crab landings for 2007 document the economic importance of crabs in the United States (Table 7.1).

The crab is covered by a hard outer shell known as the exoskeleton. The top, or dorsal, side of the crab



**Figure 7.1** Blue crab.

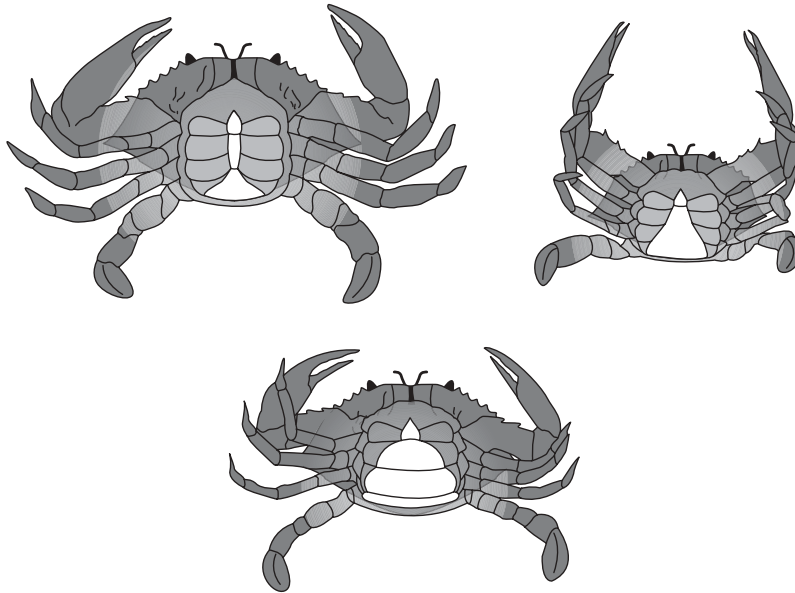
is covered by a single heavy piece of exoskeleton called the carapace (Figure 7.1) that covers the crab's head and thorax regions. Stalked eyes are located at the front of the body and the rostrum, an extension of the exoskeleton, is located between the eyes.

The ventral (bottom) side of the crab looks nothing like the carapace. The most striking feature is the turned under abdomen (Figure 7.2). The abdomen of the crab corresponds to the "tail" of the shrimp, crayfish, and lobster. Markings on the abdomen reveal the crab's sex: the male has a long, pencil-shaped abdomen; the female has a broad, semicircular marking. Under the abdomen are fine legs called pleopods, commonly known as swimmerets. Female crabs use these swimmerets as attachment for their eggs. Besides the abdomen, the other notable features of the crab's ventral side are the thoracic divisions that appear as sections of the shell.

**Table 7.1** Commercial crab landings in the United States for 2007.

Species	2007 Poundage	2007 Value (\$)
Blue crab ( <i>Callinectes sapidus</i> )	139,996,093	135,797,188
Dungeness crab ( <i>Cancer magister</i> )	57,009,363	133,038,414
King crab ( <i>Paralithoides camtschaticus</i> )	25,942,284	97,896,469
Snow or Tanner crabs ( <i>Chionectes</i> spp.)	38,282,176	56,709,578
Stone crab ( <i>Menippe mercenaria</i> )	5,964,847	26,663,606
Jonah crab ( <i>Cancer borealis</i> )	9,455,041	4,467,798
Rock crab ( <i>Cancer irroratus</i> )	4,280,351	1,971,963
Total	280,931,155	456,545,016

Source: Personal communication from the National Marine Fisheries Service, Fisheries Statistics Division, Silver Spring, MD.



**Figure 7.2** Ventral surfaces of the blue crab. Male (top left); immature female (top right); mature female (bottom).

Crabs have a number of paired appendages, including five pairs of legs, or pereopods. The first pair is modified to be the chelipeds, ending in the chela, or pinchers. They function in defense and feeding. The remaining pairs of pereopods are for locomotion and may also be used in food gathering.

Pereopods are the most obvious of the crab's paired appendages, but there are others just as important. Most of these are centered on/around the crab's head region. Between the eyes are two pairs of filamentous, hairlike structures, the antennae and the antennules. The antennules are generally smaller than the antennae and are located directly on either side of the rostrum. Between the antennules and eyes are the antennae. Together, the antennae and antennules are part of a crab's sense of smell, receiving chemical "odors" from the water. They also are sensitive to touch.

The internal systems of crabs are complex and are not discussed here. However, a brief comment on the most visible of these systems, the respiratory, is appropriate. Along the sides of the body cavity are the gill structures. These appear as eight pairs of frilly, fingerlike projections. The gills, often referred to as "dead man's fingers," are the sites where oxygen is obtained and waste materials such as carbon dioxide are removed. Water enters the gill chamber

near the base of the claws, flows upward over the gills, and passes out at the sides of the mouth.

## Blue crab

The blue crab (*Callinectes sapidus*) supports a large commercial fishery along the eastern seaboard of the United States and Gulf of Mexico. Actually, there are two blue crab fisheries, one for hard-shelled crabs and one for soft-shelled crabs. Soft-shelled crabs are blue crabs that have recently shed (molted) their hard outer shell. These crabs command a premium price in the marketplace. Because of the blue crab's economic value, a great deal of information is available on all aspects of the fishery and biology of the species.

It is found along the Atlantic coast from Nova Scotia to northern Argentina and throughout the Gulf of Mexico. Although not native to Europe, blue crabs have been found along the European coast and in the Mediterranean Sea. It is believed that these crabs "hitchhiked" in ballast tanks, or clung to ocean going vessels. Reproducing populations are now found in these regions.

The blue crab typically inhabits coastal areas, from the shoreline to a depth of approximately 91 m (300 ft), but it is most abundant in coves,

bays, and estuaries, at depths up to 35 m (115 ft). It has been taken from freshwater environments, such as Florida's St. John's River, and from hypersaline (super salty) lagoons, such as Laguna Madre de Tamaulipas in Mexico. The blue crab's normal diet includes fishes, bottom invertebrates (clams, snails, worms, other crabs, etc.), and plant matter. Although it is considered a scavenger, it is more properly classified as an omnivore that prefers fresh to decaying flesh.

The blue crab generally lives 2–3 years, with the adult stage being reached after 12–18 months. Its life history begins with the mating of sexually mature male and female crabs. The female blue crab mates only once in her lifetime, just after the molt that marks her transition from juvenile to adult. Unlike the female, the male reaches sexual maturity before he is fully grown. A male may mate with more than one female and at any time during his final few growth stages.

Prior to the female's terminal molt, she moves to lower salinity waters and pairs with a male who will carry or cradle her underneath him. At this time, both crabs are called "doublers" or "buck and rider." The female completes her final molt in this cradled position and becomes an adult. While she is in the soft intermolt stage, copulation takes place. The male transfers his sperm to the female, which she stores in seminal receptacles within her body. The sperm are able to live for about 1 year. Following copulation, the male again cradles the female beneath him until her new shell hardens. This cradling serves two purposes. It assures that there will be a male present at the only stage in the female's life when she is able to copulate. It also serves to protect her while she is in the soft stage and extremely vulnerable to predators. Once the female's new shell has hardened, the male releases her.

Spawning (laying of eggs) usually takes place 1–9 months after mating, during the spring and summer months. It is generally thought to occur in higher salinity waters at the mouths of estuaries and offshore areas. Egg laying is quite rapid and may be completed within 2 hours. Eggs are passed from the ovaries through the seminal receptacles to be fertilized on their way to the outside of the female. As the eggs pass out of the body, they are attached to the small swimmeret appendages on the female's abdomen. When first laid, the eggs are

orange, but as they mature, they turn yellow, then brown, and finally dark brown.

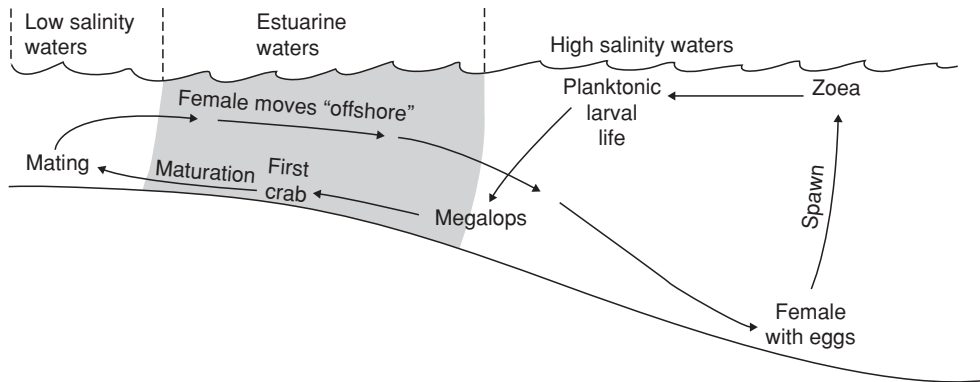
At the time of spawning, the female blue crab lays 700,000 to 2 million eggs, but only about one ten-thousandth of 1% of the eggs will survive to become mature crabs. The eggs are carried 7–14 days, at which time they hatch into planktonic zoea larvae, which are only about 1/24 in. (1 mm) long. The zoeal phase has seven stages and lasts for 31–49 days, depending on water temperatures and salinity. The optimum ranges for development are 19–29°C (66–84°F) and 23–28 parts per thousand salinity. The zoea then metamorphoses into the single megalops stage, which has both planktonic and benthic (bottom) affinities. After 6–20 days, the megalops changes into the first crab stage, at which time the crab form is first seen.

Larval (zoeal) development takes place "off-shore" in more saline waters than the confines of the estuary. However, the young crabs spend the majority of their growing life within the nursery grounds of the estuary. During the megalops and first few crab stages, there is a movement shoreward toward the nursery grounds. Figure 7.3 illustrates the movements of the blue crab during its life cycle.

Following the first crab stage, growth is rapid. Adulthood is reached 12–18 months after egg hatching. After reaching the adult stage, blue crabs live about 1 year longer.

## King crab

The king crab (*Paralithoides camtschatica*) (Figure 7.4) is the largest crab harvested, with an average weight of 4.55 kg (10 lb). The range of the king crab extends from Korea and the Sea of Japan, northeastward to Kamchatka (Russia) and into the Bering Sea, eastward along the Aleutian Islands to Bristol Bay, into the Gulf of Alaska, and southward to Queen Charlotte Sound in southern Alaska. It is most abundant in the eastern Bering Sea and the northwestern Gulf of Alaska. Adult king crabs inhabit the deep waters of the continental shelf, occurring at depths greater than 182 m (600 ft). Male crabs tend to be found at greater depths (274 m/900 ft) than females. The king crab's normal diet consists of brittle stars, sea urchins, and starfish, and to a lesser degree, other crustaceans, polychaetes, and



**Figure 7.3** Life cycle of the blue crab. Mating of sexually mature crabs takes place in lower salinity, inshore waters. Following mating, the female moves to higher salinity waters to spawn and hatch her eggs. Eggs hatch as zoea, spend some time in the plankton, then settle to the bottom as megalops. During the megalop and first few crab stages, the young blue crab moves shoreward to estuaries. There the crab grows until the entire process starts over again.

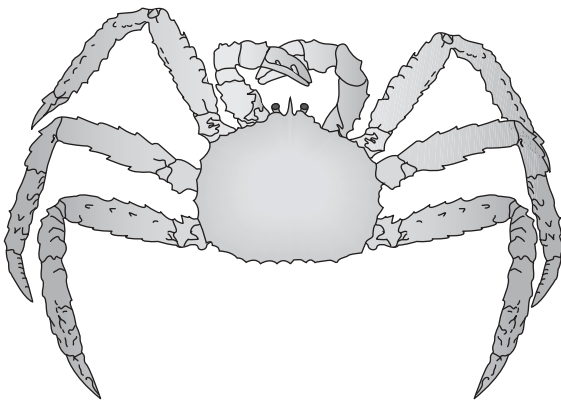
seaweed. King crabs may live 20–25 years and grow to weigh more than 11.5 kg (25 lb), with a leg span of over 1.8 m (6 ft).

The life cycle of the king crab (Figure 7.5) begins in late winter or early spring when sexually mature adults migrate shoreward for mating. Mating takes place in shallow waters, less than 18.2 m (60 ft) from late March through early May. Prior to actual copulation, there is a courtship period during which the male grasps the chela of the female in a face-to-face position. Although grasping may last 5–7 days, the act of mating lasts only a few minutes. Mating occurs immediately following a molt by the female. The male king crab may even assist the female in getting out of her old shell. After the female has

completed her molt, the male will flip her over and begin mating.

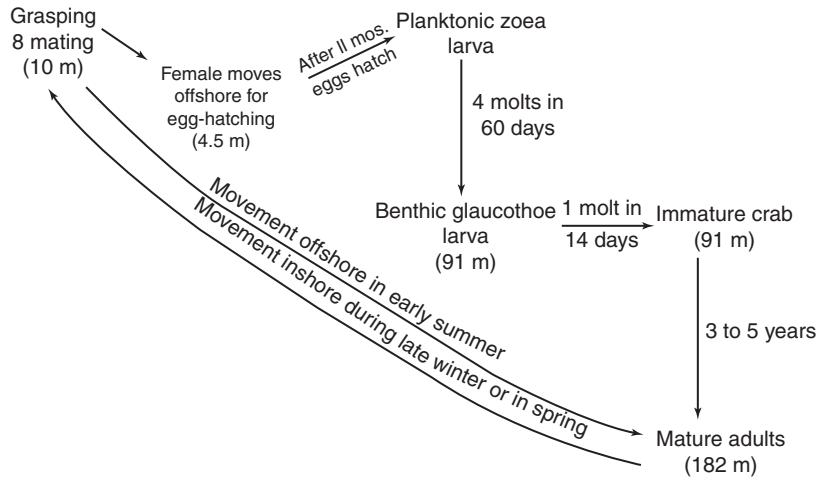
Following mating and the hardening of her shell, the female begins to move offshore for egg hatching, which occurs in approximately 46 m (150 ft) of water. The female carries eggs for about 11 months, after which they hatch as zoea larvae only 1.12 mm (1/32 in.) long. The immature king crab will molt several times a year until it reaches maturity; the molting period will then lengthen. A king crab becomes sexually mature at the age of 5 or 6 years, at a carapace width of 8.9 cm (3.5 in.) and a weight of about 1 kg (2.2 lb).

One- and two-year-old king crabs exhibit a unique gregarious behavior of grouping together into "pods." The young crabs climb onto each other forming assemblages (pods) that may be 3.7 m (12 ft) long and comprise thousands of individuals. These aggregations move slowly along the bottom and may serve as protection against predators. Occasionally, the crab disband either to feed or to change location. During this time, there is a gradual movement toward the deeper waters inhabited by the adults. As they get older, king crabs abandon the habit of podding; 3- and 4-year-old crabs spend more time grazing and tend not to form pods. However, older adult crabs may also form aggregates. In contrast to the juvenile pods that lack any orientation, older adults, in groups of 2000–6000, pile on top of another, each facing outward from the center of the group. The reasons for this action are unknown.



**Figure 7.4** King crab.





**Figure 7.5** Life cycle of the king crab. (Numbers in parentheses represent approximate water depth at which events occur.)

## Cancer crabs

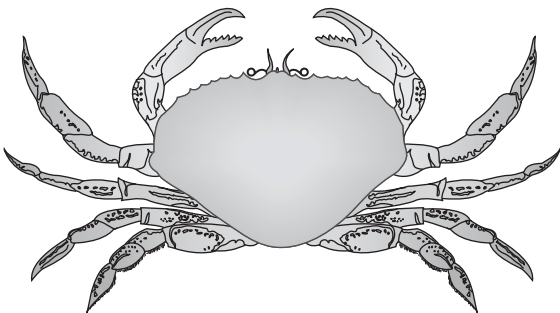
Crabs of the genus *Cancer* (family Cancridae) occur worldwide in temperate regions. In the United States, there are East and West Coast species that are harvested either in directed fisheries or as incidental catches. On the Pacific Coast, the Dungeness crab (*Cancer magister*) (Figure 7.6), named after a small fishing village, supports a large commercial fishery (Table 7.1). Harvested to a lesser degree from the Atlantic Coast are the Jonah crab (*Cancer borealis*) and the rock crab (*Cancer irroratus*).

The ranges of these three species occur within the same latitudes on both coasts. The Dungeness crab is found from the Aleutian Islands southward to Magdalena Bay in Baja, Mexico. It occurs from shore to approximately 91.5 m (300 ft). Jonah and rock crabs are found from Nova Scotia to the South

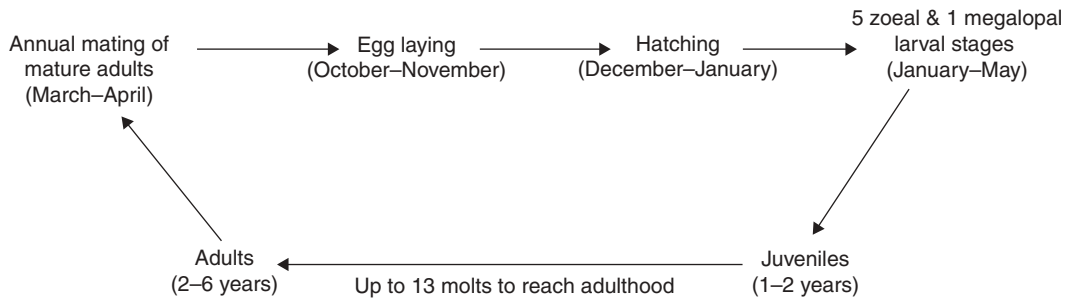
Atlantic states. The rock crab is found in shallower waters in the north and deeper (up to 575 m/1887 ft) in the south of its range. The Jonah crab is generally found in deeper waters than the rock crab (up to 800 m/2625 ft), although their ranges overlap in places and at certain times of the year. All three species are more abundant in the northern portions of their ranges.

The life cycles of the Cancer crabs are very similar. The Dungeness crab will be used as a representative for this group (Figure 7.7). The following description is based on Dungeness crabs living in California waters. The life cycle events of those to the north follow the same general sequences but occur in different months, as a result of lower temperature.

Mature Dungeness crabs mate annually, completing an entire reproductive cycle each year. Mating between hard-shelled males and soft-shelled females occurs in oceanic waters from March through May. As the time for mating approaches, the male Dungeness carries the female in a belly-to-belly embrace. This lasts for approximately 7 days; on the eighth day, the female struggles to escape. The male releases the female, permitting her to right herself. As the female sheds her shell, the male encircles her with his claws and legs. Immediately after the female has completed her molt, the male turns her over onto her back; the female extends her abdomen and the male inserts his copulatory pleopods into her seminal receptacles. Copulation lasts from 30 to 120 minutes, after which the male



**Figure 7.6** Dungeness crab.



**Figure 7.7** Life cycle of the Dungeness crab. The months given are for a California population of Dungeness crab. In more northern environments, the life cycle events occur later.

again carries the female for several days. Sperm are stored internally until October or November, at which time eggs are extruded and fertilization takes place. One to two million eggs are carried on the female's abdomen until late December or mid-January, when they hatch as zoea larvae.

There are five zoeal stages and one megalopal stage, which last for a total of 105–125 days. The optimum environmental ranges for zoeal development are 10.0–13.9°C (50–57°F) and 25–30 parts per thousand salinity. Due to the seaward movement of surface waters, the planktonic zoeae are transported offshore. Megalopae are found offshore during March but move shoreward and are found concentrated near shore in April. Following the single megalops stage, the first crab stage occurs.

Young crabs abound in areas where currents are likely to concentrate megalopae until they are ready to settle out. Hence, the youngest crabs are erratically distributed on the nursery grounds both in the ocean and coastal bays. For the next several years, growth and frequency of molting varies with crab size, sex, and location (bay or ocean). Crabs growing within bay systems molt more frequently than their counterparts in the ocean. During the first 2 years of life, both sexes increase in size at the same rate. However, after this time, females shed less frequently and do not grow as large as males. Dungeness crabs become sexually mature after approximately 1 year and may live to be 6 years old.

## Shrimp

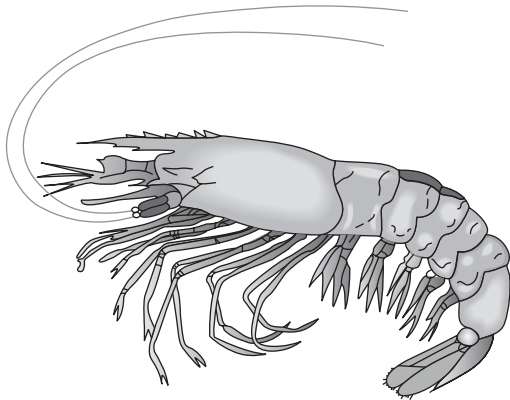
Every seafood lover is familiar with shrimp. The commercial fishery for shrimp has declined dra-

matically in the past couple decades. In 1988, approximately 150,068 metric tons (330.9 million lb) were landed in the United States; in 2007, landings declined to 106,960 metric tons (235.8 million lb), with an ex-vessel value of \$390.5 million. During this same time period, the volume of imported shrimp products has more than doubled. In 1988, approximately 228,526 metric tons (503.9 million lb) valued at \$1.8 billion were imported; in 2007, this had grown to 556,936 metric tons (1228 million lb) valued in excess of \$3.9 billion!

Worldwide, there are more than 80 different species of shrimp caught for food. Within the United States, shrimp are harvested from all waters surrounding the continental United States, Hawaii, and Alaska. The US shrimp fishery relies on two basic types of saltwater shrimp: penaeids and pandalids. The more familiar is the penaeid shrimp group, which includes such US species as the pink shrimp (*Farfantepenaeus duorarum*), the white shrimp (*Litopenaeus setiferus*), and the brown shrimp (*Farfantepenaeus aztecus*). There are many other penaeid species regularly imported to the United States.

The other saltwater shrimp commonly marketed are members of the pandalid group. The US representatives are the northern spot prawn (*Pandalus platyceros*) and northern pink shrimp (*Pandalus borealis*). Generally, pandalids are smaller than the penaeids and are more cold water species; the penaeids are tropical or subtropical.

Not all shrimp found in US markets belong to these two groups. Other US species include rock shrimp (*Sicyonia* spp.), seabobs (*Xiphopenaeus kroyeri*), and royal red shrimp (*Pleoticus robustus*). In addition, there are freshwater shrimp, often referred to as prawns. Although some of the largest



**Figure 7.8** Shrimp.

specimens, prawns are not heavily exploited in the United States.

At first glance, it would appear that shrimp (Figure 7.8) bear little anatomical resemblance to crabs. However, a closer examination will reveal the similarities. The shrimp's body is divided into two distinct sections: the cephalothorax, covered by the carapace, and the abdomen. In crabs, the carapace is flattened dorsoventrally (top to bottom); in shrimp, the carapace is compressed laterally to a more rounded shape. In both cases, the carapace houses the important internal organs. The most visible anatomical difference between shrimps and crabs is the abdomen. In shrimp, the abdomen extends out from the carapace; in crabs, it is tucked under the carapace.

Shrimps and crabs have analogous appendages, although the appendages may differ in appearance. Both have antennae and antennules, one pair of mandibles, two pairs of maxillae, three pairs of maxillipeds, five pairs of pereopods, and pleopods.

In the shrimp, the antennae may be of considerable size, sometimes longer than the body. Additionally, the inner branches of the antennae are greatly modified, taking the form of a horizontal blade called the scaphocerite, which functions as a stabilizer during swimming.

Pereopods (walking legs) of shrimp have the same basic parts as those of crabs. However, in shrimp, the third maxilliped is modified into a leg-like structure, thus giving the appearance of six pairs of walking legs. Unlike crabs, shrimp have exposed swimmerets (pleopods) on the abdomen. Also unlike crabs, shrimp use their pleopods in swimming.

Within the family Penaeidae, there are unique structures or modifications used during reproduction. Female penaeids have a peculiar copulatory structure between the last pair of walking legs called the thelycum, which serves as the storage location for spermatophores. In the males, the first pair of pleopods is modified to be a copulatory appendage, called a petasma, which functions in spermatophore transfer.

Shrimp can move around in several different ways. Using their pereopods, they can walk over the bottom. They can use their pleopods to rise up in the water column and swim. From either the walking or swimming position they can move backward quickly by flexing their abdomen.

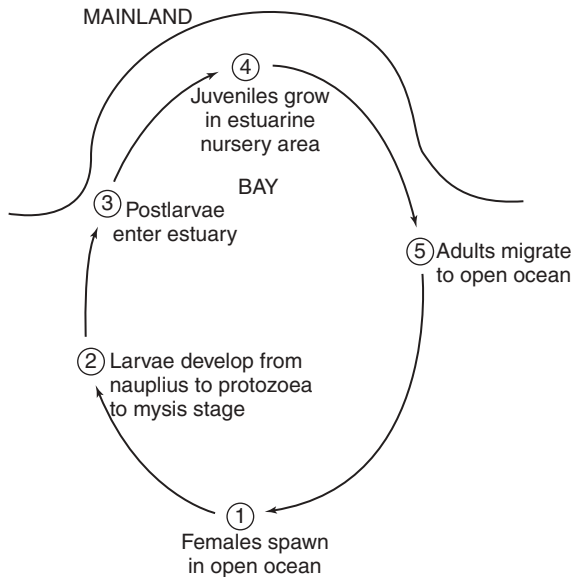
### Penaeid shrimp

With few exceptions, penaeid shrimp are found in estuaries and near shore environments, occurring over a variety of bottom types. They may occupy different environments during different stages of their life cycle. Because their environmental requirements and habitat preferences overlap, several species may occur in one area. The bulk of the commercial harvests of penaeids in the United States takes place in the Gulf of Mexico and in the southern Atlantic Ocean, although penaeids do occur as far north on the Atlantic seaboard as Massachusetts.

Because the penaeids are so commercially valuable, their life cycles are very well known. The major US species complete their life cycle within 1 year, although specific details vary from place to place and from year to year, depending on temperature, salinity, food availability, and other environmental conditions. To illustrate the basic pattern, the pink shrimp (*E. duorarum*) will be used as an example.

Pink shrimp are distributed from the shallows to depths of about 90 m (295 ft) from the lower Chesapeake Bay through the Florida Straits, around Mexico to the top of the Yucatan Peninsula. The major centers of abundance are off western Florida and in the southeastern Bay of Campeche, Mexico. This species is very active at night, feeding and moving about. During the day, it usually burrows into the bottom.

During its life, the pink shrimp completes several migrations (Figure 7.9). The first involves moving offshore for mating and spawning. As in other



**Figure 7.9** Life cycle of the shrimp. The complete cycle, from spawning to adulthood, takes approximately 1 year.

crustaceans, mating occurs between a hard-shelled male and a female in the soft stage immediately following a molt. Fifteen to twenty days after mating, spawning occurs, with eggs being fertilized as they pass from the female's body. Unlike many other decapod crustaceans, the female pink shrimp does not carry the eggs attached to her body, but broadcasts them into the water column. Here, as plankton, the eggs and developing larvae are at the mercy of the currents and tides. Spawning is most prevalent from April through July. Shrimp weighing between 0.4 and 10–67 g (2.4 oz) may produce 44,000–535,000 eggs. Eggs hatch in approximately 14 hours in a water temperature of 27–29°C (80.6–84.2°F). Following egg hatching, a progression of larval forms takes place.

During the postlarval stages, the young shrimp move back toward the coast. Catching currents moving landward, they are carried or swim into the protected bays, estuaries, and shallow lagoons that act as nursery grounds for the growing shrimp. Once on the nursery grounds, growth is rapid. However, the growth rate slows with age and is different for males and females. A shrimp that measures 14 cm (5.5 in.) is approximately 1 year old. Male shrimp attain maximum lengths of 13–14 cm (5–5.5 in.) and weights of 30–35 g (1.0–1.2 oz). Female pink shrimp grow much larger, reaching

lengths of 16–17 cm (6.3–6.7 in.) and weights of 80–90 g (2.8–3.2 oz).

Young shrimp seek shallower, often fresher, portions of the estuaries where they find abundant food supplies, a wide variety of plant and animal matter. With increasing size, the young shrimp move gradually into deeper, saltier water, finally returning to the open sea with approaching maturity. Individuals that survive to maturity may live another year or longer.

### Pandalid shrimp

Pandalid shrimp are found primarily along the southern and western coast of Scandinavia, off western Greenland, in the Gulf of Maine, and along the Pacific coast from Alaska to Oregon. *P. borealis* predominates in the northern shrimp fishery, both in New England and Alaska. *P. platyceros* contributes significantly to the Washington and Oregon shrimp fisheries. The life cycles of all the pandalids are very similar, but differ significantly from those of the penaeids. The spot prawn, *P. platyceros*, will be used as an example of the pandalid life cycle.

Spot prawns and the other pandalids produce eggs and sperm from the same gonads but at different times in their life cycles. At age 1.5 years, they mature as males, and then pass through a transition or intersexual phase at 2.5 years, finally becoming functional females at 3.5 years. Both male and female spot prawns are capable of multiple spawnings. Unlike the more prolific penaeid, spot prawns produce only 2000–5000 eggs per female at the first spawning; subsequent spawnings result in only 10–1000 eggs per female. Also, different is the fact that pandalids carry their eggs attached to their pleopods until hatching.

Following mating in autumn, the female carries the eggs for about 5 months, and hatching occurs in late March or early April. At 11°C (52°F), spot prawn larvae pass through five larval stages in 35 days before metamorphosing to postlarvae. There are four postlarval stages, which last an additional 40–50 days. Larvae of spot prawns are positively phototactic and appear to molt mostly at night. As in other crustaceans with pelagic larvae, the earliest stages are most vulnerable to predation and death by other causes.

By midsummer, late larvae and early postlarvae are found in shallower waters, less than 55 m

(180 ft), where they remain through autumn and part of the winter before returning to deeper waters. One year after hatching, spot prawns are back to the adult grounds. They average 0.2 cm (0.8 in.) in length and weigh 5.6 g (0.2 oz). Relatively few spot prawns live beyond 4 years, but they can reach a length of 25.4 cm (10 in.).

## Lobster

Lobsters are truly a luxury food item. Two kinds of lobsters are harvested commercially in the United States: the “true” or American lobster (*Homarus americanus*) and the spiny lobster (*Panulirus argus* and *Panulirus interruptus*) (Figure 7.10). These species are easily distinguished from each other. The true lobster has heavy claws, which the spiny lobster lacks. The spiny lobster has “horns” above the eyes, which are not present in the true lobster. True lobsters have marketable meat in the claws, body, and tail; in spiny lobsters only the tail is mar-

keted. Together, all species of lobsters accounted for more than \$406.5 million in revenue to fishermen in 2007 (American lobsters, \$372.6 million; spiny lobsters, \$33.9 million).

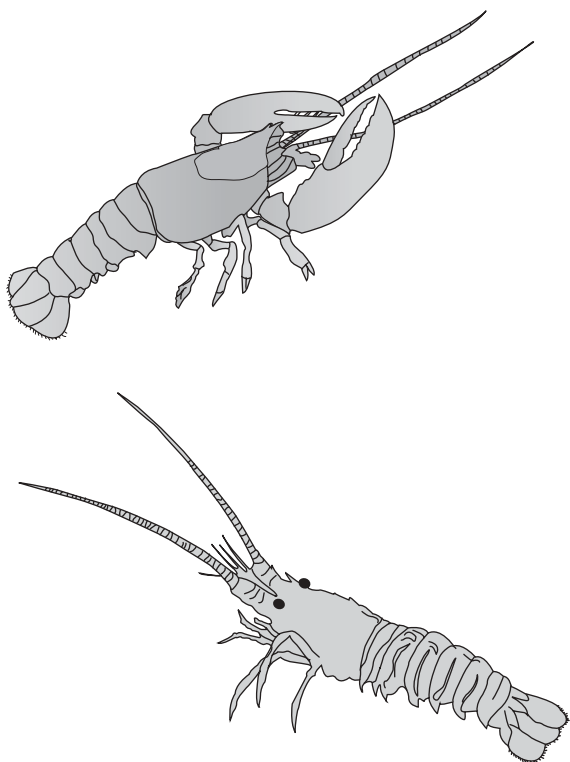
The basic body form of the lobster is similar to that of the shrimp. The most obvious difference is the large claws of the American lobster. However, these correspond to the chelipeds of the crabs and are nothing more than modified pereopods. A difference exhibited by the spiny lobster is the presence of long stiff antennae, often longer than the animal’s body.

## Spiny lobsters

Spiny lobsters, which belong to the family Palinuridae, are principally tropical and subtropical in distribution. Primarily, two species of spiny lobsters are fished commercially: *P. argus* in Florida and *P. interruptus* in California. The Florida landings account for almost 85% of the total weight and 80% of the value; hence, *P. argus* will be used for descriptive purposes.

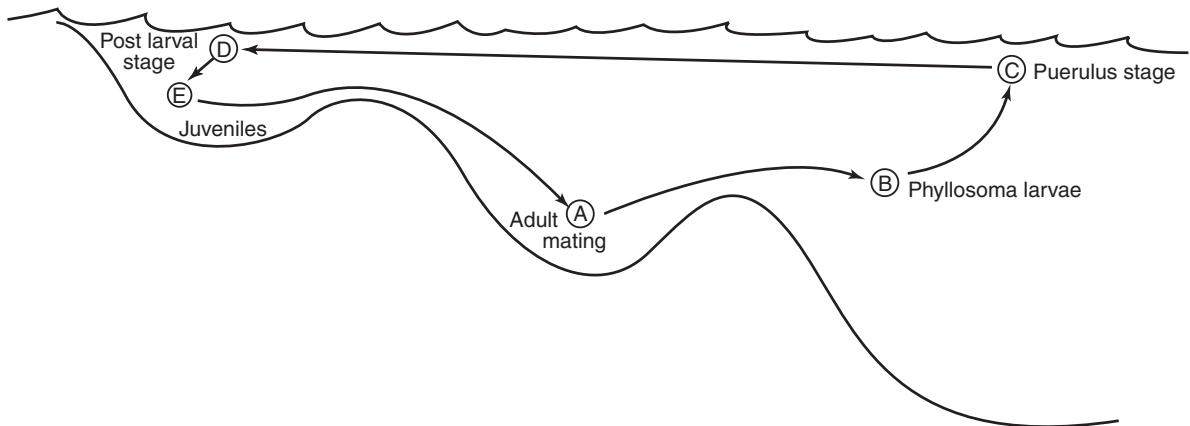
The Florida spiny lobster is found on reefs or among rocks or other objects that afford protection or place of concealment, from North Carolina southward through the Gulf of Mexico to Brazil and throughout the Caribbean islands. It occurs over a range of water depths from low tide lines to 91 m (300 ft).

The life history of *P. argus* is shown in Figure 7.11. The male passes sperm in a viscous fluid that becomes attached to the female’s abdomen. This fluid hardens to form a sperm sac, also called tar spots. When the female extrudes eggs, she breaks the sperm sac with her legs. As the eggs pass by the sperm sac, they are fertilized and then come attached to the swimmerets on the female’s abdomen. The number of eggs produced varies with carapace size: a female with a carapace length of 7.6 cm (3 in.) produces about 0.5 million eggs; one of 12.7-cm (5-in.) carapace length produces about 1.5 million eggs. The eggs hatch after about 1 month. The larvae of spiny lobsters are flattened, leaf-shaped, planktonic organisms known as phyllosomes. After 3–6 months and 6–11 stages, the phyllosoma metamorphoses into a puerulus or first postlarval stage. Pueruli, shaped like miniature adults but colorless and with a soft exoskeleton, move to shallow waters to begin their benthic



**Figure 7.10** American lobster (top) and spiny lobster (bottom).





**Figure 7.11** Life cycle of the spiny lobster. A: Adult spiny lobsters mate in offshore reefs. The female carries the eggs for about a month. B: Eggs hatch as planktonic phyllosoma larvae. C: Postlarval stage, a transparent replica of the adult. D: After moving to shallow nursery areas and becoming benthic, the pueruli undergo as many as 11 postlarval molts over a period of 2–3 years. E: Juvenile spiny lobsters begin to move to offshore reefs.

existence. After up to 3 years and as many as 11 postlarval stages in this nursery area, juveniles mature and move to offshore reefs. It then takes up to 3 years for them to attain harvestable size. Adults may grow to approximately 45 cm (18 in.) in length and may live to be 15–20 years old.

### American lobster

When people think of lobster, the American lobster is usually what comes to mind. It is perhaps the most universally recognized crustacean.

American lobsters are confined to the cooler temperate region waters between Newfoundland and North Carolina. Although they can be located from the intertidal zone to 480 m (1575 ft) on the continental slope, they are usually at depths of 4–50 m (13–164 ft).

Lobsters are by nature secretive and nocturnal, hiding during the day. Although they live on nearly any type of bottom, they prefer areas where ledges or boulders provide sheltered hiding places. Lobsters feed on a wide variety of bottom invertebrates including crabs, polychaete worms, mollusks, and starfish.

The life history of American lobsters is similar to that of other crustaceans in most aspects. Prior to mating, a sexually mature female (weighing at least 500 g/1.1 lb) will seek out the shelter of a large male lobster, and mating takes place shortly after

the female has molted. The male transfers sperm to the female using modified pleopods; sperm is stored in the seminal receptacles of the female. It will be almost 12 months before egg extrusion and fertilization occurs. The number of eggs laid varies with the size of the female, ranging from a few thousand to almost 100,000. Eggs are carried on the pleopods of the female for another 10–12 months before they hatch.

Following the extended brooding period, eggs hatch and planktonic zoea larvae emerge. After approximately 2 weeks, the larvae transform to the fourth stage (first postlarva) at which time they assume the characteristic lobster shape. At this time, the tiny lobsters seek suitable bottom habitats to begin their benthic existence.

Growth rates among lobsters vary depending on food availability and water temperatures. Hence, it is difficult to estimate the time it takes an individual to reach adult status. It is known that between 20 and 25 molts will occur from the first stage larva to maturity. Of these, the first ten will occur in the first year of life. During the next 4 years, the young lobster will have two to four molts a year. Molting generally occurs less frequently than once a year after the lobster has reached a carapace size of more than 38 cm (15 in.). Sexual maturity is reached in 5–7 years. After the onset of reproductive activity, the growth rates for males and females differ, because the female molts and carries eggs in alternate years, while the male continues to molt yearly.

Lobsters can reach weights of more than 18 kg (40 lb). The American lobster may also be one of the longest lived of all crustaceans. A 16-kg (35-lb) lobster is over 50 years old.

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# 8

## Underutilized (Latent) Fishery Species

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Michael Jahncke and Daniel Kauffman

### History of research programs on underutilized (latent) fishery species

Stock determinations, harvesting methods, handling, processing, and using underutilized fishery species were major research programs in the 1960s, 1970s, and 1980s for the National Marine Fisheries Service (NMFS) (formerly the US Bureau of Commercial Fisheries (BCF)), and for several states and universities. In the 1960s, the BCF College Park Laboratory undertook research on production of food grade fish protein concentrate (FPC) from underutilized Atlantic red hake (*Urophycis chuss*), Atlantic menhaden (*Brevoortia tyrannus*), and other underutilized fishery species (Dassow, 1988; Anonymous, 2007). This research continued into the early 1970s. The FPC program had only limited success due to high production costs, poor FPC functionality, and taste issues. FPC developed from red hake was basically tasteless and odorless without any functionality. The high-lipid content of menhaden was problematic for production of FPC. Other research projects at the time focused on drum-dried fish proteins. These products had some taste and odor, and could be hydrated and used as a meat extender, but still had limited use and acceptance by con-

sumers and companies (Spinelli et al., 1977). The dehydration process did not produce a highly stable product suitable for storage under conditions needed for long-range food distribution programs (Dassow, 1988).

In 1971, a book entitled *Our Changing Fisheries* published by the US Department of Commerce/NMFS listed and described several underutilized fishery resources available in the United States (Stans et al., 1971). Four chapters were included under the section Fisheries of the Future and were titled: Untapped North Atlantic Fisheries (Smith, 1971); Untapped West Central Atlantic Fisheries (Bullis et al., 1971); Untapped Eastern Pacific Fisheries (Pruter, 1971); and Untapped Inland Fisheries (Greenwood, 1971). Over the next 10–20 years, research efforts that focused on harvesting, handling, processing, and storage of underutilized fish were based on many of the species identified in these chapters.

In 1976, a NMFS report stated that the Gulf of Mexico contained approximately 1500 little-used species. Many were minor resources, but sizeable quantities of croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), sand sea trout (*Cynoscion arenarius*), and silver sea trout (*Cynoscion nothus*) were also available (Steinberg and Dassow, 1976).

Butterfish (*Peprilus burti*) in the Gulf of Mexico were reported to be a “virtually untapped renewable resource in the Northern Gulf of Mexico, with a potential value of \$75 million, capable of supporting a potential export industry employing 200–300 fishermen with as many as 600 individuals involved in dockside processing” (Anonymous, 1986). Research efforts during the 1980s and early 1990s at the NMFS Southeast Fisheries Laboratory in Pascagoula, Mississippi, focused on stock assessments and human food uses for these underutilized species in the Gulf of Mexico (Gledhill, 1989). The utilization fishery research program at the NMFS Southeast Pascagoula Fisheries Laboratory continued into the early 1990s.

During the late 1970s, throughout the 1980s and into the early 1990s, research at the NMFS Utilization Laboratories in Charleston, South Carolina; Gloucester, Massachusetts; and Seattle, Washington, focused on determining stock sizes of underutilized species, and how to harvest, store, process, and utilize these species for human food uses. In the Atlantic, research focused on underutilized hakes (*Urophycis* spp.), mackerel (*Scomber scombrus*), spiny dogfish (*Squalus acanthias*), hagfish (Myxiniidae), and Atlantic menhaden to name a few. In the Gulf of Mexico, species such as butterfish, coastal herrings, and associated species were investigated. In the eastern Pacific, underutilized species included the anchovy (*Engraulis* spp.), jack mackerel (*Trachurus symmetricus*), bonito (*Sarda chiliensis chiliensis*), and saury (*Cololabis saira*). In the Northeast Pacific and Bering Sea, bottom fish resources included Alaska Pollock (*Theragra chalcogramma*), Pacific hake (*Merluccius productus*), rockfishes (*Sebastes* spp.), flounders, cod (*Gadus macrocephalus*), and sablefish (*Anoplopoma fimbria*) (Steinberg and Dassow, 1976). Scientists conducted research on issues such as how to process small, underutilized species, and how to use fish processing wastes and by-products for human food uses. These laboratories also conducted research on proximate compositions, sensory characteristics, handling, processing, and storage requirements (e.g., mince, fresh, frozen or canned products, surimi, fish oil for nutritional supplements), packaging and microbial safety of species such as chub mackerel (*Scomber japonicus*), Pacific hake (*M. productus*), Atlantic menhaden, Gulf menhaden (*Brevoortia patronus*), Atlantic hake, arrowtooth flounder (*Atheresthes stomias*), and so forth (Hale et al., 1987;

Dassow, 1988; NMFS, 1989). Other research efforts included the use of Alaska Pollock and Atlantic and Gulf menhaden for surimi-based products, or as direct use as mince or fillets for human food, purified fish oil for nutritional supplements, fish mince and processing fishery by-products as meat extenders; and inclusion of minced fish at the 15% level in hot dogs; (Hale et al., 1987; Dassow, 1988; NMFS, 1989; Pensebene et al., 1991; Fiddler et al., 1992, 1993a, 1993b).

These past research efforts resulted in the generation of technical and scientific information currently used by the commercial fishing industry on how to properly harvest, handle, process, and store fishery products to help maintain quality. New products were also developed on a pilot plant scale, but except for the use of fish oil in nutritional supplements, development of new commercial products from latent species is limited. In the late 1980s, the NMFS changed its research focus, and currently no longer has any facilities designated as utilization laboratories. The utilization laboratory in Gloucester, Massachusetts was closed in the early 1990s; the Charleston and Seattle Laboratories are now major research centers for National Oceanic Atmospheric Administration’s (NOAA) National Ocean Service.

## Fishery development foundations

Of the seven Fishery Development Foundations (Mid-Atlantic Fisheries Development Foundation, Gulf and South Atlantic Fisheries Development Foundation, New England Fisheries Development Foundation, Great Lakes Fisheries Development Foundation, Alaska Fisheries Development Foundation, West Coast Fisheries Development Foundation, and Pacific Tuna Fisheries Development Foundation) only the Gulf and South Atlantic Fisheries Development Foundation and Alaska Fisheries Development Foundation are still in existence (Anonymous, 2008b, 2008c). “The Gulf and South Atlantic Fisheries Foundation, Inc. is a private, nonprofit research and development organization serving the Southeastern United States commercial fishery industry since 1976. It focuses on enhancing the long-term viability and productivity of the industry through the wise use of marine resources and application of environmentally sound business practices. Membership includes commercial fishermen, seafood processors, and

businesses or individuals closely associated with the industry” (Anonymous, 2008b). The Alaska Fisheries Development Foundation has an active research program on underutilized species. Current programs include: seeking certification of sustainability from the Marine Stewardship Council (MSC) for the Pacific cod fishery in Alaska; development of a salmon baby food product; perishable handling tests for refrigerated transport of fresh salmon fillets; modified silage for stabilizing and recovering salmon processing wastes; and refractance window dryer salmon to produce a higher quality product from lower quality products (Anonymous, 2008c). The Alaska Fishery Development foundation recently supported research on underutilized arrowtooth flounder and giant grenadier (*Albatrossia pectoralis*). Scientists determined the lipid content, fatty acid profiles, and lipid distribution of these fish (Oliveira and Bechtel, 2006).

### **Saltenstall-Kennedy fishery development funds and sea grant research programs on underutilized (latent) species**

The Saltenstall-Kennedy (S-K) Act established a fund to support fishery research and development projects, President Eisenhower signed the act in 1954 (Buck, 2004). In 1978, the NMFS began to receive funds for this competitive research program. During the next 20 plus years, the S-K program funded many projects including research on utilization of latent fishery species. These funds were used to support research on projects such as development of ethnic foods from underutilized species, use of bycatch species, and use of fish processing by-products to manufacture functional proteins, flavors, pharmaceuticals, and so forth. The program supported university and private company research efforts. Private companies conducted S-K funded research to find human food uses for fisheries such as Atlantic and Gulf menhaden and other species (Miller et al., 1989). Information from these studies has been used in the development of new value added functional seafood products. Research efforts at several universities were funded by both the S-K and Sea Grant Programs. In 2004, NOAA Fisheries announced that the competitive S-K Program was being cancelled due to insufficient funding (Buck, 2004). Current S-K available fund-

ing is still limited for this program. Past Sea Grant research efforts focused on projects such as production of surimi, minced seafood products, and other fishery products from underutilized species; use of processing wastes and by-products such as fish frames, fish scales, fish mince for human food and industrial uses (Baker et al., 1977; Baker, 1978; Zall, 1978; Goodrich and Whitaker, 1979; Cook, 1985; Jahncke et al., 1992; Hoke et al., 1994; Suvanich et al., 2000a; 2000b). Sea Grant still supports research on utilization of latent species, use of by-products, and processing wastes, but financial support is less compared with the 1970s and 1980s. One of the five major focus areas in the current National Sea Grant Strategic Plan is titled *Safe and Sustainable Seafood Supply*. The focus area states that:

“The US has witnessed the decline of many of its major fisheries at the same time that seafood consumption is on the rise, resulting in a seafood trade deficit of about \$9 billion a year. Over fishing, habitat degradation, and increasing competition among coastal users has put our fishing industry in great jeopardy. Seafood safety is a growing concern as international trade increases and fish diseases and contamination become bigger problems. Sea Grant has key roles to play in advancing our understanding of the nature of these problems and opportunities and in using its research, education and outreach capacities to support informed public and private decision making and management activities that will lead to a sustainable supply of safe seafood into the future.” (Anonymous, 2008d, 2008e, 2008f)

### **Examples of past and current underutilized (latent) species development efforts**

#### **Dogfish**

Dogfish (*Squalus acanthias*) were caught in large numbers in the 1970s primarily by trawlers from the Soviet Union (Sosebee and Rago, 2006). In 1977, with the advent of the Exclusive Economic Zone or 200-mile limit, distant water fleets were eliminated and dogfish catch decreased to less than one-fourth of previous harvests. By 1990, an intensification of fishing effort by US domestic fishermen began, due to increased international demand for dogfish



(McMillan and Morse, 1999). Domestic US commercial fishermen were encouraged by the NMFS to target the underutilized fishery (Anonymous, 2008g). Exporters sold processed dogfish into the European market. Smoked bellies were (are) a delicacy in Germany and France and it is the fish used in “fish and chips” in some parts of England. By 1996, this newly targeted fishery landed 28,200 metric tons (mt) of spiny dogfish, which was more than during the peak of the Soviet trawler fishery in the 1970s. In 1998, the NMFS ruled the fishery was “overfished” and strict quota management and trip limits were instituted. By 2004, when the spiny dogfish harvest was reduced to 1000 mt under the fishery management scheme, fishermen quit fishing for dogfish and some dogfish processors closed their doors. By 2006, stocks rebuilt to some extent, and federal regulators subsequently removed spiny dogfish from NOAA’s overfished list (Sosebee and Rago, 2006). Nonetheless, regulators believe there are an insufficient number of mature females in the current fishery. Thus, the dogfish quota is being kept at relatively low levels. The Atlantic States Marine Fisheries Commission set the quota for 2008 at 3600 mt. However, fishermen are again encountering large numbers of dogfish and would like the quota increased above current levels. Federal regulators say most of these dogfish are males or immature females, and since it can take up to 12 years for females to mature, the regulators will keep the quota at relatively low levels (Anonymous, 2008g).

## Pacific sardine

The Pacific sardine (*Sardinops sagax*) was caught in huge quantities beginning in 1916 in response to World War I food demands. In the 1930s and 1940s, sardine fishery was the largest fishery in the Western Hemisphere, with landings peaking in 1936 at 700,000 mt. During the 1930s, the fishery was large enough to account for 25% of all the fishery landings in the United States (Hill et al., 2006). The fishery was so renowned that John Steinbeck used it as the background for his 1945 novel *Cannery Row*. However, by then the fishery was declining and in the 1960s it collapsed. Scientists believe this collapse was due to a “heavy exploitation off California, combined with loss of habitat brought on by the influx of cooler waters from the Eastern

North Pacific” (Baumgartner et al., 1992). In 1967, the California legislature fishery implemented strict limitations on the fishery, and in 1974, California totally banned the directed fishery. The California ban was in place for 18 years. It was lifted in 1986 and a catch of 1000 mt was allowed. In 1992, sardines were caught off the coast of British Columbia for the first time in almost 50 years. In 1999, a sardine fishery began in Washington and Oregon (Okada and Morrissey, 2007a). In the first 8 years of this century, the harvest guidelines or quota for the American sardine fishery have fluctuated in a narrow range between 186,971 mt in 2000 and 152,564 mt in 2007 (Hill et al., 2007). While these quotas are a fraction of the 1936 catch of 700,000 mt, it is still a significant fishery.

Fishery oceanographers have long noted that sardines are sensitive to environmental conditions. As early as 1925, fishery biologists noted, “a study of the literature of the European sardine, more particularly that of the French Atlantic coast, gives ground for apprehension, for great natural changes in the yield other than those due to overfishing have at times nearly destroyed the dependent industry” (Staff, 1926). More recently, anaerobic ocean floor sediment core samples taken in the Santa Barbara basin led scientists to conclude that sardine populations naturally fluctuated even before the advent of large-scale commercial fishing (Soutar and Isaacs, 1974). Counting sardine scales in sediment cores led oceanographers to conclude that sardines have followed boom and bust cycles for more than 1500 years (Baumgartner et al., 1992). The scale record indicated that within the longer term fluctuations, the fish followed smaller cycles of about 60 years in duration. Over the longer term, scientists found there was a large sardine biomass spike just before 1000 AD. The sardine population dropped dramatically around 1100 AD, but reappeared in huge numbers around 1500 AD. While it is known that sardine numbers increase when the Pacific water temperatures increase, the dynamics of the multidecadal population shifts is not well understood (Baumgartner et al., 1992). More recently, Rykaczewski and Checkley (2008) found that the amount and direction of ocean surface wind causes changes in the upwelling of phytoplankton, which are food supplies for the sardine. Over six decades, changes in this wind stress were highly correlated with population shifts in sardine numbers.

Checkley concluded:

“This research furthers the idea that population fluctuations can be explained (in part) by natural phenomena (and not totally by overfishing). I think there’s no question that both fishing and natural forcing are responsible for the historical fluctuations in fish not only off California, but off Peru, Japan, South Africa and Spain. It’s important to realize that nature is a large player in this equation, if not the dominant one.” (Anonymous, 2008j)

With the reemergence of this fishery, investments in boats and onshore processing facilities are being made. Initially much of the sardine landings were processed for use as longline bait. The Oregon State University Seafood Laboratory conducted research on whether or not lipid content of the sardine changed as the season progresses, and whether or not improved protein and omega-3 fatty acid cold processing extraction techniques could be used on sardines (Okada and Morrissey, 2007b, 2007a). These cold-processing techniques, previously used on Pacific whiting, will allow for more protein and fish oil recovery compared with conventional heat extraction. In the future, these techniques may allow the broader use of sardines in higher value human food products instead of lower value use as fish bait. However, to date, the industry has not found that the potential profits from cold processing are sufficiently high to invest the additional capital required to implement this process.

### Atlantic red crab

Another example of a current underutilized species is the Atlantic deep-sea red crab (*Chaceon quinque-dens*). The Federal quota for this species has not fluctuated over the last several years, because its biomass apparently has been more or less constant for some time. Camera/rawl surveys in 1975 and again in the period 2003–2005 show that the biomass of crabs increased slightly in the latter period when compared to the earlier period. However, the current fishery has smaller sized male crabs compared with 1975 (Chute, 2006). Since 2003, Federal quotas for the red crab, caught off the continental shelf at depths of 2000 ft or more, have remained constant at approximately 2700 mt, but the federal government does not have sufficient

information to make a judgment on maximum sustainable yield (Chute, 2006). There are only four boats active in this small limited entry fishery. All boats are members of the New England Red Crab Harvesters Association. The boats have harvested less than the quota for the last few years while they have tried to develop higher value markets. Jon Williams, president of the Harvesters Association, contends that with the limited entry and only four active permits, the boats have maximum economic incentive not to overfish the stock. “We like to think of it as harvesting not fishing. All the boats work together. We keep track of the areas we have fished and don’t go back to them until they have had a chance to recover. It’s in our best interest to manage this fishery well” (Williams, 2008). Williams noted that value of his investment is maintained by keeping the fishery healthy and sustainable. Most of the approximately 2000 mt that has been caught annually has been turned into crab mince meat and sold to the Red Lobster<sup>TM</sup> restaurant chain at relatively low prices. But now the association is trying to move the red crab into higher value channels such as live, cluster/section or pasteurized products to increase revenue from the same size catch.

### Spin-offs from underutilized (latent) species research

Encouraging a directed or targeted fishery for underutilized species has resulted in some failures (e.g., dogfish), but also has significant successes. As stated earlier, research on utilization of latent fishery resources provided the technical and scientific foundation currently used by the commercial fishing industry on how to properly harvest, handle, and/or process and store fishery products to help maintain quality and ensure safety (Dassow, 1988). It also provided the basic research and processing information that allowed the nutritional supplement industry to produce and sell purified fish oil and omega-3 fatty acids. The health benefits of omega-3 fatty acids are well established, and it is now a multibillion dollar commercial industry. Dassow (1988) stated that the utilization fishery research programs achieved success in improving the quality, nutritive value, and safety of fishery products. Improved diets for today’s current aquaculture industry can also be

traced back to the 1970s, when the Seattle utilization laboratory studied methods for utilizing low-cost food fish in aquaculture diets (Dassow and Steinberg, 1973; Spinelli and Mahnken, 1978; Dassow, 1988). Research on underutilized fisheries helped to establish the current multimillion dollar West Coast and Alaska surimi processing industry. In 2007, surimi accounted for approximately one-third of the 1,408,000 mt (3.1 billion lb.) production of Alaska pollock volume (Anonymous, 2008a). Since the early 2000s, there have been record harvests of Alaska pollock, but stocks are now decreasing and the North Pacific Fishery Management Council recommended a 337,700 metric ton (744 million lb) reduction in harvest (Anonymous, 2008a). Today, more than 50% of global production of surimi is based on new fish species other than Alaska pollock. New species include Pacific whiting (*M. productus*), hoki (*Macruronus novaezelandiae*), Northern (*Micromesistius poutassou*) and Southern (*Micromesistius australis*) blue whiting, Peruvian anchovy (*Engraulis ringens*), atka mackerel (*Pleurogrammus monopterygius*), and jack mackerel (*Trachurus* spp.). Even tropical fish such as threadfin bream (*Nemipterus japonicus*), known as Itoyori, and lizard fish (Synodontidae) are being used (Anonymous, 2006a).

### **Nongovernmental organization and consumer pressure for sustainable management**

Attempts to use market forces to press for changes in fishery sustainability and management perhaps began with Earth Island's Institute's 1986 campaign for "dolphin safe" tuna catches. The campaign, which included a consumer boycott, was instrumental in passing federal legislation and getting the major United States canned tuna packers to alter their catching methods. The institute now claims that more than 90% of the world's tuna canners are "dolphin safe" (Anonymous, 2008k). The NOAA, in its 2007 Report to Congress on the Status of US Fisheries, found 24% of US fisheries in an "overfished" status (Anonymous, 2008h). In 1999, the Monterey Bay Aquarium started its Seafood Watch List, encouraging consumption of certain fish while discouraging consumption from fisheries it deemed unsustainable or otherwise unhealthy. The program has 52 partners that distribute identical lists. The

aquarium says 22 million of the Seafood Watch guides have been distributed (Anonymous, 2008k). Others like Chicago's Shedd and Atlanta's Georgia Aquariums also provide branded pocket guides, which are similar, although their recommendations are not identical to Monterey's (Barrat, 2008).

In 1997, the World Wildlife Fund, an environmental organization, and Unilever, a British headquartered multinational corporation, provided support to form the Marine Stewardship Council (MSC). The goal of the council was to provide a standard for certifying that a fishery was being operated in a sustainable manner and thus worthy of MSC's blue ecolabel, which would provide consumers with assurances they are eating fish from sustainable fisheries. In the United States, only a few West Coast fisheries have gained full certification. Those fisheries include Alaskan salmon (*Oncorhynchus* spp.), hook and line albacore tuna (*Thunnus alalunga*), Bering Sea cod and Pollock (i.e., Pacific cod and Pacific pollock), Oregon pink shrimp (*Pandalus jordani*), North Pacific halibut (*Hippoglossus stenolepis*) and sablefish (*Anoplopoma fimbria*) (Anonymous, 2008i).

How ecolabel influences consumer quantity demand and price is open to question as the issue has not been extensively studied. Ecolabeling was found to increase demand for shrimp and cod (Wessells et al., 1999), but since the labels are now just appearing in the market, further study is needed. Even though Alaskan salmon has MSC certification, much of it is sold without the MSC label making the measurement of the effects on consumer demand difficult to quantify (Knapp et al., 2007). Although the demand pull from ecolabeling hasn't been well measured, certification is incontrovertibly and increasingly important for fishery sales to some of the nation's largest food retailers.

In February 2006, Wal-Mart<sup>TM</sup> announced that it would purchase all of its wild caught fresh and frozen seafood from MSC-certified fisheries within 3–5 years. When Wal-Mart made the announcement, the company said it was working with a "number of MSC-certified fisheries and is giving uncertified fisheries 3–5 years to develop plans and programs to become certified. If these suppliers commit to this initiative and succeed within that time frame, Wal-Mart will continue to work with them" (Anonymous, 2006b).

Whole Foods<sup>TM</sup>, the nation's largest retailer of organic foods, started supporting the MSC in 1999

and began selling the MSC-certified products in 2000 (Anonymous, 2003). The company is now selling 17 products with the MSC blue label with four of those being sold at the fish counter, according to the MSC Web site (Anonymous, 2008h). Obtaining the MSC certification can be an expensive proposition. While the fees that the fishery pays to the MSC approved certifying agency is not disclosed, the MSC Web site states charges have ranged from \$35,000 to \$500,000. Currently, MSC deems six different organizations qualified to conduct the certification assessment. The fishery is responsible for hiring one of these six organizations to conduct the assessment.

In June 2008, Atlantic red crab fishery made it through the preassessment stage of the MSC sustainability certification. It is only the second East Coast fishery to get accepted into the full review process, although as previously mentioned, several West Coast fisheries are certified. The other East Coast fishery in the assessment stage is Maryland striped bass (*Marone saxatilis*). Its application is being supported by the Maryland Department of Natural Resources (Smits, 2008).

Full certification, which depending on the data available can be a lengthy process, would allow access to new more valuable markets for red crab and encourage the development of value added product (Williams, 2008). The certification process must be managed by an independent agency approved by MSC. In this case, Scientific Certification Systems, Inc. is assessing whether the Atlantic red crab fishery meets MSC's "environmental standard for sustainable and well-managed fisheries" (NOAA, 2008).

## Future trends

Increasingly, individual fisheries are required or encouraged to be managed as part of whole fishery ecosystem by the Federal government. Although it has long been understood that changes in one fishery will affect other fisheries, until recently, Fishery Management Plans (FMP) tended to focus only on the species in question. While FMPs still apply to individual species, Congress is asking that the NMFS move toward an ecosystem-based management scheme. While such a regulatory scheme can be so complicated they are difficult to manage, an initial step might "require only that managers

consider how the harvesting of one species might impact other species in the ecosystem" (Fluharty et al., 1998). In Alaska and California, some FMPs now include ecosystem-based rules. East Coast councils are considering similar provisions. Non-governmental organizations (NGOs) are increasing pressure for ecosystem-based fishery management plans (Pikitch et al., 2004). Sustainability continues to be a "buzz" word for both federal and state governments and NGO organizations. Consumers and commercial outlets are demanding high-quality, safe products along with protection of the environment, habitat, and fishery stocks. Organizations like the MSC are finding ways to employ market forces to encourage sustainability. The convergence of all these developments makes it unlikely that there will be major future US federal programs encouraging the targeting of underutilized species. Research and development efforts are focusing on waste management, better use of processing wastes and by-products, biofuel and pharmaceutical development from aquatic resources, and so forth. Both aquaculture and commercial fisheries must focus on being ecofriendly and sustainable.

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## Processing Finfish

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Lori Marsh and George J. Flick, Jr.

Within the past 50 years, consumers have made major changes in their food purchasing habits. For centuries, fresh fish and shellfish were purchased at retail markets and converted into dishes at home. As social patterns changed and disposable income increased, consumers began to purchase partially or fully prepared seafood. These seafood dishes, although more expensive than the raw product, provided convenience for consumers at a reasonable price.

Today, heightened awareness of the health and nutritional aspects of foods and concerns for the environmental sustainability of production methods also drive consumer preferences. Consumers expect a high-quality, fresh, healthful, nutritious product that is easy to prepare. These factors have led to the demand for fresh, ready-to-cook seafood products such as salmon steaks; processed, chilled, ready-to-eat products such as smoked fish, fish salads, and fish spreads; frozen fish products such as fillets; and fabricated and further processed seafood products such as breaded fish sticks.

Many traditional convenience products are coated (battered or breaded), and many items use minced fish as the primary ingredient. Coated product sales have not experienced substantial growth in recent years; however, the consumption

of minced fish further processed as surimi products has increased significantly. This chapter discusses fish filleting, mincing and some mince-based products, and coatings. Chapters 10, 18, and 29 are devoted to surimi, freezing, and smoking technologies, respectfully; hence, they will not be discussed here.

### Filleting

A fish fillet consists of the dorsal and abdominal muscles of the fish. Typical fillet forms include bone-in, boneless, and skinless. These market forms can be produced using hand labor or with the complete or partial assistance of mechanization. The ability to use hand labor, partial mechanization, or complete mechanization will depend on the volume of fish processed, the size of the fish to be processed, and labor costs. Typically, automation of the filleting process is desirable to reduce labor costs and increase the volume of product processed. Specific machine designs are a function of the equipment manufacturer, fish species and size, end use of the fillet, and other factors. Some machines require that the fish first be headed and gutted, others headed only; some machines accept a whole fish. Filleting

leaves meat on the fish frame, yield varies with machine and fish species. However, the remaining meat can be recovered as mince.

## Mince

Minced fish, which is flesh separated in a comminuted form from the skin, bones, scales, and fins, is a versatile but unstable commodity. In addition to recovering meat remaining from the filleting process, mince technology offers a method to use underutilized species, primarily pelagic fish. Mince is generally an intermediate product that is often frozen into blocks and is incorporated into a wide range of further processed products, for example, sausages, frozen battered and breaded products, and dried fish flesh flakes. Mince is also the starting point for surimi, which is, in turn, an intermediate product that receives further processing. Chapter 10 is devoted to a discussion of surimi production.

### Raw materials and sources

In principle, bone separation processes can be applied to any species of fish, crustacean, or mollusk. In practice, these processes can be best justified for those species where significant added value will accrue. Separation techniques can increase yields obtained from currently utilized commercial species by reclaiming flesh from filleting wastes and other by-products. Separation techniques can also increase the use of previously underutilized species by transforming them into products that are in greater demand and by upgrading species that have previously been used for industrial or animal feeding purposes. Finally, separation technologies can also be used to exploit bycatch materials that otherwise would be discarded at sea.

Different raw materials have different technological properties, and to a large extent, the raw material species or species mix determines both the degradative problems and the potential process and product applications of the mince. Compositional changes due to species, spawning cycles, and seasonal response have a major effect on fat and protein quality. Conditions and handling methods throughout the world generate raw material of widely differing qualities. Generally, minced fish technologies

are more sensitive to raw material qualities than technologies that use intact fish flesh.

Mince technology can obtain a higher yield from whole (headed and gutted) fish than is possible with filleting and can reclaim additional flesh from filleting wastes. Frozen blocks prepared from both fillets and minces are major commodities in international commerce.

Fish mince blocks are produced primarily from Alaska pollock, whiting, and pink salmon. These blocks are primarily used for the manufacturing of fish sticks (Lee, 1997). Species most commonly used for production of mince from fish frames include cod, catfish, and tilapia. The primary market for mince from frames has been the manufacturing of the second-grade surimi.

Traditional product forms (e.g., battered and breaded fish sticks) made from minced dark-flesh fish species and from frames have received little market acceptance. This has promoted the design of newly engineered products from fish mince with appropriate technologies and novel formulation strategies.

In developed countries, mince is based predominantly on the gadoid fish: cods, hakes, haddocks, pollocks, and croakers. Mince yields are generally high and the microbiological quality good. However, the color, texture, and taste of commercial blocks made from these minces are highly variable.

### Separation processes

Fish mince quality depends on the raw material and also on the separation process. The process sequence, the equipment used, and the operating conditions can influence the potential usefulness of the final product.

### Anatomy and biochemistry considerations

Mincing is not a simple separation of flesh from bone. Separation processes must effectively fractionate the raw material into a range of anatomically and physiologically distinct components, which can affect the minces texture, flavor, and appearance. The criteria for a separation process cannot be established until the desirable and undesirable components are identified.

Most apparent is, of course, the bone fraction, which can be up to 15% of whole or gutted fish, or

more than 30% of filleting wastes. Several problems are associated with bone contamination of minces: (1) physical injury can result from the consumption of sharp, hard, or pointed bone fragments; (2) the visible presence of even soft or harmless bone is considered aesthetically undesirable in most of the world; (3) smaller bone particles can cause a gritty texture; (4) bone contents over 2–3% can approach threshold toxicity levels for fluoride content; and (5) bone marrow exudate has been implicated in the development of oxidative fat rancidity.

However, bone is not a constant material. The skull and vertebrae are more highly calcified than the spine, ribs, and pin bones. Thus, the mincing of heads and frames can give a higher proportion of hard, brittle fragments than is obtained in mincing whole fish or fillets. Calcification varies between species, most notably between pelagic and demersal fish, and increases with age. Most international (Code Alimentarius Commission, 1995) and US (USDC/NOAA/Seafood Inspection Program, 1979) quality specifications for minced fish define limits for bone content based on weight, number, or size distribution.

A variety of mince contaminants can damage texture or texture stability. For example, mixing blood and other organ tissue with fish flesh during mincing enhances the enzymatic degradation of trimethylamine N-oxide (TMAO) to dimethylamine (DMA) and formaldehyde. A cross-linking of the flesh proteins with formaldehyde can cause severe textural damage. The reaction is enzymatic, seems to be limited to certain species, and occurs predominantly in frozen storage. The gadoid fish species are especially susceptible to this process (Taylor et al., 2007). The major enzyme source is the kidney. This enzyme is heat labile but is reactivated by an unidentified compound in the muscle. Thus, localized heat treatment is not sufficient to prevent texture degradation. Other sources of the enzyme include the blood and blood clots, the pyloric caeca, the dark brown lateral muscle, and possibly the skin. Mincing of susceptible species (e.g., gadoids) reportedly accelerates formaldehyde-mediated denaturation, presumably by the mixing of the source organs with the flesh. Apparently, preparing minces from mixed species (e.g., bycatch) that contain formaldehyde-producing species can also cause degradation of the flesh of nonformaldehyde-producing species.

Significant texture degradation can arise through enzymatic proteolysis (protein breakdown) of the minced fish. This process is most apparent when whole fish are used, and gut proteases (protein that breaks down muscle tissue) are dispersed through the muscle tissue. Even low levels of contamination by visceral materials from gutted fish can cause extensive proteolysis of the mince. Other active proteases include the catheptic enzymes of the muscle tissue itself and those generated by microbial spoilage.

Minces from both demersal and pelagic species are susceptible to extensive fat degradation; therefore, separation methods should aim to reduce both the source of the fat and the materials catalyzing the fat decomposition. High levels of unstable, polyunsaturated lipids are found in the skin, in the subcutaneous and dark lateral tissue, in the viscera, and in the brain and nerve tissues. Contaminating minces with these materials may cause flavor and oxidative rancidity. The mincing process can accelerate the degradation by dispersing the fat-degrading enzymes, by accelerating nonenzymatic oxidation through increased surface area, and by dispersing organic and inorganic oxidation catalysts. The enzymes are found mainly in visceral material and in the dark muscle. Nonenzymatic degradation is catalyzed mainly by the hemoproteins (hemoglobin, myoglobin, and oxyhemoglobin) in the bone marrow, in blood vessels, and in the flesh itself. Skin also contains pro-oxidant components.

Mincing frequently results in a product that is darker than the raw material because of contamination by melanoid skin pigments, the black belly membrane, blood, head, and gut contents. During longer term storage, browning and yellowing reactions of the proteins and lipids also become apparent. The United States offers color standards for frozen mince blocks (USDC/NOAA/Seafood Inspection Program, 1979).

Visceral contamination is mainly associated with the aesthetic aspects of taste, texture, and color, but consideration must also be given to possible toxicological and microbiological factors, which can only be assessed by examining the specific raw material. Despite the presence of food poisoning organisms in the guts of several species used for mince production, no instances of disease-causing bacterial spoilage have been reported. Similarly, although many species concentrate pollutants



such as heavy metals and pesticides, no problems have been reported in commercial mince products. Problems may occur, however, with parasite contamination. Many species used for mince production, particularly the underutilized marine resources, can be heavily parasitized. Worms and larvae in the flesh will be transferred to the mince, many surviving intact.

In general, parasites from marine fish are aesthetically unappealing rather than harmful; however, there are technological problems associated with the rapid proteolysis caused by myxosporidia. Some parasites of freshwater fish (e.g., *Anisakis*) pose potential dangers to human health. For example, the risk of nitrosamine formation in nitrite-treated DMA-producing species is well known. These reactions are accelerated in mince products by the dispersion of hemoglobin, which acts as a catalyst. Although washing and antioxidant treatment can reduce the effect, DMA-producing species should not be used for nitrite-cured mince products.

Toxins can arise in mince from contamination by certain fat products, notably high levels of sphingomyelins and other complex lipids from nerve and brain tissue, and the reaction products from advanced oxidative fat degradation. Potent neurotoxins can arise from visceral contamination of mince from certain tropical species; again, raw material sorting is the only effective method of control.

Lastly, consideration should be given to the distribution of nonpoisoning bacteria in the raw material. In whole fish, the highest bacterial counts are found in the viscera and on the skin and gills. However, the mincing of whole (gut-in) fish gives a mince with counts similar to that obtained from degutted fish. More significant are the differences in filleting fractions, where it is generally found that frames give higher counts than minces from fillets, V-cuts, or frame trimmings. The mincing process itself will also increase bacterial counts.

### Mechanical separation

Most separation techniques use a perforated filter to screen the flesh from nonflesh components. Early separation devices were adapted from those used in the fruit and meat-processing industries, but now a wide range of machinery specifically designed for fish separation is available (Figure 9.1). Three operating principles are used: (1) a belt and perforated

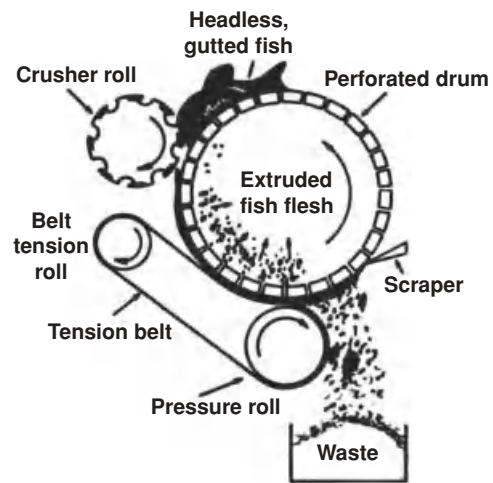


Figure 9.1 Mechanical flesh separator.

drum system (a variation of this system has been developed where the belt and drum surface move at different speeds, thus increasing the shear rate and consequent yield); (2) a screw feed and perforated cylinder system; and (3) two concentric cylinders, the inner perforated and rotating. All have their advantages and disadvantages.

The belt-and-drum systems benefit from readily adjustable pressure and easy cleaning, although belt wear can be high when using raw materials with large or hard bone particles. Some residual bones from fillets or gutted whole fish are needle-shaped, and the mince may consequently exceed some specifications for limits of bone. Some bone particles in mince made from skeletons of whole fish that have had fillets removed but still carry some flesh are blunt and irregular in shape. These products might not meet specifications limiting the permitted weight of bone present. Use of a drum with smaller perforations not only reduces bone content but also yields a mince of poorer texture. Perforations from 1 to 7 mm are available commercially, but a 3-mm drum generally offers the most reasonable compromise between bone removal and acceptable mince texture.

Screw cylinder systems do not have the same wear problems as belt and drum systems, but generate higher shear rates and consequently greater textural damage. In general, screw cylinder systems are more expensive, but all systems give similar yields: 60–80% for whole fish and 30–70% for fillet wastes. However, despite their apparently simple

operating principles, the relationships among pressure, perforation size, and perforation area with yield, contaminant levels, and shear damage are complex.

As problems have developed, machine designs have been adjusted. The high spoilage rates of minces have led manufacturers to remove dead spaces from the fish-carrying areas. Recognizing that ferric contamination from machinery can accelerate oxidative fat degradation, stainless steel and nonmetallic materials are being used for components that come in contact with the mince. Oxidation can be further reduced by separation under water or under washing solutions.

Mechanical filters that screen bone from untreated raw material are now the most widely used. However, several alternative methods are evolving. Fine pastes can be obtained by grinding and filtering; bone-free minces can be obtained by tumbling and screening; and precooking can be used to weaken connective tissue. Traditionally, such techniques have been used prior to manual picking or deboning, but now mechanical systems have been developed. These methods have the advantages of reducing nonprotein contamination, softening bones, and reducing texture and flavor degradation; however, protein functionality is lost. Mince, of course, can be generated by the comminution of bone-free flesh obtained by traditional filleting methods.

Many operators now use multipass systems, whereby high-quality mince is generated by low pressure and intermediate perforation size. Extra yield is obtained by generating lower quality minces at higher pressure and lower perforation sizes on subsequent separation steps.

Machines are also available for heading, gutting, dressing, and prebreaking of many species that can be used whole for mince production, notably for consistent catches of small pelagic fishes. However, a major need for mechanical heading and gutting systems for mixed material, such as bycatch, remains. Consideration is also being given to mechanization of bone separation systems suitable for some developing countries.

#### *Physical quality effects of mechanical separation processes*

Mechanical deboning systems obviously have a major effect on mince quality; therefore, under-

standing these effects is vital for the optimization of the product.

A strong positive correlation is found between screen perforation size and bone content in the mince. Similar relationships are found between the degree of preprocessing size reduction and separation pressure with final bone content. Increasing perforation size also increases the proportion of thin, sharp bones in the mince. More difficult to establish are the relationships between the shear and pressure conditions of the separator and the damage to texture and storage stability. It is important to distinguish between direct pressure effects and the effects of increased dispersion of degradative enzymes.

There is increasing evidence that high shear rates damage protein functionality. Increasing pressure can lead to a reduction in water-binding capacity and to an actual loss of water content. Conversely, increasing the raw material's water content has been found to correlate with increasing susceptibility to shear damage during mincing.

Extremes of pressure can have dramatic effects on mince: above 300 kg/cm<sup>2</sup>, significant fat separation occurs and rancidity development is accelerated; above 1500 kg/cm<sup>2</sup>, a large proportion of the protein is solubilized and denatured, although yields are substantially improved. Excessive protein denaturation damages most mince applications.

Increasing pressure and shear may increase mince discoloration and susceptibility to protein degradation in storage. Shear has less effect on immediate lipid degradation, although the effects of pressure on temperature and subcutaneous fat release can damage longer term lipid stability.

For mechanical separators, the effects of pressure, perforation size, and perforation area on bone content, protein functionality, discoloration, and lipid stability require a compromise for optimal machine conditions.

### **Nonmechanical separators**

In addition to mechanical deboning systems, several chemical and biochemical techniques have been developed. Protein can be recovered from both whole fish and filleting waste by enzymatic or acid proteolysis followed by centrifugal or filtration bone separation. Yields are high but protein functionality and integrity are generally low. These

materials are best suited as inert extenders in composite products.

## Washing

Many mince processes employ postseparation washing to remove inorganic salts, water-soluble proteins, pigments, visceral contamination, bacteria, and decomposition products. In some species, fat content can also be reduced by washing, and the washing of minces from whole fish can provide products of similar quality to those obtained from gutted material. Washing of gadoid mince can eliminate formaldehyde production from TMAO, and washing is essential in applications such as kamaboko production where acceptable products cannot otherwise be produced. Washing is generally achieved by multiple passes using chilled, preferably chlorinated water followed by pressing, centrifugation, or rotary sieving. Alkaline washes can inhibit protein hydrolysis by acid proteases, although fish flesh may contain alkaline proteases that will be activated by such treatment. Washing with ascorbic or citric acids may inhibit degradation of flounder minces. Reduction of wash water pH can also reduce color, water uptake, protein loss, and TMAO levels.

Although washing improves the texture of finely minced gel products, it has less effect on coarse textured minces. Similarly, although washing may be necessary for minces heavily contaminated with pigment or visceral material, it has little effect on the flavor or appearance of minces from higher quality raw materials. Washing has little effect on muscle tissue that is inherently colored, such as the gray flesh of saithe and blue whiting, the dark flesh of pelagic species, and the green flesh of certain tropical bycatch species. Discolored minces may be acceptable for incorporation into meat products, as discussed later.

The need for a washing step should be carefully considered, as it can have undesirable effects. Gross protein yield loss can be substantial, up to 25%, and soluble micronutrients including vitamins, minerals, and free fatty acids are also lost. This method can lead to the secondary problem of effluent disposal. Washing with hard water can damage texture and catalyze fat degradation; washing with seawater or brine can further increase protein loss. Despite the availability of effective dewatering machinery,

it is difficult to control the final water content of the washed mince. In many situations, washing of the raw material prior to mincing is more appropriate and is a good manufacturing practice.

## Mince stabilization

As mentioned, mincing can accelerate the degradation of fats, proteins, color, and bacteriological quality. This section reviews work on the stabilization of fish minces, and Section "Mince products" discusses the product applications of these technologies.

### Fat stabilization

Fat degradation is a major problem in minces from both fatty and low-fat species. It occurs in all product applications except canned systems.

Fish fats in mince are characterized by their high levels of long-chain polyunsaturated fatty acids. Although these may be nutritionally desirable, they are highly susceptible to enzyme hydrolysis and nonenzymatic oxidation. Undoubtedly, the mincing process accelerates these reactions through physical surface effects and through the dispersion of catalytic contaminants. However, measuring fat degradation is extremely difficult, and it is less clear which reactions are increased by mincing and what effects they have on sensory quality.

Several approaches are available for the stabilization of fats in fish minces. Most widely studied is the use of antioxidants.

Polyphosphates are added to mince mainly to enhance protein functionality and water binding. They have been found to have antioxidative properties, particularly, when used in combination with other additives.

Several process techniques can inhibit fat degradation. Glazing and oxygen impermeable packaging inhibit the oxidative deterioration of frozen mince blocks. Studies have confirmed the following regarding oxidation of frozen mince blocks: oxidation is a surface effect; impermeable packaging has a greater protective effect than degassing and elimination of occluded air; and slow-frozen glazes provide more effective protection than rapidly frozen glazes. Impermeable packaging is one of the most effective means of protecting dried mince product.

Rapid heat treatment of minces at temperatures above 49–60°C deactivates lipolytic enzymes, thus protecting the mince against free fatty acid formation. However, cooking tends to enhance oxidative deterioration. An effective way to prevent oxidation is to hydrolyze the fats with added lipase and then wash out the free fatty acids. Washing can also remove other oxidation catalysts from the mince, although careful control of wash water temperature is needed to prevent acceleration of oxidative degradation.

Much work has been done on understanding and controlling fat degradation in minced fish. However, fat stability remains a major factor limiting the use of many small pelagic and underutilized species for mince production.

### **Protein stability**

Much recent work has been done on the nature, stability, and enhancement of fish protein functionality. The proteins of deboned mince are particularly susceptible to degradation and yet are of high inherent functionality. Minced fish has particular problems of protein stability, but it is also a versatile material in terms of the wide range of technological properties that can be exploited in process and product development. The functional properties of major interest are heat-setting capacity, gel-forming ability, and water-binding capacity. Maintaining these properties requires that the myofibrillar proteins are preserved in their native, nondenatured form. This process, in turn, requires minimizing a range of degradative reactions.

### **Color stability**

As with fillet materials, the mince products' color and appearance are vital consumer attributes. In developed countries, whiteness and homogeneity of color are major parameters in the acceptance of products such as mince blocks and kamaboko. In the developing world, products such as the fish balls of Southeast Asia must also be white or a uniform gray, but in other products such as spiced or dried mince, color is less important.

The mincing process generally has the greatest effect on color; however, further degradation can occur during storage. Yellow/brown discoloration occurs in frozen minces, and bacterial and nonenzymatic browning occurs in nonfrozen materials.

Oxidative discoloration of fats and blood pigments can also be extensive. Color assessment and specification can be accomplished by subjective or instrumental methods.

Several techniques are available for improving mince color. Most commonly used is water washing, which can be effective for whole fish, frame, and mixed bycatch minces.

The alternative to whitening is color masking, such as incorporating fish mince into products where a darker color is expected. Examples of such products include those where mince is used as a meat extender or in smoked, spiced, or curried minces.

### **Bacteriological stability**

The major determination of minces microbiological quality is the quality of the raw material. Thus, protracted holding of filleting wastes before mincing or poor storage of whole fish raw materials increase the total counts in the minced product and the risk of spoilage. "Dustbin" practices of stockpiling prior to mincing should be avoided. Under good hygienic conditions, preprocessing raw materials by scaling, heading, and evisceration has little effect on the minces final quality. Even mincing gut-in materials leads to only small increases in counts, and no pathogenic species are found in the viscera of most raw materials. Similarly, if temperature and cross-contamination are controlled, the mincing process should not lead to more than a one log cycle increase in counts. Gashti (2002) provides data on microbiological and chemical variations in minced Atlantic pollock. Standards of process hygiene have been defined by the Food and Agriculture Organization of the United Nations (Code Alimentarius Commission, 1995). The bacteriology of commercial frozen mince blocks produced under these standards has been extensively studied, and the large majority fell within international trading standards.

There are many instances where potential raw materials for mince production are spoiled or semispoiled. Most of these materials occur because of warm temperatures, and thus contain thermophilic spoilage organisms, which are highly amenable to chill or iced stabilization. Unfortunately, many current practices lack proper chilling and, hence, generate raw materials of high initial counts. Under such conditions, mincing will lead to substantial increases in microbial counts by dispersion of high

levels of surface contamination throughout the muscle tissue. Even minces prepared under the most controlled conditions are extremely susceptible to postmincing contamination. Thus, minces with high levels of initial contamination have an extreme risk of spoilage in handling, storage, and further processing. In wet minces, initial spoilage is predominantly putrefactive, and the product becomes inedible before there is any risk of toxicity. However, poor handling practices can lead to contamination by food poisoning organisms. The presence of scombroids (e.g., tuna and bonito) and certain other species in the raw material can also introduce toxin producers in the mince.

## Mince products

The range of mince products established in the world market is limited and dominated by block frozen materials and surimi (Chapter 10). We discuss blocks briefly here, but more emphasis is given to product technology currently under development.

## Frozen products

The annual production of frozen blocks probably amounts to more than  $500 \times 10^3$  metric tons (550,000 tons), although the statistics are inadequate. Blocks can be produced solely from minces or from mixtures of mince and fillet in various proportions. Producing mince blocks is generally done in molds in plate freezers, often with the incorporation of salt, phosphate, sugars, and other additives. Manufacturing practices and standards for frozen blocks are suggested by the Food and Agricultural Organization/Codex Alimentarius (Code Alimentarius Commission, 1995) and have been adopted by most producing countries. The primary aim is to produce frozen blocks of uniform shape that are intended for further processing. The CODEX Standard addresses the following areas: (1) freezing processes, (2) essential composition and quality factors, (3) glazings, (4) allowable concentrations of histamines, (5) allowable additives (moisture/water retention agents, antioxidants, acidity regulators, and thickeners), (5) hygiene and handling, (6) labeling, (7) sampling, examination, and analyses, (8) definition of defects, and (9) lot acceptance.

Headed and gutted fish, fillets, V-cuts, and frames are all used as raw materials in commercial mince block production. These materials mainly come from established whitefish sources, but increasingly also from underutilized whitefish, pelagic, and mixed bycatch species. Thus, blocks of a wide range of composition and sensory properties are produced. It has been common practice to confine the proportion of mince added to fillet blocks to about 15% of the total mixture.

Although mince blocks are a major commodity in international trade, they are only intermediates in the manufacture of final retail products, such as battered fingers, sticks, steaks, and cakes. A retail trade is also developing in the United States and Japan for bulk packs of frozen mince for further preparation by the consumer. This concept could be extended to chilled and intermediate moisture products.

Mince should be frozen as soon as it is made or immediately incorporated into products and then frozen within 5 hours of manufacture; products should be kept chilled while awaiting freezing. The storage life of frozen mince made from good-quality cod and haddock flesh is at least 6 months at  $-29^{\circ}\text{C}$  or 3 months at  $-18^{\circ}\text{C}$  without any significant loss of quality, but mince from hake and Alaska pollock apparently have a shorter cold storage life as do minces that include kidney or gut. Minces made from fatty fish require protection against oxidation in cold storage.

In the normal procedure for making a mince block, the appropriate weight of material is packed into a waxed cardboard carton fitted into a frame contained in a shallow, light metal tray. The frames, often divided to accommodate two cartons, should be strongly constructed of aluminum or galvanized steel in order to withstand the pressures when the block expands during freezing. Aluminum frames are preferred because they are less likely to damage the plates of the horizontal plate freezer, although deformation can occur more easily during handling and during freezing if the carton is overfilled. The length and width of the frame space should be accurate to 1 mm to provide a block of precise dimensions.

The carton is formed by a folded, one-piece waxed and scored card of food-grade quality with either a smooth or dimpled surface. The carton helps maintain fish quality by providing protection from dehydration in storage and transportation,



from damage in handling, and from dirt and bacteriological contamination. It also allows easy release from the frame and from the frozen block of fish. Some processors believe dimpled surfaces make release easier and give a smoother block surface with few voids. Much of the carton's protection is lost if it is opened (e.g., to inspect the block in quality control) because the intimate seal between fish block and carton is broken.

The folded cartons are fitted in the frames on trays, with all tie carton tabs overlapped on the outside to prevent them from being embedded in the block. The space formed by the carton can be termed a mold.

### Packing

The mold must be filled with the correct amount of fish because underfilling results in voids; overfilling results in some material being squeezed out on the freezer plates, bulging of the surfaces, uneven contact with the freezer plates, and possibly fracture of welded joints on the frame. Allowance must be made for the block to expand during freezing. The weight of fish will vary slightly with species; the amount of mince required for a given volume is less than the amount of fillet. After weighing, the fish should be transferred quickly to the mold because delays can result in drip loss. The balance pan should be kept free of drip and residue. By strict control, the block weight can be kept within 5% of the desired value.

Mince added to fillet blocks should be distributed throughout the block to avoid a sandwich effect of a layer of mince in the middle and to avoid concentrations of mince. Usually, the mixture of fillets and mince is spread from the center and pressed into the corners to form a block with random packing.

After the mold is filled, the surface is smoothed and the carton closed so that the overlapping cover edge fits between the side of the carton and the frame to prevent the edge from being embedded in the block. Normally, the trays and frames containing the filled molds are stacked on a pallet to accumulate a full load for the horizontal plate freezer. In handling loaded trays, care should be taken to ensure the mold does not slip through the frame and become trapped between the base of the frame and the tray. If frozen in this position, contact with the freezer plate will be poor, and it may be difficult to remove the frozen block from the frame.

Long delays in accumulating a freezer load should be avoided. If considerable drip accumulates before freezing and it can be foreseen, some compensation for weight loss should be made when the mold is filled in order to prevent voids. Drip accumulation also results in ice pockets in the frozen block.

### Freezing and storage

Before loading the freezer, the freezer plates should be clean and free from residues of frozen fish and ice, which might cause indentations on the blocks or damage to the cartons. Any drip accumulated in the tray should be poured off. The freezer should be loaded evenly to maintain good contact between blocks and plates and to prevent warping of the plates. Spacers should be inserted where there are no blocks, and frames of different thicknesses must never be stacked on the same plate.

Given good contact and efficient heat transfer with a refrigeration temperature of  $-40^{\circ}\text{C}$ , blocks up to 6.4-cm thick can be frozen to a mean temperature of  $-29^{\circ}\text{C}$  in less than 2 hours. If these practices are followed, one defrost of the freezer in 24 hours will be sufficient for cleaning.

When removing frozen blocks from the frames, the block should be pushed evenly from the bottom surface to avoid damage to the carton; the cover or lid tends to be torn if the blocks are pushed out from the top surface. The blocks are packed in corrugated cardboard master cartons for added protection and easier handling during cold storage and distribution. To obtain maximum storage life, the frozen blocks should be transferred immediately to cold storage at  $-29^{\circ}\text{C}$ .

### Reformed, transformed, and textured products

As they come off the separator, fish minces are amorphous granular slurries. Coarse minces may have a perceptible structure of fibers and fiber bundles; fine minces and minces from soft-textured species have a homogeneous pasty consistency. Thus, some forming or structuring process is needed to achieve higher levels of textural integrity.

Intact fillets have three levels of texture: fibrosity, flakiness, and gross bulk structure. If fillet simulation is required, forming techniques can achieve some or all of these. Frozen mince blocks achieve fibrosity from the inherent characteristics of the mince and gross structure from compaction in

the freezer mold. Mixed mince and fillet blocks also have some degree of flakiness similar to the structure of an intact fillet. Flakiness can be achieved in all mince products by several reforming techniques. Most widely studied has been the use of alginate gels to set the mince into a sheet structure, followed by layering and compaction of the sheets to simulate the myotome flakes. Fibrosity can be enhanced by the incorporation of spun vegetable protein fibers, extrusion-textured vegetable protein, precooked fish muscle, and alkali/acid-precipitated mince protein fibers.

Few of these flake- or fiber-forming processes are practiced commercially. However, extensively used are techniques for the forming of individual portions from mince. Regular portions can be cut from frozen mince blocks. Blocks can also be portioned by frozen extrusion forming; this method eliminates yield loss in sawdust but can cause shear damage to the muscle proteins. A wide range of machinery is available for the low-pressure extrusion forming of fresh minces. An infinite variety of shapes and sizes can be produced, including fillets, shrimp tails, balls, and regular geometric portions. Additives such as salt, phosphate, soy protein, and gums are used to obtain the optimal characteristics for extrusion and to control the final product texture. Colors, flavors, and seasonings can also be used. A range of high-quality products aimed mainly at developed Western markets are manufactured using extrusion-forming techniques. The firm, elastic textures are particularly suited to shellfish and mollusk analogs. The incorporation of shrimp into mince portion can markedly improve acceptability and oxidative stability.

Formed products such as sausages, cakes, patties, balls, loaves, and burgers are well established in many countries. Although their forms vary with cultural preferences, many of these products are ideal vehicles for minced fish. Mince in sausage products is the most extensive, an industry dominated by Japanese kamaboko production. Outside Japan, most mince sausage products are fine-textured, heat-set emulsion products rather than heat-set protein gels.

Mince is used as an extender in meat-based sausages in the United States. The color of frame mince and pelagic mince is effectively masked in products such as frankfurters; usage levels are limited by flavor effects. Mince has also been used as a meat extender in patties and burgers. Other

emulsified mince products include highly comminuted, soft-textured pastes for uses such as spreads, or dips, and coarsely chopped products for such uses as fish burgers and loaves. The formation of oil-in-water emulsions may be effective in reducing contact between the fish fat and ambient oxygen.

Mince can be used as an ingredient in many composite products. The ubiquitous fish cakes, rissoles, and croquettes are generally bonded with cereal flours or starches, seasoned to local preference, and preserved chilled or frozen. Higher levels of mince are used in traditional products such as fish balls (Southeast Asia and Scandinavia) and Gefilte fish (Israel, Europe, and the United States). Such products are being further developed in the United States and elsewhere. In the United States, high levels of mince are used in fish patties. Other formed products studied for mince utilization include fried or extrusion-expanded, starch-based snack products, sliced salmon, or saithe analogs and filled products.

## Conclusions

Mince separation techniques have been applied to a range of raw materials, including commercial and underutilized species, whole fish and filleting waste, bycatch, and pelagic and freshwater sources. For many of these fish, mincing is the only viable means of utilization. Development of separation processes is now highly advanced, with a wide range of separators available commercially. Mince proteins are both highly functional and highly unstable, and hence, are generally frozen. Frozen denaturation can be minimized by a wide range of cryoprotectants.

## Batters and breading

Breading and battering is used extensively for preparing frozen, ready-to-cook foods. Typically, minced or filleted fish are battered, prefried, and then frozen. Ingredients used in batter and breading formulations include the following: (1) polysaccharides such as flours, starches, and gums, which improve viscosity and help control the shelf life of the coated products through interaction with proteins and lipids; (2) proteins and lipids such as milk powder, milk protein fractions, and egg albumin,

which increase the water-holding capacity of the flour; (3) fats, which contribute to the texture and flavor of the product; (4) seasonings such as spices, salt, and sugar, which affect flavor and can have antioxidant and antibacterial properties; (5) leavening agents, such as sodium bicarbonate and tartaric acid, which are used in tempura batters; and (6) gums such as xanthan, which effect the viscosity and water-holding capacity (Venugopal, 2006).

Consumer appeal and texture of a coating vary among the types of products such as red and white meat, fish and shellfish, and vegetables. Even within a group, such as fish and shellfish, the physical characteristics may vary depending on consumer preference within a market area. For example, corn breading might be preferred in the southern United States; flour coating would be used in the northeastern United States.

Flour in a dry batter mix constitutes approximately 80–90% of the total weight; in a breadening mixture, it normally ranges between 70% and 80%. Major flour sources include corn, rice, soy, and barley. Wheat flour differs from the others because it has the ability to form a cohesive mass when hydrated and subjected to mixing. There are also differences in the wheat flour depending on whether soft or hard wheat is used.

Several major characteristics or functional properties can be used to distinguish between breadings. These are as follows.

### Mesh

Breadings are cereal-based coatings consisting primarily of flours, starch, and seasonings. Particle size is the major factor affecting the appearance and texture of the coated food. Mesh size may be fine, medium, or coarse. If a fine mesh is used, the batter's ability to absorb liquid is increased. A coarse coating can result in a loosely adhering product that will fall off during handling or transportation. Consequently, breadings are chosen that represent a balance among different mesh sizes.

### Browning rate

The amount of sugars in the coating largely determines browning rate. A fast browning rate provides for high processing rates, which could permit

either the use of shorter frying times and/or lower temperatures. Using a shorter frying time and lower temperature reduces shrink, while faster processing increases efficiency and reduces labor and capital equipment expenditures. In some applications, reducing the sugar content and retarding the browning rate is desirable, particularly with large or thick foods that require long frying times. Consequently, the ability to vary browning rates permits the balancing of color, texture, and cooking time.

### Moisture and oil absorption

The rate at which a particular breading absorbs moisture and oil depends on several factors, including particle size and porosity. A coating with a porous structure will absorb and release moisture and frying oil faster than a denser product. There are various types of prepared breadings that are applied to battered foods to enhance their appearance or sensory qualities.

The trend toward healthy foods has increased consumer preference for lower fat products. Hence, significant research has been conducted on reducing fat content in fried foods by incorporating oil absorption barriers into batter formulations. The inclusion of hydrocolloids (Annapure et al., 1999; Sanz et al., 2004), methylcellulose, or hydroxypropyl methylcellulose (Albert and Mittal, 2002; Fiszman and Salvador, 2003) in batter systems has reduced oil uptake in coated fried products.

### Battered and breaded seafoods

Seafood accounts for approximately 50% of all frozen battered and breaded products in the United States. Precooked and raw fish portions are the most frequently coated products followed in order by specialty products such as shrimp, fish sticks, and scallops. Breadings have been long used in the seafood industry, but the application of batters did not come into prominence until the 1960s. In the mid-1960s, a relatively new concept called batter frying became prevalent within the seafood industry. In this process, the food is usually given a pre-dust with flour or dry batter mix, coated with a batter, and prefried to set the batter and impart the desired frying oil content for enhanced texture and quality. Batters can be either tempura (leavened)

or nonleavened. Production rates for batter-fried products are half that for a breaded product due to the space between products on the conveyor belt and additional time required for coating and draining. A process that eliminates the frying step for the manufacture of frozen, battered food products has been developed (Venugopal, 2006). In this process, a batter that incorporates methylcellulose is used, and instead of frying, the coated product is immersed in hot (70°C) water. After the water step, the product is further heated in a microwave oven for a short period, cooled, frozen, and packaged for storage at -18°C or below.

With the increase in popularity of ready-to-eat and microwavable products, one of the biggest challenges that limited the expanded consumption of battered products was the inability to produce a microwavable product that retained crispiness. Improvements in batter composition and preparation process have improved the crispiness of the microwave oven-cooked products (Venugopal, 2006).

Another problem associated with battered products has been the uneven distribution of coating on the product. In some instances, the batter fails to coat the entire product leaving large void areas. Also, the coating can be too heavy or so thin that it loses flakes or chips off.

### Quality assurance of battered and breaded seafood products

An effective quality assurance program should be initiated to ensure the production of high-quality battered and breaded food products. The program should include all incoming fish blocks and other frozen seafood products. Quality control examinations are important to ensure that the block adheres to purchase specifications such as block dimensions and weight, microbial counts, foreign matter, water content, additives, evidence of decomposition, or quality determination (freeze-thaw cycling), and species. Quality assurance is important because seemingly minor compositional properties, such as water, can have a direct effect on batter adhesion or cooking time. All quality assurance programs should include an examination of batter mixes, breading, and batter ingredients. The quality program should also extend to storage conditions

because experience has shown that products stored in a dry, cool environment produce higher quality batter coatings.

An important step in monitoring quality is proper batter mixing. Cold water increases batter adhesions; consequently, most processors maintain water temperature at 10°C or lower. The batter mix is hydrated by adding water either in a mixing bowl with a large whip or an automatic batter mixing machine. The batter should be mixed past the point where no unwanted lumps remain. In most cases, the batter will perform better if mixed for a longer, rather than shorter, period. If the batter is not properly mixed, it results in a partially hydrated batter with poor preparation characteristics, lumps, and gummy textures.

It is important to maintain temperature control of hydrated batter mixes in order to control the growth of pathogenic microorganisms, such as *Staphylococcus aureus*. A company may wish to establish a Critical Limit for time and temperature for hydrated batter mixes. For example, the temperature may not be allowed to exceed 50°C for more than 12 hours nor 21°C for more than 3 hours cumulative. The exact time and temperature limits for the batter mix should be established on the basis of available scientific data.

Batter viscosity should be monitored and closely regulated during production. There are several methods of measuring viscosity, and it is recommended that measurements be taken on the production line and in the laboratory. All adjustments to the batter should be made as soon as possible.

Prior to battering, seafood products are generally given a predusting to create a product surface that will increase batter adhesion. Salt has been used as an additive to increase adhesion because it melts the ice on the product surface and the resulting liquid can hydrate the product, thereby improving adhesion. It is sometimes appropriate to include taste and odor ingredients in the predusting. Their inclusion in the batter can affect product characteristics such as browning.

After predusting, the product is moved through the batter applicator on a conveyor belt. Batter applicators are usually of two types: (1) the product being coated is completely submerged in batter or (2) the batter is poured on in a continuous cascade. The amount of batter pickup is affected by several factors including line speed or degree of batter hydration. Incomplete coverage can be caused

by line speed, product shape, faulty or lack of pre-dusting material, and the degree of glazing on the product surface.

The final operation, prefrying, sets the batter coating and facilitates further processing. Prefrying produces a desirable color, provides a crunchy texture, and improves sensory characteristics. Proper prefrying depends on maintaining the desired frying oil temperature, ensuring that the oil is replaced or filtered as necessary and that frying time is properly maintained. Prefrying times of 30 seconds are usual.

After cooking, the product is usually frozen. Care should be exercised to ensure that the products do not cover each other or touch during frying, as this can cause the batter coating to be removed when the product is separated at packaging. All products should be frozen as quickly as possible to ensure that the coating adheres to the product.

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## Webliography



# 10

## Surimi and Fish Protein Isolate

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Jae W. Park

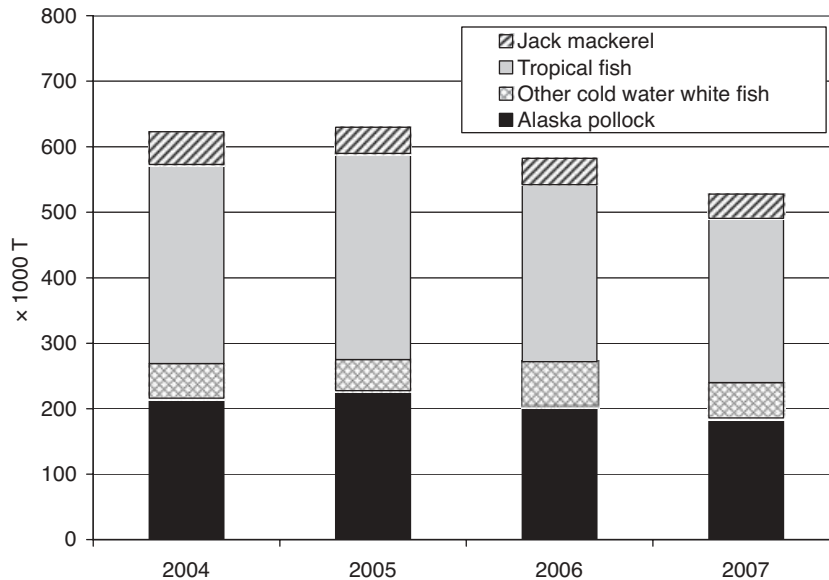
### Introduction

Surimi is a Japanese term for washed fish mince and has become a universal term for stabilized fish myofibrillar proteins. Myofibrillar proteins are refined and stabilized through various processing steps consisting of heading, gutting, mincing, washing, refining, dewatering, blending with cryoprotectants, freezing, and frozen storage. Modern surimi production was established after Nishiya et al. (1960), discovered a technique to prevent freeze denaturation of Alaskan pollock surimi with the addition of sugar along with sodium polyphosphate. Since then, surimi has been frozen and used as a raw material for kamaboko and other surimi-based products.

During the modern history of surimi for the last 50 years, several innovations were developed to utilize surimi as a functional, profitable, and sustainable ingredient. These include the discovery of cryoprotectants, efficiency improvement of heading and gutting machines, and the introduction of decanter technology. Cryoprotection improved the quality of surimi, while the other two made a significant contribution to increasing production yield. The production yield has improved from 13–15% in the early 1990s to 28–30% currently in 2007–2008.

Various species have been utilized in the production of surimi. Any species considered as a resource for surimi must meet the following three conditions. The species must be currently abundant, underutilized, and economically competitive. Obviously, Alaska pollock (*Theragra chalcogramma*) has been utilized as the primary fish source for a long time. Annual surimi production from Alaska pollock was as high as 300,000 tons. However, recently its production has been reduced significantly below 200,000 tons (Figure 10.1) due to various reasons. There is a great demand for pollock fillets from the European market due in part to the strength of the Euro. In addition, the landings of other species including tropical fish such as threadfin bream (*Nemipterus* spp.) have decreased since 2005. Global production of surimi was about 500,000 tons in 2007. It is expected to be below 500,000 tons in 2008 with a global demand of over 600,000 tons, which translates into year 2008 as a surimi crisis year with the price of FA grade pollock surimi approaching \$6.00/kg.

Fish protein isolate (FPI) is a new form of purified fish proteins that can be utilized as a replacement for surimi. Conventional surimi processing from white flesh fish utilizes typically 25–30% of the whole fish. A process for FPI using acid or alkali extraction



**Figure 10.1** Surimi production from major species.

followed by isoelectric precipitation provides extremely high yields (35–45%) with the inclusion of sarcoplasmic protein, and it also demonstrates better functional properties (Hultin and Kelleher, 2000).

### Manufacturing of surimi

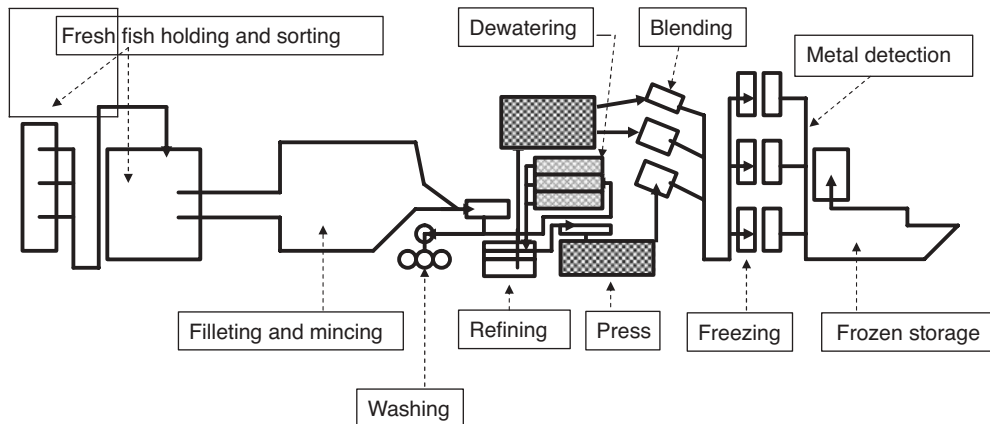
Surimi processing is a continuous process consisting of unloading/receiving/holding, sorting, heading, gutting, filleting, mincing, washing, dewatering, refining, screw pressing, blending with cryoprotectants, block forming, freezing, and frozen storage (Figure 10.2). Technically speaking, it is a refining process to isolate myofibrillar proteins by removing unnecessary components such as skin, bones, sarcoplasmic proteins, and fat. Detailed processing technology is well described by Park and Lin (2005).

There is a distinctive difference in the freshness of fish at the time of processing between warm-water fish and cold-water fish. About 40% of Alaskan pollock and Pacific whiting surimi is currently processed at sea by factory trawlers within 2–8 hours after harvest. Some are processed in prerigor, and others are processed soon after reaching postrigor on the vessel. Shore-side operators process fish,

which has been kept in champagne ice during transportation at sea, mostly within 24–72 hours. However, tropical fish in Thailand, India, Vietnam, and Southeast Asia are stored in ice and processed into surimi within 1–10 days after harvest. Some tropical fish are frozen at sea and processed at shore even a few weeks after harvest. Due to the extremely sensitive thermal stability of cold-water species, the manufacturing of surimi from frozen fish is impossible. The proteins from cold-water species are denatured easily. However, tropical fish, which are much less sensitive to temperature changes, can be processed into surimi of fair quality even using frozen fish. As fishing grounds are moving farther from the shore in Southeast Asia, it is not uncommon to see more frozen fish converted into surimi.

### Mincing/deboning

It is most common to use a roll-type meat separation technique for the mincing/deboning operation (Park and Lin, 2005). Dressed fish is pressed between a rubber belt and a steel drum with numerous orifices of 3–5 mm in diameter. With cold-water species like Alaska pollock (commonly 800–1000 g) or Pacific whiting (commonly 400–600 g), fish, headed and eviscerated in a butterfly shape, are subjected to the deboner instead of skinless or



**Figure 10.2** Flow chart for surimi manufacturing. (Adapted from Draves, 2008.)

skin-on fillets. This change made a significant impact on the production yield from 13–14% in the early 1990s to current yields of 28–30%. However, tropical fish, which are extremely small with a weight of 30–50 g, are headed and gutted manually before subjecting to the deboner.

During mincing, manufacturers need to prevent microbial and proteolytic enzyme contamination. Dressed fish must be free of microorganisms and free of internal organs like liver, intestines, and kidneys. Once dressed fish that is externally contaminated with microorganisms and/or guts is ground by the deboner, the microbial load and proteolytic enzymes cannot be reduced or removed regardless of how many times washing is repeated. Therefore, incoming raw materials to the deboner must be free of microorganisms and guts. If washing is desired, it must be done before deboning.

### Washing and dewatering

Washing is conducted primarily to remove sarcoplasmic proteins. Sarcoplasmic protein, one of three major muscle proteins, consists primarily of heme proteins, bad enzymes (trimethylamine oxide demethylase (TMAO demethylase) and proteolytic enzymes), and good enzyme [transglutaminase (TGase)]. These components, except TGase, must be removed rapidly during washing and dewatering. Washing will improve the whiteness and texture of surimi gels.

Heme proteins are responsible for the pigmentation of unleached mince. The iron-containing heme proteins of blood and red muscle cells are

hemoglobin and myoglobin, respectively. Denaturation of the heme proteins, before or during processing, can result in their binding to myofibrillar proteins and cause discoloration of surimi (Lanier et al., 2005). Once sarcoplasmic proteins are denatured, possibly due to oxidation and/or temperature abuse, it is extremely difficult to remove the red pigment from the myofibril. Therefore, washing the mince immediately after harvest would be more effective in removing discoloration.

According to US industry experts, the amount of water used in surimi processing is significantly different between surimi processors at sea and surimi processors on shore: perhaps 2–3 kg of water versus 8–10 kg water for the production of 1 kg surimi. In Southeast Asia where postharvest hours before the surimi production are longer, the water usage is even higher, often exceeding 15 kg. This indicates that fish freshness ultimately controls the effectiveness of washing.

An extensive study on water to meat ratio and washing conditions was conducted by Lin and Park (1996a). More proteins were washed and lost as washing time and/or washing cycles increased. Five to ten minutes of washing with a 2:1 water to meat ratio was recommended. However, the freshness of fish and postharvest time will also affect the result.

Unlike red meat from land animals, fish myofibrillar proteins were found to be salt-soluble as well as water-soluble. As washing is repeated, Lin and Park (1996a) observed a significant loss of myosin heavy chain (MHC). Stefansson and Hultin (1994) also demonstrated the solubility of cod myofibrillar

proteins in water. They proved almost all myofibrillar proteins can be dissolved if the ionic strength approaches near zero. This information indicates that extended washing times can result in a significantly reduced yield.

There has been a practice in the industry to use a small amount of salt or seawater during the first washing with the hope to increase washing efficiency and production flow. However, it is extremely important to realize the consequences of this practice. A partially damaged protein that is exposed to salt will likely undergo protein denaturation during long-term frozen storage rapidly, which will significantly reduce product quality.

## Refining

The refining process removes connective tissues, scales, and pin bones. According to Kim and Park (2005), the approximate composition of refiner discharge was 81.4% moisture, 1.9% lipid, 15.4% protein, and 1.0% ash. They also found the majority of protein in refiner discharge was stroma protein derived from connective tissue. The orifice size of the refiner is commonly 1.5–1.7 mm. Fast operation causes more impurities in the meat, while slow operation produces clean meat. Almost all surimi manufacturers have used a Fukoku refiner until the recent introduction of the Brown refiner (Covina, CA, USA). According to US industry experts, the Brown refiner is designed in a more user-friendly structure for cleaning and adjusting paddle height. However, the selection should be made after careful evaluation based on individual operation (Park and Lin, 2005).

## Screw pressing

The moisture content of meat increases from 82–85% to 90–92% as fish mince goes through repeated washing (Park and Lin, 2005). The mechanical screw drives the moisture from washed meat using its compounded structure. It is ideal to reduce the moisture content to 82–85% by controlling the speed of the screw press. However, it is not uncommon in today's production-driven operation to use a small amount of salt in the final wash water to improve water removal. Salt partially unfolds myofibrillar proteins and reduces the water-holding ability. However, this residual salt

will gradually deteriorate the myofibrillar proteins during frozen storage, resulting in poor gel texture.

In recent years, decanter technology has been utilized as a replacement to the conventional screw press (Park and Lin, 2005). Its application has been successful. However, special care is required if salt is used to facilitate the easy removal of water. Decanter technology has also been successfully used to recover insoluble meat particles from wash water, including screw press discharge water, by almost all surimi manufacturers with daily production at 20 tons or more. The use of a decanter is one of the major contributors to the significant increase of surimi production yield from 13–15% in the early 1990s to 28–30% in 2007–2008.

## Blending with cryoprotectants

The addition of cryoprotectants is important to ensure maximum functionality of frozen surimi because freezing induces protein denaturation and aggregation. Sucrose and sorbitol, alone or mixed at approximately 9% w/w to dewatered fish meat, serve as the primary cryoprotectants in the manufacturing of surimi. However, 6% sucrose alone is used in surimi manufactured from warm-water species, perhaps due to the higher thermal stability. In addition, a mixture (1:1) of sodium tripolyphosphate and tetrasodium pyrophosphate at 0.2–0.3% is commonly used as both a chelating agent, inactivating metal ions in the surimi, and as a pH-adjusting agent (Park and Lin, 2005).

Several types of blending methods are commercially used. Any method can be used to incorporate cryoprotectants as long as the blending principle is understood. Cryoprotectants have to be uniformly blended without raising the meat temperature, preferably 10°C for cold-water species.

## Freezing, metal detection, and frozen storage

Once washed meat is blended with cryoprotectants, fresh surimi will be formed into 10 kg blocks in a plastic bag (3–7 mL), which is then placed on a metal tray. The trays are placed in a contact freezer and held for 2.5 hours or longer until obtaining the target core temperature (typically –25°C). After inspecting the frozen blocks with a metal detector,

two 10-kg frozen surimi blocks are packed into a cardboard box. Once boxes are palletized, they should remain frozen during transportation and storage. Temperature fluctuation during storage and transportation must be avoided for longer shelf life.

Metal detection is a critical control point (CCP) for the surimi HACCP plan. FDA's Health Hazard Evaluation Board has supported regulatory action against product with metal fragments of 7–25 mm in length (FDA, 2001). Corrective actions shall be taken if metal inclusion occurs. Processors need to make sure that the unsafe product does not reach the consumer and must take corrective actions to address the cause of the deviation. However, FDA HACCP does not specify what metal detection control levels must be used. It is left to the discretion of the individual manufacturer. As for the limit of calibration, there is a different setting between shore-side and onboard operations, respectively. Because of continuous motion, onboard calibration is extremely difficult. In most US operations, metal calibration for shore-side operations is 2–3 mm for ferrous or nonferrous and 3–4 mm for stainless steel, while onboard operations use 3–4.5 mm for ferrous or nonferrous and 4.5–5 mm stainless steel. This limit is far below the FDA's action limit of 7 mm (Park and Lin, 2005).

### Factors affecting surimi quality

There are two broad factors affecting surimi quality. They are biological (intrinsic) and processing (extrinsic) factors. The biological factors are fish species, seasonality, sexual maturity, and freshness/rigor conditions. The processing factors are salinity, water quality, harvesting, onboard handling, and time/temperature control (Park and Lin, 2005).

A few species, like Pacific whiting and lizardfish, possess a significant amount of proteolytic enzymes. Washing is not effective to remove all proteolytic enzymes. Alaska pollock has been known as a fish that gives no proteolytic enzymes. However, recent studies by Kimura et al. (2002) and Noguchi (2001) reported that Alaska pollock is infested with microsporia, which induce gel softening upon slow heating. It is now true all species contain gel softening proteolytic enzymes although each to a different degree.

Time and temperature control is the most important factor in surimi manufacturing. Their importance is even more critical with cold-water species. Keeping the temperature near zero would be an ideal condition. Fish must be processed as fast as possible. Can warm water be used for surimi manufacturing of tropical fish? Even though tropical fish are not as sensitive to the temperature change as cold-water species, it is recommended to keep the temperature below 5°C.

Lin and Park (1996b) studied the effect of storage temperature on the degradation of MHC of Pacific whiting. More than 50% of MHC was degraded when fish was stored at 20°C for 20 hr. However, the degradation rate was reduced by half when the fish was kept at 0°C. This study clearly indicates that long-term storage of Pacific whiting, even at near zero degree temperatures, can have a negative effect on surimi quality and yield.

### Surimi gel preparation and measurement

A Codex Code for frozen surimi, under the guidelines of the FAO/WHO, was developed by the governments of Japan and the United States. Detailed methodology is listed by Park (2005). The value of surimi is primarily determined based on gel texture. However, gel preparation and analysis do not properly correspond to manufacturing of surimi-based products (hereafter surimi seafood). A discrepancy exists between slow cooking for gel preparation and fast cooking for crabstick production. Conventional sausage cooking in a 3-cm casing in a 90°C water bath, which is used by almost all surimi manufacturers and surimi buyers, results in extremely slow heat penetration. It takes 20 minutes or longer for the core temperature of the sausage to equilibrate to 90°C. During this slow cooking, proteolytic enzymes are exposed to their active temperature zone (40–60°C) for more than 5 minutes. As a result, surimi proteins are not able to develop firm texture due to degraded myofibrillar proteins.

Some enzyme-laden surimi like Pacific whiting and lizardfish form no gel when subjected to water bath cooking. However, they are successfully utilized in crabstick manufacturing where surimi paste is extruded in a thin sheet (1–2 mm thick) and cooked rapidly by reaching 90°C within 30–40 seconds. In this fast cooking, proteolytic enzymes do not have enough time to be activated at 40–60°C



before the temperature reaches 70°C or higher, which inactivates the enzyme and, therefore, protects the protein from enzyme degradation.

To overcome this discrepancy of gel results between the two cooking methods, North Carolina State University worked with Industrial Microwave Systems (Cary, NC, USA) to develop a microwave-driven fast cooking machine. In the meantime, Oregon State University developed a portable ohmic cooker. Accurate assessment of surimi quality is a short cut to maximize the value of surimi. Therefore, to determine surimi quality, surimi gels should be prepared using a rapid heating method provided by either microwave or ohmic cooking.

## Fish protein isolate

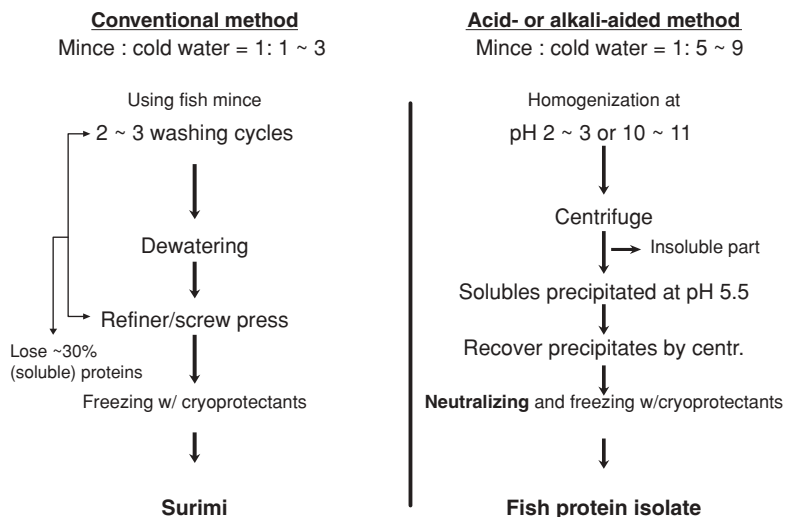
What is fish protein isolate?

The advantages of a process for isolating a high-quality human food from underutilized raw materials (dark muscle fish or frames left after filleting) are obvious. To upgrade products made from pelagic species and by-products would not only add economic value, but would be a more responsible use of an important resource (Hultin et al., 2005). This technology originated from the process of soy protein isolate or calcium caseinate. Dr. Hultin's pioneering work on fish (Hultin and Kelleher, 2000) created a National Sea Grant's col-

laborative regional research project with Dr. Park at Oregon State University and Dr. Lanier at NC State University in 2000–2002. The process consists of homogenizing fish tissue, extracting myofibrillar and sarcoplasmic proteins in acid ( $\text{pH} < 3.0$ ) or alkali ( $\text{pH} > 10.0$ ) before recovering at  $\text{pH} 5.5$  by centrifugation, and neutralizing before freezing with cryoprotectants (Figure 10.3).

Surimi processing and FPI processing have a distinctive difference in their processing chemistry. Conventional surimi processing avoids any possible denaturation to maintain protein quality. However, the FPI process induces chemical denaturation by adjusting the  $\text{pH}$  to an acid or alkali condition (Park, 2008).

Several groups in the United States have led numerous studies on functional FPI made from various species (Pacific whiting, herring, catfish, Pacific sardine, Atlantic croaker, tilapia, jack mackerel, menhaden, rockfish, trout, krill, and giant squid) (Park, 2008). Alkaline extraction appears to give better gelling functionality (Kim et al., 2003; Yongsawatdigul and Park, 2004; Kristinsson and Liang, 2006; Thawornchinsombut and Park, 2007; Chen and Jaczynski, 2007a). Slightly whiter color for alkali-extracted FPI gels was reported by Kim et al. (2003) with Pacific whiting, Kristinsson et al. (2005) with catfish, Chaijan et al. (2006) with sardines, and Perez-Mateos and Lanier (2006) with menhaden. However, acid-extracted FPI demonstrated slightly whiter gel when studied by



**Figure 10.3** Processing steps for conventional and pH shift methods.

Yongsawatdigul and Park (2004) with rockfish and Chen and Jaczynski (2007a, 2007b) with rainbow trout and krill. For gel color, there was no distinctive difference whether FPI was prepared through acid or alkali extraction. Therefore, color appears to be species dependent (Park, 2008).

Better lipid removal, lower oxidation during storage, and reduced proteolytic degradation are advantageous results from alkaline extraction (Undeland et al., 2002; Kristinsson and Liang, 2006; Chen and Jaczynski, 2007a, 2007b). However, recovery yield was even for the two methods. Interestingly, salt addition to FPI resulted in a negative effect on gel texture, indicating fish proteins were chemically unfolded during pH-driven extraction. Textural properties of acid- or alkali-extracted FPI decreased as NaCl increased, especially at 2–3% (Kim and Park, 2008).

The myofibrillar proteins in FPI were not extracted well when NaCl was added perhaps due to protein aggregation caused by acid or alkali extraction. FPI solubility was not closely related to their textural properties. ATPase activity is mostly lost during acid and alkali extraction, and the protein does not regain its native configuration as the pH is readjusted to 7.0–7.5 (Choi and Park, 2002; Kristinsson and Hultin, 2003, 2004). However, they also confirmed that a native configuration and ATPase activity are not prerequisites for the gelation of FPI.

### Superior gelling properties of FPI

Various research groups demonstrated superior gelling properties of alkali-extracted FPI. It was thought in general that improvements in functionality are directly linked to the extent of partial unfolding of myosin on alkali followed by refolding at neutral pH (Kristinsson and Hultin, 2003; Thawornchinsombut and Park, 2007). The change in pH could have led to conformational changes resulting in better charge distribution (Kristinsson and Hultin, 2004). They suggested that on acid unfolding, the myosin rod may fully dissociate due to electrostatic repulsion within the coiled-coil, while it does not dissociate at alkaline pH. Both pHs led to significant conformational changes in the globular head fraction of the MHCs, suggesting that it takes on a molten globular configuration.

A large part of the myosin light chains is lost during both pH treatments. On pH readjustment to neutrality, the heavy chains take on a structural form similar to the native state with the coiled-coil rod reassociating from acid pH while leaving the globular head less packed, more hydrophobic and structurally less stable. The irreversible change in the globular head region led to the failure of light chains to reassemble and resulted in a drastic loss in ATPase activity and more exposure of reactive thiol groups (Kristinsson and Hultin, 2004).

Sarcoplasmic proteins are removed in conventional surimi manufacturing to concentrate the content of myofibrillar proteins, while they are retained in the FPI process (Park, 2008). Do sarcoplasmic proteins enhance the gelling properties of FPI? Even though the removal of sarcoplasmic proteins would enhance the gelation properties of surimi (myofibrillar proteins), various studies confirmed that sarcoplasmic proteins positively contribute to the gelation of myofibrillar proteins (Morioka et al., 1992; Kim et al., 2005; Park and Park, 2007).

Sato and Tsuchiya (1992) observed stronger, more deformable meat gels correlated with more homogeneous dispersion of proteins when viewed by transmission electron microscope (TEM). Recently, Wright and Lanier (2008) reported that stronger, more deformable gels were made from alkali-extracted FPI, possibly due to more homogeneous dispersion as viewed by TEM.

### Future

Given the year 2008 crisis of surimi supply around the world, FPI made from various types of fish, including by-products, pelagic fish, or even frozen fish, could be an ultimate answer as a surimi replacement. Superior gelling properties of alkali-extracted FPI were probably due to a combined effect of better charge distribution through conformational changes, partial refolding at neutrality, homogeneous dispersion of myofibrillar proteins through mechanical homogenization, and retained sarcoplasmic proteins.

### Utilization of surimi and fish protein isolate

The history of surimi seafood started in Japan perhaps in the twelfth century (Nozaki, 2005).



unfortunately required to be labeled as imitation crabmeat. While the crabstick became popular in the United States, the consumption rate ceased to grow after the mid-1990s probably due to the negative image of the term “imitation.” Like the rest of the world, the US FDA finally approved the use of “crab-flavored seafood, made with surimi, a fully cooked fish protein” on November 20, 2006.

Detailed processing technology of crabstick production is well described by Park (2005). Processing steps generally consist of comminution, sheet extrusion, cooking, cooling, slitting, bundling, cutting, packaging, metal detection, pasteurization, chilling or freezing, and storage as described in Figure 10.4. Comminution is achieved to extract salt-soluble myofibrillar proteins while mixing with other ingredients. Depending on the species, optimum final chopping temperature must be applied: 0–5°C for cold-water species, 20–30°C for tropical species, and 10–15°C for temperate water species.

Surimi seafood paste is then extruded onto the stainless steel belt or drum at a thickness of 1.0–2.0 mm. As the sheet travels under gas and/or steam or on the heated drum, fish proteins are cooked, which sets the external texture. In most cases, color paste is also coextruded underneath the sheet and cooked simultaneously. The cooked sheet is slit for fiberization and bundled into a continuous rope. Once the rope is cut into flakes (with diagonal cut) or chunks (with straight cut), the product is vacuum-packed. The next step is metal detection. Its calibration limit is similar to that of frozen surimi explained earlier.

All vacuum-packed products are subjected to pasteurization. According to the FDA HACCP guideline (FDA, 2001), the product, if sold in a vacuum pack in a refrigerated condition, must be heated to at least 85°C for at least 15 minutes and its water phase salt concentration must be 2.4% or higher to control nonproteolytic *Clostridium botulinum* type B. In addition, a storage temperature less than 3.8°C is recommended. At the same time, FDA also allows the use of  $F_{90} = 10$  minutes. Detailed pasteurization control can be found at Su et al. (2005).

The use of FPI as a raw material for surimi seafood has not been explored on a commercial scale yet. Since its reaction to salt is different from conventional surimi, specific care is needed. Consequently, blending conventional surimi with FPI

would not be feasible. Further studies are definitely needed.

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# 11

## Waste (By-Product) Utilization

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The rise in world population and standard of living for developing countries, coupled with an increasing understanding of the health aspects of a diet rich in seafood products, increases the demand for seafood. At the same time, world fish landings remain flat or have slightly declined. The increasing demand for seafood is being met in part by aquacultured products, many of which require fish meal and/or fish oil in their feed formulation.

The production yield for whole raw seafood varies greatly and depends on how it is processed. The fish processing industry generally calculates yield based on a gutted fish with head on, which typically averages about 40%. Demand for ready-to-eat and other value-added products that require skinless, boneless fillets, further increases the percentage of landed fish weight designated as waste. Also, when harvesting fish and crustaceans, many species are inadvertently caught that are not processed for human consumption. This catch also represents “waste” and its utilization is often regulated. The increasing demand for seafood, coupled with decreasing natural supplies, increasing demand for fish meal and oil, and the understanding that biological waste must be properly treated to avoid environmental degradation all support the utilization of fish by-products. In fact, most

by-products are no longer regarded as waste but are considered raw material for further processing.

Sorting and handling of by-products can begin on board the fishing vessel for some species and often includes removal of heads and viscera. For others, whole fish are delivered to shore-side plants or mother ships where the by-products are handled as the fish are processed. The by-products available for further processing vary depending upon the primary process. For example, by-products from gutting, freezing fillets, salting, and canning all have different qualities and, hence, different potentials. Crapo et al. (1993) have estimated the amount of by-product produced from processing of many Pacific cold-water marine fish species. The composition of different by-products such as heads, frames, viscera, and skin differ greatly in their proximate composition and also the composition of the same by-product such as heads have been shown to differ between species (Bechtel, 2003b).

A comprehensive review of all utilization options for seafood waste is beyond the scope of this chapter. In fact, an entire book was recently published on the subject (Shahidi, 2007a). Numerous studies investigating possible by-product utilization options have also been published (Bechtel, 2003a). Ockerman and Hansen (2000) provide some

detail on processing the more important seafood by-products.

It is important to remember that technical feasibility does not necessarily translate to economic feasibility; hence, a seafood processor must carefully review by-product utilization options before committing to a specific process. Things that should be considered include the following: (1) handling and sorting systems on board fishing vessels and means to transport by-products from the vessel to the processing plant(s); (2) safe and cost-effective preservation methods; (3) volume and schedule of availability of the by-product; and (4) distance from processing site to market and associated transport costs (especially important for bulky, relatively low-value by-products such as fish silage).

## Human consumption

Edible products for human consumption represent a relatively high-valued by-product and, hence, deserve first consideration. Options for maximizing edible yield from fish include but are not limited to utilizing fish mince, tongues, cheeks, fins, fish heads, stomachs, skin, and roe/milt. Also, nutraceuticals show potential as a by-product from the fish industry.

### Mince

Considerable quantities of fish flesh typically remain after filleting. Several components of the by-product stream such as fillet trim, frames, tongues, and cheeks can be used to produce a human grade fish mince (Regenstein, 2004). Methods of separating and recovering this flesh are generally divided into mechanical and nonmechanical techniques. Nonmechanical methods, involving chemical and biochemical methods, tend to result not only in high yields but also in irreversible changes in protein functionality. Mechanical techniques involving bone separator technology offer a product (mince) that can be further processed into acceptable food products.

Fish-bone separators are well established and tend to rely on one of the following operational principles (Taylor et al., 2007): belt and drum, screw feed with perforated cylinder, or two concentric cylinders. There are advantages and disadvantages

to each system, including initial cost, maintenance requirements, and resulting shear damage on the fish flesh.

Recovered fish flesh (mince) is a high-quality nutritional product but there are disadvantages, including both aesthetic considerations and acceleration of the degradation of lipid and bacteriological quality. For mince from whitefish, mince color is a major factor in consumer acceptance; darkening and lack of color homogeneity reduce acceptance of mince. However, due to its nature, it is possible to mix mince with a wide range of foodstuffs to modify texture, flavor, appearance, and functionality, hence reducing the inherent disadvantages. Strategies for improving mince color include whitening with hydrogen peroxide, whitening with titanium dioxide, and masking the color through the addition of other ingredients such as curry or tomato flavoring (Taylor et al., 2007.).

Mince from more than one fish species can be combined and additional by-products and bioactive compounds can be added. For example, the National Fish Quality Center, St. Petersburg, Russia and the State University of Trade and Commerce Center, Russia have jointly developed methods to combine salmon by-products containing bone, such as heads and frames, with pollock mince. They reported the addition of bone increased the phosphorus and calcium content of the resulting food form (Mukhina, 2003). In another Russian study, specialists at the Moscow Plekhanov Institute of the National Economy used bone tissue along with vegetable fillers (carrot and cabbage at a rate of up to 30% of mince mass) to prepare food items from fish mince (Mukhina, 2003). Fish bones were softened using a controlled temperature and pH process. Based on mince properties such as water retention, viscosity, and flavor, they concluded that inclusion of bone tissue at a rate of 15% of the mince mass was optimum.

Protein powders can be made from by-products using processing and extractions techniques including enzymatic hydrolysis, pH extraction methods, and extraction of soluble protein fractions from heated materials (Sathivel and Bechtel, 2007). Most protein powders and specialized protein ingredients will be produced for human uses; however, there are some products such as insoluble protein fractions that can find uses as aquaculture, farm animal, and pet animal feed ingredients. Protein powders have been made from different fish

processing by-products by Sathivel et al. (2004), in a process that involved grinding, heating to denature enzymes and release lipids, sieving to remove bone and large tissue fragments, centrifugation to remove lipid, and drying of both the soluble and insoluble protein fractions. Another method of extracting and concentrating protein from by-products (e.g., heads, frames, etc.) involves using pH extraction and isoelectric precipitation (Underland et al., 2002; Kristinsson and Demir, 2003). In this process, the ground tissue is mixed with water and the pH adjusted to an alkaline or acid pH to solubilize the protein. Bone and other unsolubilized materials are removed by centrifugation and then the pH is adjusted to 5.5, to precipitate the protein, which is collected by centrifugation. The protein can be used directly and has many desirable functional properties, and can be dried or milled.

## Roe

There is a high demand for roe, and hence it is almost always recovered and marketed (Bledsoe et al., 2003). For example, Arason (2003a) reported that roe represented only 6% of the quantity of groundfish by-products exported from Iceland in 2001; however, it commanded 26% of the export value. Likewise, Crapo and Bechtel (2003) indicate that roe from Alaskan pollock and cod and salmon are highly valued and hence saved, not discarded.

## Fish heads

Fish heads contain relatively little meat, but due to texture and flavor, this meat is considered a delicacy. For example, fish tongues and cheeks are sought after in many countries; hence, opportunities for their marketing exist. Mechanical automation of the process of removing cheeks, tongues, and upper head meat from fish heads greatly reduces labor requirements (Arason, 2003a). In Iceland, heads have been dried for export (Arason, 2003b) and in Alaska, some cod heads, often with gills removed, are frozen for export.

## Pharmaceutical nutraceuticals and other products

Shahidi (2003) defines nutraceuticals as “ingredients or extracts with clinically proven health

promoting activity, including disease prevention and treatment.” Nutraceuticals may be delivered as supplements or as functional food ingredients and include highly unsaturated long-chain omega-3 fatty acids, derived from livers of lean whitefish and flesh of fatty fish, and chitinous materials, carotenoids, and biopeptides derived from by-products of crustaceans.

Omega-3 fatty acids have received a great deal of attention for their health benefits and are discussed elsewhere. For therapeutic purposes, they are generally concentrated and Shahidi (2003) discusses various concentration options. In addition to omega-3 fatty acids, there are a range of structured lipids available in fish by-products that have been reported to affect metabolic parameters such as immune function, nitrogen balance, and lipid clearance from the bloodstream. Kerry and Murphy (2007) provide a detailed discussion of the physical and chemical properties of lipid by-products from seafood waste.

Marine by-products are sources for a number of marine enzymes (Haard, 1992), agrochemical agents (Peng et al., 2003), vitamins A and D, and other bioactive substances (Ohshima, 1998). Losso (2007) describes many bioactive compounds found in marine animals that have been studied and found potentially useful in human medicine. He cites examples including squalamine, collagen, and elastin, among others. Squalamine is an aminosterol present in the liver, gallbladder, intestine, testes, and stomach of dogfish shark (*Squalus acanthias*).

Collagen and elastin are components of fish skin. Nagai and Suzuki (2000) have extracted and characterized collagen from different species of fish skin and by-product. Potential uses of collagen extracted from fish skin and bone are in cosmetic, medical, and pharmaceutical products. Applications of collagen that Losso (2007) describes include treatment of urinary incontinence, pain associated with osteoarthritis, cartilage engineering to repair joint cartilage defects, and other implants in humans. Commercial elastin applications included medical treatments and applications in skin and hair care products (Losso, 2007).

Johnson et al. (2003) suggests that new markets for fish bone meal will likely involve products for human consumption. They offer several examples of the use of fish bone meal as a calcium supplement by blending it into products such as entrees

in school lunches, confectionary and candies, and in baby foods.

### **Aquacultural, agricultural, and bulk food uses**

Seafood processing by-products have many uses in the aquacultural and agricultural sectors. The majority of by-products from shore-side fish-processing operations are used to make fish meal and fish oil. Primary uses of fish meals and oils are as feed ingredients for fish and shrimp, livestock, poultry, and pet feeds. Chapter 27 is dedicated to a discussion of fish meal and fish oil production and, therefore, that topic will not be covered further here. Fish oils from cold-water species are especially rich in long-chain omega-3 fatty acids that are required as essential nutrients in marine and freshwater aquaculture diets (Sargent and Tacon, 1999). However, the production of hydrolysates and silages from fish processing by-products will be discussed. Additional agricultural uses for fish processing by-products include use as a fertilizer and as an organic soil amendment (compost).

#### **Fish hydrolysates**

An alternative to making fish meal from seafood processing wastes is to make fish hydrolysates (Raa and Gildberg, 1982; Hardy, 1992; Kristinsson and Rasco, 2000; Sathivel et al., 2003). Hydrolysates are often of lower nutritional value as feed ingredients than equivalent whole protein fish meal products (Stone and Hardy, 1986, 1988); however, the high digestibility of protein hydrolysates can be of importance in diet formulation for very young animals with immature digestive systems. Hydrolysates are potentially valuable aquaculture feed ingredients as sources of amino acids, as feed binding agents, and for their attractant and palatability properties (Lieske and Konrad, 1994). Hydrolysates have also been reported to stimulate an immune response in fry (Gildberg and Mikkelsen, 1998). Protein hydrolysates are commercially produced for use in animal milk replacers and as animal feed and pet food ingredients that have unique palatability and functional properties.

Fish hydrolysates are made by proteolytic digestion of the fish wastes. After proteolytic digestion, bones, undigested solids and often oil are separated from the hydrolysate. The liquid hydrolysates are usually concentrated and sometimes dried. Liquid hydrolysates can be stabilized by acidification to reduce microbial growth, and oxidation can be retarded by adding an antioxidant. During the drying or concentration process, protein hydrolysates become very viscous and difficult to dry completely. One solution has been to mix hydrolysates with dry ingredients (often, plant materials) and then co-dry the mixture. There are three basic methods of producing hydrolyzed fish wastes: addition of acids or bases to produce silage (Goldhor and Regenstein, 1991), addition of proteolytic enzymes, and the use of microbial fermentations (Dapkevicius, 1998).

#### **Fertilizer and compost**

Seafood wastes contain valuable plant nutrients including nitrogen, and have been used as plant fertilizers. However, unprocessed fish waste can be difficult to handle, rapidly decomposes, and can produce odoriferous nitrogen compounds. It is common for fish by-products to be stabilized for use as plant fertilizers, either through hydrolysis, acid conversion to fish silage, or composting (Goldhor and Regenstein, 1991).

Composting offers a relatively low technology, low-cost alternative for stabilizing fish by-products. Composting involves the manipulation or control of the natural decomposition of organic matter (Christian et al., 1997) by providing an environment in which the mixed populations of microorganisms (mainly bacteria, fungi, and actinomycetes) responsible for the decomposition can thrive. During decomposition, the microorganisms multiply, consume oxygen, and release carbon dioxide, water, organic by-products, and heat. The decomposition organisms require an optimum ratio of carbon (C) to nitrogen (N) to provide both a balance of energy-generating C and microbial cell-building N constituents. A ratio between 25:1 and 35:1 C:N is generally recommended. Seafood processing wastes typically have a much lower C:N ratio, and hence, a material high in carbon must be added. Particle size and moisture content are also important parameters in the composting process. Proper selection of an additive or bulking agent

can help satisfy the C:N ratio requirement as well as particle size and moisture considerations. Because the microorganisms consume oxygen in the decomposition process, it is also critical that some means of aeration be provided. Martin (2007) provides a detailed discussion of composting options for seafood wastes. Composting seafood wastes according to US national standards for organic materials such that the product could be certified for use in organic vegetable production would maximize the compost value.

Mukhina (2003) describes a composting project in which seafood processing waste is mixed with pulp-and-paper and woodworking by-products. The resulting product was tested and found to contain a full range of nutrients necessary for plant growth. Mukhina (2003) concludes that the resulting compost "is a good soil builder, reduces soil acidity, enhances water-holding capacity at the level of roots, and stimulates soil bacteria activity including potential oil destroyers (and, hence, can be used in bioremediation activities in areas with oil-polluted soils)."

Another possible by-product that could be marketed as a plant fertilizer is fish bone meal, which is separated from fish meal after processing. Bone meal is high in phosphorus and is currently being sold in the United States to organic farmers and individual gardeners. Johnson et al. (2003) point out that, in addition to phosphorus, fish bone meal also contains significant levels of secondary macro- and micronutrients necessary for plant growth. A recent laboratory study has evaluated nutrient release from bone meal and hydrolysate made from fish processing by-products for use as fertilizers (Zhang et al., 2007).

## Nonnutritional uses

A number of uses for seafood by-products have been identified that do not fall in the food, feed, or fertilizer categories including production of biodiesel, various uses for chitin and chitosan extracted from crustacean shells, carotenoid pigments, leather, pharmaceutical and cosmetic products. An interesting use of fish processing by-product has been as a component of a starch/pulp-fiber-based packaging foam and cast film (Imam et al., 2008). Biodegradable packaging materials containing fish mineral and protein

by-product materials may eventually find uses in industrial packaging materials.

## Biodiesel and fuel

Fish oil extracted from fish processing by-products has been used for many years as boiler fuel depending on fish oil markets and the local price of diesel. Steigers (2003) describes a demonstration project to evaluate the use of Alaska produced fish oil as a supplemental fuel for a specific diesel-fueled engine generator set. No increased engine wear was reported when running with a 50/50 blend of low sulfur no. 2 diesel fuel and fish oil. It was noted that exhaust gas emissions of CO, particulate matter (PM), and SO<sub>2</sub> decreased significantly as fish oil content was increased; however, these decreases were offset with an increase in nitrogen oxide (NO<sub>x</sub>) emissions.

Zang and El-Mashad (2007) have evaluated producing biodiesel directly from fish oil. These processes reduce the viscosity of the fish oil so that it can be combusted directly in engines without causing typical engine problems such as choking of fuel injectors and buildup of carbon deposits in the combustion chamber. Chiou et al. (2008) has evaluated biodiesel made from oil extracted from salmon by-products.

## Chitin and chitosan

Chitin is a major component of the exoskeleton of crustaceans and is the second most abundant natural polymer on Earth, exceeded only by cellulose. Chitosan, which is also abundant in nature, is obtained by alkaline or enzymatic deacetylation of chitin. A wide range of uses and proposed uses for both chitin and chitosan have been identified. Shahidi (2007b) offers the following broad areas of application: antimicrobial agent, edible film, food additive, nutrition, water treatment, agriculture, cosmetics, and biomedical and pharmaceutical materials. Ockerman and Hansen (2000) suggest uses for chitin including paper and textile additives and finishes; food wrapping film and specialty filaments; absorbents for metal ions; cements for leather; drilling muds; photographic products; coagulants useful for flocculating suspensions and wound healing compounds. And



for chitosan, potential uses included Ockerman and Hansen's (2000) coagulation of food processing waste for uses in feeds; dewatering of sludge; water purification; ion exchange; chelating solids for chromatography; tough, flexible films; wound healing promotion; adhesives; and ion exchange membranes.

## Carotenoid pigments

Simpson (2007) provides a detailed discussion of pigments from by-products of seafood processing. This discussion on carotenoid pigments is extracted from that document. Carotenoid pigments are responsible for the red, orange, and yellow coloration of flesh and skins of species such as salmonids and the exoskeletons of crustacean such as shrimp and lobster. While salmonids and crustaceans require carotenoids for many functions, they are incapable of synthesizing them; they must be ingested through diet. Plants, bacteria, and microalgae are capable of synthesizing carotenoids and provide a source for animals in the wild. Consumers tend to associate color with food quality, and hence, carotenoids are routinely incorporated into the diet of farm-raised salmonids. The vast majority of the carotenoid pigments used in aquacultural diets are synthetic. Because of increasing consumer demand for products without synthetic additives, fish farmers have incentive to use carotenoids from natural sources.

Simpson (2007) also notes that one method for imparting carotenoid pigments to salmonids is to include crustacean offal in the diet formulation. The offal can be fed directly (either fresh or frozen), processed into meals before inclusion in the feed ration, or acid ensiled. It is also possible to strip the carotenoid pigments from the crustacean offal with soy oil or by coextraction as pigment-protein (carotenoprotein) complexes.

## Leather and gelatin

Ockerman and Hansen (2000) report that the same techniques that are used to convert land animal hide to leather can be applied to aquatic animals. The major differences include the external covering that must be removed (hair vs. scales) and the generally smaller size of aquatic animals. Leather from

fish species has many desirable properties including being smooth, flexible, fine textured, durable, strong, long wearing, and nonscuffing. Leather from aquatic animals may have a hard time competing economically with synthetics and leather from land animals.

There are markets for food-grade gelatins extracted from fish skin. Gelatin has been extracted from fish skin by Choi and Regenstein (2000) and many others. Fish skin gelatins melt at lower temperatures than those extracted from porcine and bovine skin or bone. Fish gelatin can also be used to make edible films, and Avena-Bustillos et al. (2006) found that films made from fish skin gelatin have more desirable water vapor permeability properties when compared to films made from other types of gelatin. Properties of films made from fish skin gelatin can be altered by cross-linking of the gelatin prior to casting the film (Chiou et al., 2006), and antimicrobial agents can be incorporated into fish gelatin films (Bower et al., 2006).

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# 12

## Processing Mollusks

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Nearly all mollusks are processed prior to use. Processing may vary from boxing bivalves for the live market to further processing including frozen, canned, and pickled products.

The industry depends on natural stocks that fluctuate from year to year. The varying supply often causes processors to be reluctant to expand their operations, to adopt new technology, or to make major investments in new product development. The processing of mollusks tends to be labor intensive with relatively little mechanization. Processing of mollusks is done for several reasons: to convert the raw material to a more desirable form, to preserve the products, to maintain quality, to fully utilize the raw product, and to assure safety. Mollusks such as clams and oysters are shucked to provide a usable market form. Molluscan shellfish are smoked, frozen, or canned to prolong shelf life and stabilize quality.

### Processing for the live market

Bivalve mollusks, including oysters, mussels, and clams, are often presented to the consumer in the live state; however, they are also processed for the

live market. Bivalves can survive out of water for extended periods, which allows them to go through the processing chain.

Temperature control is the most critical factor for providing a good product, yet few harvesting boats provide refrigerated storage. Soft-shell clams are harvested primarily during the warm summer months. Though oysters and clams are mostly harvested during the winter and the spring, some are harvested in the summer. On-deck temperatures in the summer often exceed 30°C (86°F), which can reduce product quality and permit the growth of pathogenic bacteria. Of primary concern are species of the *Vibrio* genus, including *Vibrio vulnificus*, *Vibrio parahaemolyticus*, and *Vibrio cholerae*. For optimum quality and shelf life, bivalves should be cooled and stored at temperatures less than 10°C (50°F).

Processing shellfish for the live market is usually limited to washing, sorting, and packing. Oysters are often received as clusters or clumps covered with mud. Because single oysters are desired for the half-shell market, the clusters are broken into singles manually and the shell debris is discarded. Once the oysters are broken apart, they are often sorted by size; a medium-size oyster is preferred for the half-shell market. Some restaurants prefer the outside shell to be relatively free of mud, although

the mud serves to keep the oyster moist and tends to keep the oyster alive longer. A variety of washing methods, from hand scrubbing to mechanical pressurized washing, can be used to clean the shellstock. Simply hosing down a pile of oysters rarely provides effective cleaning. Once the oysters are sorted and washed, they are boxed and shipped to market.

Hard clams (*Mercenaria mercenaria*) are often sold in the shell by size, with smaller clams being higher priced. The clams are sorted either manually or mechanically, and then washed and boxed for shipment. The Manila clam (*Tapes philippinarum*) is handled in a manner similar to the *Mercenaria* clam. The soft-shell clam (*Mya arenaria*) is also washed and boxed before sale. The clams are often placed in clean water for a short time to remove grit and sand from the intestinal area.

Mussels destined to be sold live are processed by removing the beard. Live mussels sell very well along the eastern seaboard and to a lesser extent along the Pacific coast. Mussels represent one of the best opportunities for seafood market development, as the product is inexpensive and plentiful thanks to aquaculture techniques.

Wet storage of bivalves is limited but may be practiced more in the future. Requirements for wet storage are similar to those for depuration and are covered in Chapter 15 of the Guide for the Control of Molluscan Shellfish, National Shellfish Safety Program. Wet storage can be used to prolong shelf life and improve taste. For example, “salty” oysters are preferred for the half-shell market, but much of the available shellstock is harvested from low-salinity waters. Oysters are osmoconformers (their internal salt content reflects that of the surrounding water), so when shellstock is placed into higher salinity water, their salt content quickly changes to match that of the environment.

## Processing for the fresh market

Mollusks are processed for the fresh market in a variety of ways, from shucking of bivalves to cleaning of squid. Most processing is done manually. Mechanical means of shucking bivalves are used, but products of mechanical shucking most often are further processed.

## Bivalves

Shucking is the process of separating the meat of bivalves from their shell. Those destined for the fresh market are usually shucked by hand, a labor-intensive job requiring considerable skill. Each bivalve requires a slightly different method of shucking, and methods can vary from one region to another. For example, the most common way to shuck oysters is to insert the shucking knife through the lip or bill of the oyster, cut the abductor muscle, and remove the body from the shell. However, in some areas, oysters are opened by “popping the hinge,” in which the knife is inserted between the hinge of the oyster and twisted to break it apart. In general, the first method gives a better product, and a number of variations of this method are used commercially.

As oysters are removed from the shell, they are sorted by size. Eastern oysters (*Crassostrea virginica*) are normally packed according to the number of meats per gallon: very small have over 500 meats; small or standard have 301–500; select or medium, 211–300; extra select or large, 160–210; and counts of extra large less than 160. Price normally increases with size.

After shucking, the meats are washed and packed. Washing is often done by blowing, a process in which air is pumped into the bottom of a tank to agitate the oyster meats. Grit and shell particles settle to the bottom. After 10–15 minutes, the air is shut off and water is added and allowed to overflow the tank. When the water is clear, the oysters are removed and packaged. Oysters have a standard of identity that requires that they not be exposed to water for more than 30 minutes or be blown for more than 15 minutes, and the oysters must be packed dry. After packing, they tend to lose liquid, which is called free liquor. The amount of free liquor depends on the season of harvest, the condition of the oyster, and geographic location of harvest. Oysters may lose 30% of their weight as free liquor, although losses of 5–15% are more the norm. Because of the large variation in free liquor, many firms purchase oysters by the pound after the liquor is removed from the container.

Until the mid-1980s, the Eastern oyster dominated the fresh oyster market; however, in recent years, *Crassostrea gigas* has increased its market share significantly, even in the East and Gulf Coast areas. *C. gigas* tends to be large. Their appearance is



somewhat different than that of the Eastern oyster. They tend to be larger, whiter, and often have a dark area around the gills. Also, the liquor in the containers is often cloudy, which is considered a defect in packs of *C. virginica* but is normal for packs of *C. gigas*.

More than 22 species of clams are listed by the US Food and Drug Administration (FDA) as being harvested commercially or recreationally. Only five of these species are of commercial importance: the hard clam (*M. mercenaria*), the surf clam (*Spisula solidissima*), the ocean quahog (*Arctica islandica*), the soft-shell clam (*M. arenaria*), and the geoduck (*Panope generosa*). These five species account for 99% of the commercial catch.

Most clams are shucked by hand. The hard clam is held in the palm of the hand with the shell hinge against the palm. A strong, slender knife is inserted between the halves and the shell is pried open, the abductor muscles cut, and the meat removed from the shell. Most hard clams that are shucked are large and destined to be minced for clam chowder. Other clams are also shucked by hand. Clams are washed, sometimes by blowing as described for oysters, packaged, and sold.

Geoduck clams are often very large, averaging 1.36 kg (3 lb), but can go up to 6.8 kg (15 lb). The geoduck is mostly neck, and the meat yield is about half the original weight.

Surf clams, ocean quahogs, and occasionally large hard clams are shucked mechanically. The clams are either placed on a flat conveyor belt and passed through an open gas flame or are steamed at high temperature in pressure vessels. The heating, which often partially cooks the meat, greatly weakens the muscle-shell bond, and the meat is removed from the shell by tumbling. The meat and shells are separated in a brine tank.

Currently, in the United States, there are four commercially important species of scallops: the sea scallop (*Placopecten megellanicus*), the bay scallop (*Aequipecten irradians*), the calico scallop (*Argopecten gibbus*), and the Pacific sea or weathervane scallop (*Patinopecten caurinus*). In the United States, only the abductor muscle is consumed, but Europeans consume the entire scallop. There is also demand for the abductor muscle with the roe attached.

Sea scallops usually are processed onboard ship, and the hand shucking process is similar to that for oysters. The soft-body parts are removed leaving only the eye or abductor muscle. In some cases,

sea scallops destined for export to European markets are processed so that the roe (gonads) remain attached to the eye. In Europe, the roe are esteemed as a delicacy and are even more desirable than the eye. The meat's color may range from white to gray or bluish, and even a slight yellowish or pinkish color is not uncommon. The meat is packed into bags and stored in ice. Many scallops are soaked in a solution containing sodium phosphate that increases their water content. Currently, there is no reliable analytical method to determine whether scallops have been treated with a phosphate solution. Some firms have established purchasing standards for moisture content.

Bay and calico scallops usually are shucked on land. Their small size makes them uneconomical to shuck by hand on ships, although they are often shucked by hand on shore.

Scallops are also shucked mechanically. Machines that use a shock-heat-shock method have been used on ships, although currently most are used ashore. In this process, the scallops are passed through a sorter to remove trash and then are fed into a tank of hot water 80–100°C (176–212°F) or through a steam tunnel by rollers that grip the shells and sling them against a steel baffle. They are removed by conveyor and undergo a second shock-heat-shock treatment. Then they are dropped onto a vibrating screen that separates the meat and viscera from the shells. The animal then goes to an eviscerator that grips and pulls the viscera from the meat. The meat is then washed or it may be placed in a brine tank to remove shell fragments. The meats are then inspected and washed. There are, of course, many variations in these procedures.

## Gastropods

Two species of abalone (*Haliotis rufescens* and *Haliotis corrugata*) are harvested and processed commercially. Most often, they are sold fresh. The foot of the abalone is the only part consumed by humans. The muscle is very tough and usually must be tenderized.

The Queen conch (*Strombus gigas*), generally harvested from the Central American waters, is usually cut from the shell on board and then taken to a processing facility. Conch is processed by knocking an elongated hole in the spire; a razor-sharp blade is used to cut the animal free from its shell.

The viscera and other soft parts are removed from the foot and the tough dark skin is removed. The marketable meat yield is about half the total in-shell weight. Ocean conch imported in the United States is frozen. Most conch processed in the United States is actually whelk, a distant relative. Two species are important: the knobbed whelk (*Busycon carica*) and the channeled whelk (*Busycon canaliculatum*). Most are steamed in retorts and sold as precooked meats, although some are available raw. Another species, the waved whelk (*Buccinum undatum*), is found from New England to northern Europe, achieving most of its commercial importance in the United Kingdom.

Cephalopods are often sold as is for the fresh market or with minimal processing. The popularity of cephalopods is increasing in the United States but is far more popular in Europe and Asia. Squid is the most common cephalopod in US markets. The yield is very high, with 80% of the animal potentially consumable.

Squid are cleaned by first removing the intestines, which come out when the head is pulled free. The pen (a remnant of a shell) is removed next, the mantle is then skinned, and the tentacles cut from the head. This process is done completely by hand and is labor intensive.

Cuttlefish are cleaned in a manner similar to squid. Octopus is processed for the fresh or frozen market by simply inverting the head and removing the intestines.

## Further processing

### Batter and breading operations

Many molluscan products are sold battered and/or breaded. Coating seafood with batter and/or breading before cooking is a common practice of home-makers, food processors, and commercial food service establishments. Commercial batter and breading of seafood, including mollusks, followed by freezing offers a widely valued convenience to consumers. The United States is the world's largest consumer of breaded seafood products. Breaded mollusks such as oysters and scallops tend to cater mostly to luxury consumer markets or to the restaurant trade.

Batters and breading enhance product appearance and taste characteristics, including a more

desired texture, color, and flavor. They also act as a moisture barrier, holding in the natural juices, thus often making the product more tender.

In general, a batter refers to a liquid mixture of water, flour, starch, and seasoning into which seafood products are dipped. Breading is defined as a dry mixture of flour, starch, and coarse seasoning that is applied to moistened and battered products before cooking.

Examples of battered and breaded products, which are usually sold frozen, are scallops, oysters, clam strips, clam cakes, and squid rings. The mollusks are prepared as described for fresh seafood. Refer to Chapter 9 for a more detailed discussion of batter and breading operations.

### Freezing

Frozen molluscan products available commercially include most of the types described for the fresh market as well as battered and/or breaded products. In many cases, freezing is a normal part of processing; nearly all commercial battered and breaded products are frozen. Whelk and conch are primarily available as frozen products. However, some mollusks freeze better than others, and the frozen storage life will vary with species. Other important considerations include packaging, rate of freezing, and storage temperature. In general, oxygen impermeable packing is best. Also, the faster the freezing rate and the lower the storage temperature, the better the product. It is important that the product to be frozen is of good quality. Quality deteriorates during frozen storage, thus freezing should **never be** used as a means of salvaging product near the end of its fresh shelf life.

### Oysters

Most shucked oysters are sold fresh, but many food service establishments prefer frozen oysters because they provide ease of storage and a constant supply. Oysters change composition, especially after spawning in the summer, which affects yields. Also, demand patterns are such that shortages often occur during Thanksgiving and Christmas holidays. Although it affects oyster appearance and quality, freezing can provide an adequate supply of good quality oysters year round.

The free liquor content of previously frozen oysters may be as high as 20–30%; therefore, the yield is less. Freezing may also cause the oyster to darken. The amount of darkening depends on the freezing rate. Slow freezing greatly increases both darkening and free liquor content. Oysters should not be frozen in 3.78 L (1 gal) metal cans because the freezing rate is slow and metal ions may accelerate darkening. It is better to freeze them in oxygen-impermeable bags, which are laid flat to increase surface area. Both Eastern oysters and Western oysters may be frozen for at least 10 months and maintain acceptable quality.

Freezing oysters is not only an effective method of preservation but also capable of reducing the presence of *Vibrio* spp. bacteria. The survival of *Vibrio* spp. bacteria is dependent upon both frozen time and temperature. A long-term study (4–6 months) of half-shell Gulf of Mexico oysters (*C. virginica*) at  $-20^{\circ}\text{C}$  ( $-4^{\circ}\text{F}$ ) showed reduction of low levels of *V. vulnificus* ( $<10^3$  cell/g of oyster) in oysters to undetectable levels.

Pacific oysters (*C. gigas*) containing approximately  $3.5 \times 10^5$  MPN were flash-frozen ( $-95.5^{\circ}\text{C}$  ( $-139^{\circ}\text{F}$ )) and stored at  $-10^{\circ}\text{C}$ ,  $-20^{\circ}\text{C}$ , and  $-30^{\circ}\text{C}$  ( $14^{\circ}\text{F}$ ,  $-4^{\circ}\text{F}$ , and  $-22^{\circ}\text{F}$ ) for 6 months. Storing oysters at  $-10^{\circ}\text{C}$  was more effective for inactivating *V. parahaemolyticus* than storing at  $-20^{\circ}\text{C}$  or  $-30^{\circ}\text{C}$ . Populations of *V. parahaemolyticus* in the oysters declined by 2.45, 1.71, and 1.45 log MPN/g after 1 month of storage at  $-10^{\circ}\text{C}$ ,  $-20^{\circ}\text{C}$ , and  $-30^{\circ}\text{C}$ , respectively, and continued to decline during storage. The levels of bacteria were further reduced by 4.55, 4.13, and 2.53 log/MPN/g after 6 months of storage at  $-10^{\circ}\text{C}$ ,  $-20^{\circ}\text{C}$ , and  $-30^{\circ}\text{C}$ , respectively. These results provided postharvest processing (PHP) validation-verification that a process of flash freezing, followed by storage at  $-21^{\circ}\text{C} \pm 2$  ( $5.8^{\circ}\text{F} \pm 3.6^{\circ}\text{F}$ ) for 5 months, is capable of achieving greater than a 3.52 log (MPN/g) reduction of *V. parahaemolyticus* in Pacific oysters (Liu et al., 2009).

## Clams

Only a small part of the total clam harvest, mostly clams going to the chowder market and for further processing, is frozen, and frozen storage is limited to 4–6 months at  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ) because of rancidity and toughening. As with oysters, the packaging, freezing rate, and storage temperature affect quality.

Surf clams, ocean quahog, and large hard clams are often frozen after mechanical shucking. After the clams are removed from the shell, the viscera are removed. The meats are then washed and cut or diced for packaging and freezing. Previously, this industry used mostly surf clams, but species management practices have caused many plants to process ocean quahogs also and, more rarely, the hard clam.

## Scallops

Scallops, especially breaded scallops, are often sold frozen. Scallops, which also are frozen without breading, have a frozen shelf life of about 12 months at  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ).

## Conch and whelk

Almost all conch and whelk meat is frozen, especially the Queen Conch. Once processed, it is frozen in 2.3–4.5 kg (5–10 lb) bags.

## Abalone

As mentioned earlier, only the foot of the abalone is consumed. In preparation for freezing, the muscle is sliced across the grain into 1.27 cm (0.5 in.) steaks. The critical part in the process is the tenderizing step. The steak slices are put on a table and allowed to relax, then hit just once with a wooden mallet. Most of the abalone meat is consumed in California, where state regulations prohibit it from being shipped beyond state boundaries. Abalone is found in other countries, including Korea and South Africa, and products from these nations occasionally find their way to American markets.

## Canning

Many species of molluscan shellfish are canned throughout the world. In the United States, clams and oysters are the most important canned molluscan shellfish. Other canned species include mussels, cockles, squid, scallops, snails, and abalone.

## Oysters

Various standards for canned oysters are covered by the US FDA standards of identity, which include

standards of fill container and require a drain weight of at least 59% of capacity. The volume of oysters canned is small compared to the quantity sold fresh, but they are still a popular item and can be found in most supermarkets.

Oysters for canning may be shucked either mechanically or by hand. For mechanical shucking, the oysters are first washed, often with high pressure, to remove mud and debris. After washing, they enter a steam tunnel or retort. The best results are obtained by using a preheated stage followed by a short cooking at high temperatures and pressure in special retorts. This process causes the hinge material to degrade, thus causing the shell to gap wider. Once the oysters are steamed, they are conveyed to shucking units where the meats are separated from the shells. Mechanical shucking has the advantage that all oysters are shucked. The oysters are cooked slightly, which makes them unsuitable for the fresh market, although they are excellent for canned products.

The oysters are packed by hand into cans, with Number 2 and Number 95 the most popular sizes. Fill-in weights depend on the oysters' condition and composition, which change with season, water salinity, and other environmental factors. If the oysters are mechanically shucked, the amount of cooking incurred during steaming affects the fill-in weight, as the oysters may lose considerable weight during heating.

After the oysters are put in the cans, a weak brine solution, heated to near boiling, is added. The cans are then closed and retorted.

Four different styles of canned oysters are on the market: whole oysters, stew oysters, oyster stew base, and smoked oysters. Canned stew oysters are prepared by chilling the oyster meat to firm the flesh, then slicing the meats in a mechanical slicer. Fifty grams of meat are allowed in a 280 g (10 oz) can, and just prior to sealing, a mixture of milk, salt, monosodium glutamate, and disodium phosphates are added. Some packers also add oyster nectar, which is prepared by boiling whole oysters. Finally, a small amount of butter is added and the cans are vacuum-sealed and retorted. Canned oyster stew base consists of sliced oysters and nectar. The user then makes a stew as desired. This product is mostly canned for the institutional market in large cans.

Smoked oysters are made from precooked whole small oysters or from sliced large oysters. The meats are placed into a 20°S (salinometer) brine

for 3–4 minutes, then drained, spread onto racks, and smoked 2–3 hours. Sugar can be added to the brine for flavor. The meats develop a dark golden color and smoked taste. The smoked meats are packed into cans or glass jars to which salad oil is added. The containers are vacuum-sealed and processed. Many smoked oyster products are from Korea where *C. gigas* is used. Smoked oysters canned on the East and Gulf coasts of the United States are *C. virginica*.

## Clams

At least 14 species of clams are canned in various countries. In the United States, six species are canned, with hard clams, soft-shell clams, and razor clams (*Siliqua patula*) accounting for most of the production.

On the East Coast, where Maine, Maryland, Massachusetts, and Florida, account for most of the processing, the hard-shell and soft-shell clams are the principal species canned. The clams are washed and retorted under pressure. They are removed from the steamer and sorted by size, small or large, and by color, light or dark. Hand shucked clams also are used.

The clams are packed into "C" enameled cans, including sizes 211 × 400, 307 × 409, and 300 × 404, with the first two being preferred. Clams shrink considerably during processing, so "fill weights" are greater than "drain weights." Dark discoloration is a problem sometimes encountered with canned clams.

On the West Coast, particularly in Oregon, Washington, and Alaska, the razor clam is the principal clam canned, usually as minced clams. The clams are washed and scalded. The meats are shaken out of the shells and split along one side to remove sand and mud. They are washed a second time and the siphon, body side walls, and stomach are removed. The remainder is chopped and packed into cans. Brine or clam juice is added, and then the cans are closed and processed.

## Other mollusks

Although clams and oysters account for most canned mollusk production in the United States, other species, including mussels, scallops, abalone, cockles, donax, snails, and squid are also canned. The canning of mussels (*Mytilus edulis*) is a small but

growing industry on the United States' East Coast. They are first steamed 5–10 minutes, then shucked and packed into cans. Juice from the steaming process and salt are added.

Canning of scallops is done almost exclusively in Japan. The scallop meat is packed with 2% brine and processed. Abalone of the family Haliotidae are sometimes canned in other countries and have been canned in the United States, where the foot muscle is minced and canned. In other countries, such as Japan, the processing is different. After the animal is removed from the shell, the visceral mass and mantle fringe are trimmed. The meat is then washed, dry salted for 24–48 hours, rubbed to remove mucous substances, and canned.

Cockles (*Cardium* spp.) canning is a minor industry in the northwestern United States but an important industry of Western Europe. In Spain, they are washed, steamed, shucked by agitation, and canned. In France, they are pickled prior to canning. They are then drained, packed into jars, covered with a spiced vinegar, and processed. Donax (*Donax laevigata*), which is found on the Florida and Southern California coasts, is used primarily in soups prepared by boiling the entire mollusk. Land snails, escargots, are also canned with and without shells. Finally, squid is canned in the United States and several other countries. In the United States, squid is canned in oil; in Japan, it is canned after boiling and seasoning. For canning, the squid is cleaned as described for fresh marketing. It is washed, blanched at 40–50°C (104–122°F) in salt-water, and the skin is removed. The squid may be minced (as in Japan) or canned as mantles in oil.

## Pickled mollusks

Pickling seafood with vinegar and spices is an ancient form of food preservation. It is more often used with fish, but some mollusks are also processed this way.

In the 1800s, pickled molluscan products, especially oysters, were prepared commercially over most of the US Atlantic Coast. They are not nearly as popular now but are prepared in some areas, especially in Virginia and Louisiana, for local consumption.

Pickled mussels are becoming a popular seafood. Mussels are plentiful and economical because of aquaculture techniques, and the acceptance of pick-

led mussels is increasing. Clams are also pickled but to a lesser extent than mussels and oysters. Pickled cockles are common in France. The meat is dipped in 3% salt brine, drained, and covered for three days with a 3% vinegar solution containing 3% salt. The cockles are then drained, packed, and covered with spiced vinegar.

## High pressure processing

High pressure or hydrostatic pressure processing offers mollusk processors several advantages over conventional processing methods. For example, pressure is transmitted uniformly throughout the system in contrast to thermal processing. Products are treated evenly throughout, regardless of the shape of packaging or volume of product. Pressurization and decompression cycles can be rapid, allowing short processing times. Furthermore high pressure systems are energy efficient, as once the required pressure is reached, it can be maintained with no additional energy input. One of high pressure's major advantages is the production of safer foods that retain the appearance, flavor, texture, and nutritional qualities of the unprocessed product.

High pressure is being increasingly used to process all species of oysters. There are two advantages of high pressure processing of mollusks, especially oysters. First, *Vibrio* spp. are relatively sensitive to high pressure. *V. vulnificus* causes the highest mortality rate (50%) of any food pathogen in the United States. Ingestion of this microorganism can cause fatal septicemia and gastroenteritis in susceptible individuals. The microorganism cannot be removed by depuration or relaying. A treatment at 260 Mega Pascals (MPa) for 3 minutes at ambient temperature significantly reduced *V. vulnificus*. *V. parahaemolyticus* was reduced with a treatment of 345 MPa for 90 seconds. Table 12.1 contains the effects of pressure, time, and temperature on log reductions of various *V. vulnificus* and *V. parahaemolyticus* isolates. Second, during high pressure treatments, the adductor muscle detaches from the shell allowing for ease of hand shucking or machine processing through a tumbling process (Murchie et al., 2005). A treatment of 241 MPa for 2 minutes caused detachment of the adductor muscle in 88% of oysters (*C. gigas*) while a treatment at 310 MPa resulted in 100% efficiency (He et al., 2002). An optimum pressure for the destruction of *Vibrio* spp.



**Table 12.1** Log reductions of *Vibrio* spp. in oysters using high pressure processing.

Sample type	High Pressure Parameters			Log Reductions for spp.		References
	MPa (psi)	Temperature (°C)	Hold time (s)	V.p.	V.v.	
Shell oysters, <i>Crassostrea virginica</i>	241 (35,000)	8–10°C	120		>4.8	Cook, 2003
Homogenized <i>C. virginica</i>	241 (35,000)	8–10°C	120		>5.0	
Homogenized <i>Crassostrea gigas</i> <sup>a</sup>	250 (36,359)	8–10°C	180	>4		Calik et al., 2002
	250 (36,359)	8–10°C	240	5		
	275 (39,855)	8–10°C	180	>6		
	300 (43,511)	8–10°C	60	>5		
Shell oysters <i>C. virginica</i> <sup>a</sup>	275 (39,855)	8–10°C	240	3.5		
	300 (43,511)	8–10°C	120	4		
Shell oysters <i>C. gigas</i> <sup>a</sup>	241 (35,000)	21°C	600	3.5		
	276 (40,000)	21°C	300	4.0		
	310 (45,000)	21°C	180	5.1		
	345 (50,000)	21°C	120	6.2		
Shell oysters <i>C. gigas</i> <sup>a</sup>	241 (35,000)	21°C	600	5.2		Koo et al., 2006
	276 (40,000)	21°C	300	4.9		
	310 (45,000)	21°C	180	4.8		
	345 (50,000)	21°C	120	5.3		
Shell oysters <i>C. virginica</i> <sup>a</sup>	241 (35,000)	21°C	120		4.3	
	276 (40,000)	21°C	120		3.7	
	310 (45,000)	21°C	120		3.6	
	345 (50,000)	21°C	60		4.6	
Shell oysters <i>C. virginica</i> <sup>a</sup>	241 (35,000)	21°C	360	5.7		Kural et al., 2008
	276 (40,000)	21°C	300	4.3		
	310 (45,000)	21°C	120	4.3		
	345 (50,000)	21°C	60	4.8		
Shell oysters <i>C. virginica</i>	450 (65,250)	1°C	120	>6.5	1.0	
	400 (58,000)	1°C	120	5.8		
	350 (50,750)	1°C	120	5.4		
	300 (43,500)	1°C	120	4.9		
	250 (36,250)	1°C	120	3.1		
Shell oysters <i>C. virginica</i>	450 (65,250)	20°C	120	>6.5		
	400 (58,000)	20°C	120	5.9		
	350 (50,750)	20°C	120	5.3		
	300 (43,500)	20°C	120	3.9		
	250 (36,250)	20°C	120	2.1		
Shell oysters <i>C. virginica</i>	450 (65,250)	35°C	120	>6.5		
	400 (58,000)	35°C	120	>6.5		
	350 (50,750)	35°C	120	>6.5		
	300 (43,500)	35°C	120	4.9		
	250 (36,250)	35°C	120	3.5		
Shell oysters <i>C. virginica</i>	450 (65,250)	40°C	120	>6.5		
	400 (58,000)	40°C	120	>6.5		
	350 (50,750)	40°C	120	>6.5		
	300 (43,500)	40°C	120	5.4		
	250 (36,250)	40°C	120	3.5		

**Table 12.1** (Continued).

Sample type	High Pressure Parameters			Log Reductions for spp.		References
	MPa (psi)	Temperature (°C)	Hold time (s)	V.p.	V.v.	
Homogenized	350 (50,750)	20°C	60	4.7		
<i>C. virginica</i>	350 (50,750)	30°C	60	5.9		
	350 (50,750)	40°C	60	7.4		
	350 (50,750)	45°C	60	7.7		
Shucked	300 (43,500)	−2°C	8		>7.0	Kural and Chen, 2008
<i>C. virginica</i>	300 (43,500)	−2°C	5		>7.0	
	300 (43,500)	−2°C	3		6.5	
	300 (43,500)	−2°C	1		4.3	
	250 (26,250)	−2°C	10		>7.2	
	250 (26,250)	−2°C	6		7.1	
	250 (26,250)	−2°C	4		6.0	
	250 (26,250)	−2°C	2		4.7	
	200 (29,000)	−2°C	15		6.7	
	200 (29,000)	−2°C	9		4.8	
	200 (29,000)	−2°C	6		4.9	
	150 (21,750)	−2°C	20		4.2	
	150 (21,750)	−2°C	10		3.7	
	300 (43,500)	1°C	8		>7.0	
	300 (43,500)	1°C	5		>7.0	
	300 (43,500)	1°C	3		6.0	
	300 (43,500)	1°C	1		4.5	
	250 (26,250)	1°C	10		>7.2	
	250 (26,250)	1°C	6		6.3	
	250 (26,250)	1°C	4		5.4	
	250 (26,250)	1°C	2		4.9	
	200 (29,000)	1°C	15		5.8	
	200 (29,000)	1°C	9		5.3	
	200 (29,000)	1°C	6		4.4	
	150 (21,750)	1°C	20		3.9	
	150 (21,750)	1°C	10		3.5	

V.v., *Vibrio vulnificus*; V.p., *Vibrio parahaemolyticus*.

<sup>a</sup>Clinical strains of *Vibrio vulnificus* and *Vibrio parahaemolyticus* were used.

microorganisms that also release the adductor muscle will vary with oyster species, season, and growth conditions.

Bivalve shellfish readily bioconcentrate enteric viruses such as hepatitis A virus, which can persist in shellfish tissues for periods of several weeks or more. It was demonstrated that feline calicivirus, a norovirus surrogate, was inactivated at 275 MPa. Hepatitis A virus received limited inactivation at 300 MPa for 5 minutes in cell culture. When the pressure was increased to 460 MPa, a 7 log reduction was obtained. Eastern oysters contaminated to

nearly 6 logs were reduced to >1, >2, and >3 logs at 1 minute treatments at pressures of 350, 375, and 400 MPa, respectively. These results suggest that high pressure processing treatments of raw shellfish is a viable strategy for the reduction of infectious hepatitis A virus.

High pressure treatments have also enhanced some of the physical properties of oysters. The oysters are more voluminous following treatment and were judged in sensory studies as more acceptable in appearance than untreated oysters. They were also considered as more juicy due to the intrusion of

processing water into the oysters and also more flavorful. However, depending on the pressure treatment, a cooked appearance can be imparted due to adiabatic heating (3°C/100 MPa (37°F/100 MPa)). High pressure treatment (260 MPa for 3 minutes) had fewer negative effects on tissue color than thermal pasteurization (75°C/167°F for 8 minutes) and cool pasteurization (50°C/122°F for 10 minutes) (Cruz-Romero et al., 2007).

Mollusks, mussels, scallops, and oysters, were subjected to varying pressurization treatments from 1 to 2 minutes at 7°C and 20°C (44°F and 68°F). Pressure treatments readily inactivated total viable count, psychrotrophic bacteria, H<sub>2</sub>S-producing microorganisms, coliforms, and pseudomonads. The range of bacteria present in the mollusks decreased with increasing pressures. Gram-negative bacteria were inactivated to a greater degree than Gram-positive bacteria. The main types of bacteria after pressure treatments and subsequent storage were *Bacillus*, *Acinetobacter*/*Moraxella* and lactic acid bacteria. Together, these constituted up to 96% of the bacteria isolated after sampling all the pressure treated samples (Linton et al., 2003). In some cases, the inactivation of a class of microorganisms or a specific bacteria can approach 5 log units. However, reductions from 2 to 3 logs are common. Pressure treatments do not significantly inhibit lipase activity during storage.

## Irradiation and electron beam

The US FDA has approved ionizing radiation for many foods including seafood. Irradiation is particularly valuable as an endpoint decontamination procedure since it can eliminate potentially pathogenic bacteria. An X-ray treatment (5 MeV) was capable of achieving greater than a 6 log reduction of *V. vulnificus* with treatments of 0.75, 1.0, 3.0 kGy in pure culture, half-shell, and whole-shell oysters (*C. Virginica*), respectively. A treatment of 0.75 kGy reduced the inherent microorganisms in half-shell oysters, to less than the detectable limit (<1 log CFU/g) (Mahmoud, 2009). A second study (Mahmoud and Burrage, 2009) demonstrated that greater than a 6.0 log reduction of *V. parahaemolyticus* could be achieved in pure culture, half-shell, and whole-shell oysters at 0.75, 2.0, and 5.0 kGy, respectively. A treatment of 1.0 kGy reduced the inherent

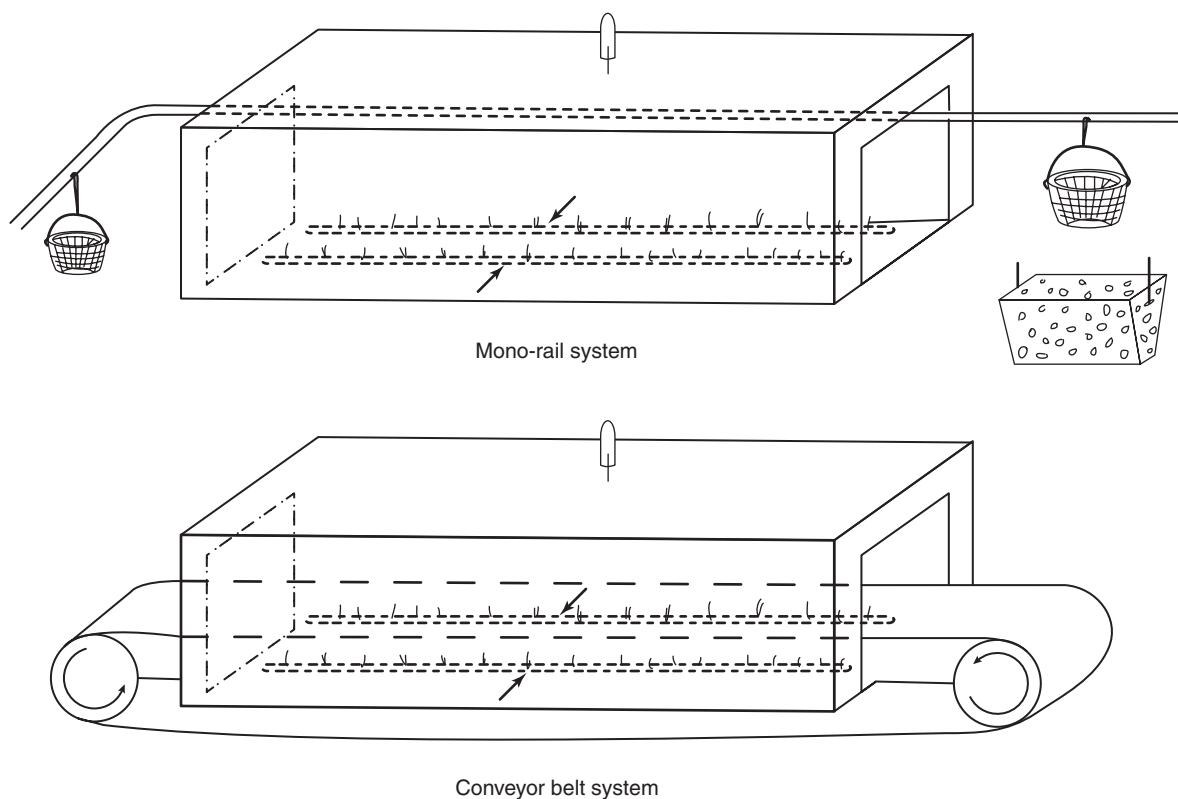
microorganisms on whole-shell oysters from 4.7 log to less than the detectable limit (<1.0 log CFU/g).

Live oysters (*C. virginica*) were inoculated with *Vibrio* microorganisms and exposed to 0–3 kGy doses of Cobalt-60 gamma irradiation (Andrews et al., 2003). *V. vulnificus* (MO-624) was reduced from 6 log CFU/g of oyster meat to undetectable levels (<3 MPN/g) with 0.75–1.0 kGy irradiation exposure. *V. parahaemolyticus*, 03:K6 (TX-2103), required 1.0–1.5 kGy for reduction to undetectable levels. Sensory difference tests, triangle method, by 146 volunteers confirmed that panelists, many of whom worked in the seafood industry, were unable to distinguish nonirradiated from irradiated (1 kGy) oysters. An irradiation treatment (1 kGy) of clams (*Ruditapes decussates*) showed a noticeable 1–3 log reduction in total plate counts, whereas the mesophiles, *Staphylococcus*, and coliforms were abundant in the control group (6.3, 2, and 1.7 log CFU/g, respectively).

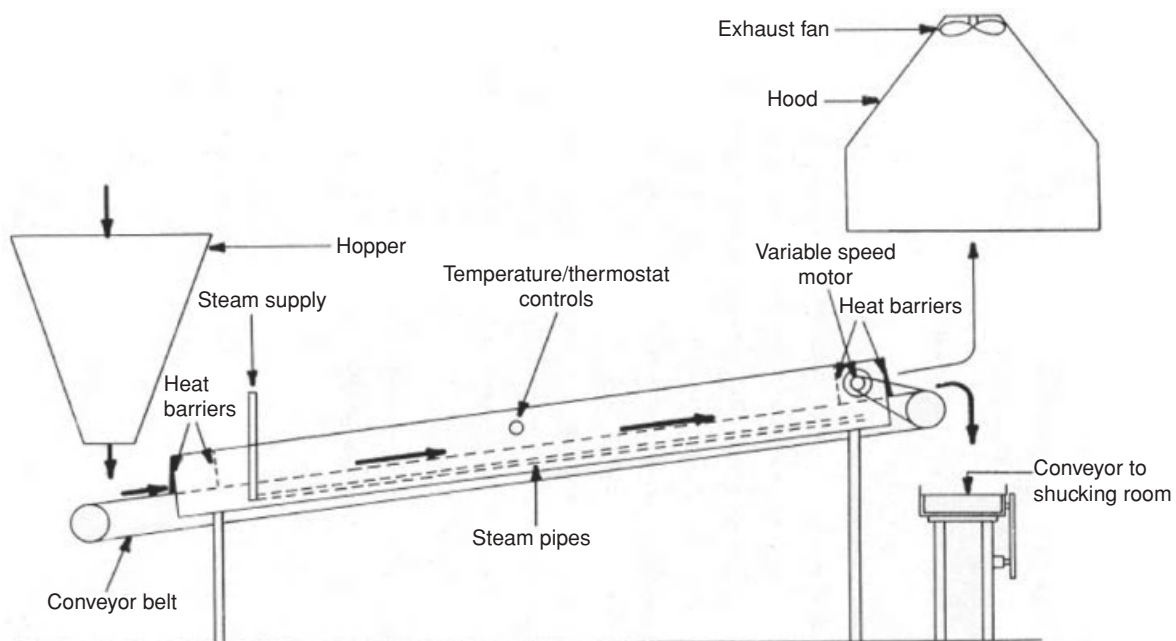
## Steam tunnel

Steam-shock is an oyster shucking process that uses steam to relax the oyster's adductor muscle, causing the oyster's shell to gape sufficiently enough to permit a shucking knife to be inserted without physical force. Inserting the knife without first prying the shells apart or breaking the bill of the shell saves the shucker's effort. Reducing effort and eliminating unnecessary motions translate directly into increased productivity. The increase in productivity has been estimated at between 20% and 35%. Also, since the oysters are partially opened, it is possible to employ less-skilled shuckers.

The steam-shuck process exposes oysters, still in their shells, to live steam only sufficiently long enough to raise the temperature of the meat to about 49°C (120°F). This takes from 90 to 150 seconds depending upon the nature of the oysters and the temperature of the steam, and is achieved by carrying the shell stock through a steam tunnel, either on a flat conveyor belt (Figures 12.1 and 12.2) or in a bucket hung from an overhead monorail. Heat transfer efficiency ranges from 25% to 35% depending upon the design of the tunnel. The conveyor belt method is preferred since it provides a more uniform exposure of the oysters to the steam. A screw conveyor could be a rather efficient system to heat and transport oysters over the belt



**Figure 12.1** Steam tunnel construction and transport system.



**Figure 12.2** Oyster steam tunnel (Huang et al., 1982).

configuration. The steam-shocking produces a meat that is considered raw and is sold as such in the market (Brown, 1982).

The steam-shocking process has a second advantage in that it can produce a reduction in the natural flora present in the oyster when combined with rapid chilling of the meats. Aerobic plate count reductions range from 1 to 2 logs.

This process also has the advantage that it can be used to produce a pasteurized product by heating the meats to about 60°C (140°F). At 60°C, the meat yield loss is about 20%.

## Heat shock

In the heat-shock method, oysters are immersed in hot water at a given temperature for a definite period of time, followed by immediate chilling. All shellstock subjected to the heat-shock process are washed immediately prior to the heat-shock operation in flowing potable water. Water temperatures not less than 18°C (65°F) nor more than 24°C (75°F) are recommended. During the heat-shock process, the water should be maintained at not less than 63°C (145°F) nor more than 66°C (150°F). The water should be completely drained or removed from the heat-shock tank at least once each 3-hour period. The shellstock subjected to the heat-shock process should not be immersed in the heat-shock water for periods longer than 3 minutes. Typical processing ranges from 2 to 3 minutes. Experience and research indicated the temperature range of 63–66°C (145–150°F) to be adequate to facilitate removal of oysters from the shell without apparent physical change to the oyster.

The heat-shock process results in an overall reduction in coliform and fecal coliform levels. The greatest reduction occurred in the samples examined immediately after shocking. A comparison of oysters examined immediately after shocking with cold shucked oysters indicated a reduction in coliform and fecal coliforms of 50% and 25%, respectively. Holding oysters on the shucking bench appears to result in a slight increase in these two groups of bacterial indices as compared to oysters examined immediately after shocking. However, the levels after heat shock remained significantly lower than the levels obtained from samples from the cold shucking process. A 35°C (95°F) plate count showed a slight decrease at the 25 and 50 percentile

levels both in oysters immediately after shocking and in shocked oysters held on the shucking bench. At the 90 percentile level, the plate count of the oysters immediately after shucking was comparable to the count obtained from cold-shucked oysters. At this percentile level, counts from shucked oysters held on the shucking bench were slightly higher than counts obtained from cold shucked oysters or oysters examined immediately after shocking (Flick, 1982).

A variation of the heat-shock procedure, heat-cool pasteurization, has been used as a pasteurization process for the reduction/elimination of *Vibrio* spp. bacteria. The process involves submerging the raw product into warm water followed by immediate cold water immersion. Shellstock is washed, graded, sorted, banded, and treated. Banded oysters are placed on a large tray and then a hoist lifts and places them in warm water at 53°C (127°F) for 24 minutes. The trays are lifted out and placed in 4°C (40°F) water for 15 minutes. The trays of cooled, banded oysters are stacked on carts to drip dry ready for storage or shipment.

Gulf of Mexico oysters (*C. virginica*) containing 10<sup>2</sup>–10<sup>4</sup> MPN/g of *V. vulnificus* were subjected to a commercial heat-shock process where the internal temperature of the oyster meat ranged from 50°C to 60°C (122°F to 140°F). Reductions for the *V. vulnificus* ranged from 1 to 4 logs. Cook and Ruple (1992) found that temperatures above 45°C (113°F) caused death in selected strains of *V. vulnificus*. Decimal reduction times ( $D_{47}$ ) for 52 strains of *V. vulnificus* in PBS2 (peptone buffered saline with 2% salt) suspension media averaged 78 seconds, whereas a  $D_{50}$  of 39.8 seconds was determined for 18 of the hardest strains tested. Heating oysters for 10 minutes at 50°C was adequate to reduce *V. vulnificus* in oysters from a 4 log to undetectable levels. However, their study found that a 5-minute treatment was insufficient to reduce the bacteria levels to undetectable levels (<0.3 MPN/g).

## Postharvest processes

Gulf Coast oyster processors are implementing technologies to ensure safer alternatives to traditional raw oysters for at-risk consumers. Serious illness and death can result when at-risk individuals consume raw oysters containing *V. vulnificus*.



The health conditions that place individuals in the at-risk consumer category include the following:

- (1) Liver disease: from hepatitis, cirrhosis, alcoholism, or cancer.
- (2) Iron overload disease: hemochromatosis.
- (3) Diabetes.
- (4) Cancer: including lymphoma, leukemia, and Hodgkin's disease.
- (5) Stomach disorders.
- (6) Any illness or medical condition that weakens the body's immune system.

Several processes allow oysters to be consumed raw, but with added safety features that reduce *V. vulnificus* to nondetectable levels. The processes include the following:

- (1) Individual quick freezing
- (2) Heat-cool pasteurization
- (3) High pressure or hydrostatic pressure
- (4) Gamma or e-beam irradiation

A description of these processes have been included earlier in the chapter.

### **Postharvest processing validation/ verification guidance for *Vibrio vulnificus* and *Vibrio parahaemolyticus***

The US FDA has established procedures for the initial validation of a process or when there has been a change to a previous validation process. A brief description of the procedure is as follows:

- (1) Data on ten processed samples obtained on each of three processing days (total of 30 samples) are required.
- (2) All samples used on a processing day must come from the same lot of shellfish and be determined to have an adjusted geometric mean (AGM) MPN of 10,000/g or greater.
- (3) Samples should be distributed throughout the processing day. A sample will consist of 10–12 oysters processed at one time.
- (4) The 0-hour level may be achieved through naturally occurring *Vibrio* levels in shellfish and, where not practical, by time/temperature

abuse. (Inoculated pack samples may be used as appropriate).

- (5) Analytical methodology to determine *Vibrio* levels should be the official methods previously endorsed by the Interstate Shellfish Sanitation Conference (ISSC).
- (6) Microbiological testing for initial levels will be by a 3-tube MPN using appropriate dilutions ( $10^{-1}$ – $10^{-6}$ ).
- (7) Microbiological testing for processed samples will be by a single dilution 5-tube MPN, inoculating with either 0.01 g or 0.1 g of shellfish per tube based on the AGM Interval.
- (8) The numerical value of the endpoint criteria should be less than 30/g and achieves a minimum 3.52 log reduction.

### **Flavoring agents from processing effluents**

Clams, oysters, and mussels are delicate shellfish and are commonly marketed fresh. Raw shellfish are shucked, blown (washed), drained, and packaged. However, some shellfish are subjected to a thermal process to facilitate a mechanical shucking process. These processes generate a large amount of waste water containing proteins, nonprotein nitrogenous components, and other solids. Many of the solids in the processing waste waters have resulted in a disposal problem. Many shellfish processing plants discharge the liquid effluents directly into receiving waters causing a threat to the environment. Alternatively, the wastes are discharged into a municipal sewer system resulting in expensive charges due to the waste water volume and its accompanying suspended solids and biochemical oxygen demand.

The wastes have been converted to food ingredient agents for use in soups, snacks, natural flavorings, and animal feeds (Brunette et al., 1983; Reddy et al., 1989; Kim et al., 2000; Cros et al., 2004). Many of the procedures consist of a concentration process through vacuum heating, spray drying, or boiling. Another process utilized a 3-step operation to produce a natural flavoring and a cleaned water stream. The liquid waste was centrifuged before being desalinated by electrodialysis and then concentrated by reverse osmosis. The sensory profiles of the concentrates were judged slightly **different from the unprocessed shellfish liquids**. Nevertheless, the concentration process preserved the native

characteristic aroma of the cooked shellfish. The flavor of the effluents can also be improved by an enzymatic process. Basically, the effluents are treated with various enzymes, such as amylases and proteases. A protease/amylase process has a particular appeal because during thermal processing amino acids and peptides released by protease action can react with reducing sugars liberated by amylase action to generate cooked meat aroma. This technology has been used for the production of meat and savory flavors.

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# 13

## Processing Crustaceans

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Lori S. Marsh

Crustaceans comprise a relatively small proportion of the marine food products marketed. However, they are typically marketed as cooked, ready-to-eat products, which command a relatively high price. Hence, they are an important group. Processing of the major crustacean species of commerce including crabs, crawfish, lobsters, and shrimp will be discussed.

### Crabs

There are many crab species that are commercially marketed throughout the world. These include swimming or blue crabs (*Callinectes sapidus* and *Portunus pelagicus*), snow and/or tanner crab (*Chionoecetes opilio*), rock crab (*Cancer irroratus*), Jonah crab (*Cancer borealis*), stone crab (*Menippe mercenaria*), Alaska king crab (*Paralithodes camtschaticus*, *Paralithodes platypus*, and *Lithodes aequispinus*), and Dungeness crab (*Cancer magister*). Processing methods for the various crab species tend to be similar. Detailed information for processing of swimming or blue crabs is presented and is representative of other species. Typical cooking methods and times, market forms, and processing methods for other crab species are presented in Table 13.1.

### Swimming or blue crabs

Figure 13.1 presents a typical process flow chart for blue crabs. Crabs arrive at the processing plants either directly from boats (A) or by truck transport (B) from landing sites. Upon receiving (C), they are weighed and may be spray washed in a tumble washer prior to placing in a cooler for holding live crabs (D). Swimming or blue crabs are cooked either by boiling or steaming (E), depending on their harvest location. Immediately after cooking, the crabs are placed in a screened room at ambient temperature until steam no longer is emitted from the crabs (F). After atmospheric cooling is completed, the crabs are placed under refrigerated storage (G). At this point, crabs are typically hand picked (H) into several market forms (lump, backfin, flake, claw, and cocktail claw). In some cases, the claws are removed from the crab by hand but picked by machine; to accomplish this, they are either returned to the storage cooler (M to G) before moving to a mechanized claw picker (N) or taken directly to the mechanized claw picker (N). The mechanized claw picker also packages the product. Another option during hand picking is to remove the top shell and legs and send these to a meat bone separator for further processing (R). After picking

**Table 13.1** Typical cooking, market forms, and processing methods for commercially important crabs.

Crab species	Cooking method/time	Market forms	Processing methods	References
Swimming, <i>Callinectes sapidus</i> and blue, <i>Portunus pelagicus</i>	Boiling or steaming	Hand picked into lump, backfin, flake, claw, and cocktail claw	Precooked fresh, or frozen, pasteurized, canned	
Snow (also called tanner), <i>Chionocetes opilio</i>	Boiled	Whole, sections (four legs and one claw), cocktail claws (cap on or off), hand-picked meat, leg meat, salad meat	Precooked frozen, canned	www.tridentseafoods.com
Stone, <i>Menippe mercenaries</i>	Boiled for approximately 8 min	By law, only claw is sold; animal returned to sea; sold in three sizes—small, medium, and large	Precooked fresh and frozen	Personal conversation, Steve Otwell, University of Hawaii
Rock, <i>Cancer irroratus</i> and Jonah, <i>Cancer borallii</i>	Boiled 12–14 min	Traditionally, hand-picked meat from claw; more recently, residual meat from walking legs removed using mechanical deboner	Picked meat primarily sold fresh; claws typically sold frozen, intact or as cocktail claws, precut and tips removed; deboned meat sold as minced meat to food service industry	Personal conversation, Denise Skonberg, University of Maine
Alaska king—red king, <i>Paralithodes camtschaticus</i> ; blue king, <i>Paralithodes platypus</i> ; and golden king, <i>Lithodes aequispinus</i>	Cut into sections and boiled in freshwater for 25–30 min	Primary processing typically involves freezing in sections; secondary processing cuts legs apart at shoulders and trims, grades legs and claws by size	Fresh or frozen	Personal conversation, Joe Fraizer, Food Products Association, Seattle, WA

by hand or processing through a meat bone separator, meat is taken to a packing room (I). Packed crab may be frozen (Q), thermally processed, that is, pasteurized (P), or sold fresh. After processing, product is held in either a refrigeration room (J) or a freezer (Q) until it is shipped to distribution channels.

### Mechanical separation

The crab body parts including the tops, legs, and small claws, which are not picked by hand, are either processed in a bone meat separator or in a Harris Claw Machine. Each of the meats has distinct visual, textural, and flavor attributes. Minced meat produced in a bone meat separator is pack-

aged for institutional use in crab cakes, soups, or seafood stuffing. The meat has a dark color and lacks a defined texture, which prevents its successful marketing in the retail trade.

The Harris Claw Machine employs a hammer mill to reduce the body parts into small pieces that release the meat from the shell. The ground particles fall into a separation tank containing a brine solution where the meat floats and the shells sink. The meat is removed by a conveyor belt to an inspection table where shell and other materials are removed by hand. The shell is removed from the bottom of the claw machine by a conveyor belt to a waste disposal site. This meat, like that produced in the meat bone separator, is also marketed for institutional trade.



Example blue crab processing flow chart

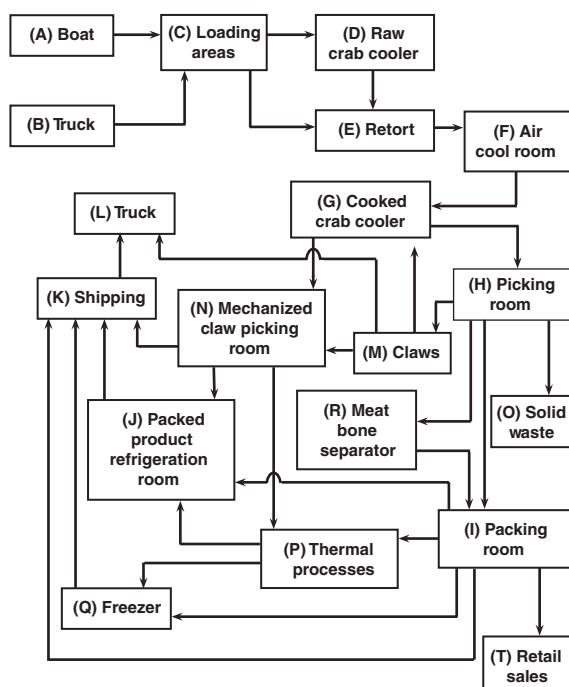


Figure 13.1 Example blue crab processing flow chart.

## Further processing

Fresh crabmeat is a highly desirable market form that demands a premium price; however, it is quite perishable, and under normal refrigeration, the shelf life is typically only 7–10 days. To extend shelf life, once the meat is processed, it can be frozen, pasteurized, or canned. Although blue crab can be frozen successfully, few processors do so because it has traditionally lost value as a frozen product.

## Pasteurization

Pasteurization allows the product to maintain the characteristics of fresh crabmeat while extending shelf life by destroying bacteria that would cause spoilage of the fresh product under normal refrigeration conditions. Pasteurized crabmeat, like pasteurized milk, must be kept refrigerated; however, since normal spoilage microorganisms have been destroyed, pasteurized crabmeat has a shelf life of at least 6 months.

To pasteurize crabmeat, it must first be placed in a container that is hermetically sealed. Container

options include aluminum cans, plastic pouches, and plastic cans. Sealed containers are immersed in a hot water bath followed by an ice slush cooling tank, both of which should have circulating water to assure uniform temperature throughout. Time/temperature parameters are important for both the heating and cooling stages, since cooling quickly is bactericidal to some heat resistant bacteria. Time/temperature parameters for the pasteurization process are generally designed around a target organism. For blue crab, pasteurization requirements were developed empirically to achieve a desired refrigerated shelf life with no specific target organism. A  $z$ -value of  $8.9^{\circ}\text{C}$  ( $16^{\circ}\text{F}$ ) and a reference temperature of  $85^{\circ}\text{C}$  ( $185^{\circ}\text{F}$ ) were chosen. The National Blue Crab Industry Association adopted a minimum commercial pasteurization process of  $F_{8.9/85} = 31$  minutes for their pasteurization guidelines (Gates et al., 1993).

## King crab

Alaska king crab (red king, *Paralithodes camtschatica*; blue king, *Paralithodes platypus*; and golden king, *L. aequispinus*) is an extremely large crab, weighing as much as 11 kg (24 lb). Fishing areas extend in a large crescent from Southeastern Alaska to the Bering Sea side of the Aleutian Peninsula and island chain.

Only healthy male king crabs are kept because conservation regulations prohibit the taking of females. The crabs are held live on board the boats in tanks containing either circulating seawater or refrigerated seawater. Occasionally, inshore day boats will bring in the crabs as a deck load.

At the processing plant, crabs from the fishing vessels are processed immediately or placed in holding tanks of circulating seawater similar to those found on the boats. Only live crabs are processed. During the processing operation, the back shell is pulled off, the crab cut in half, and the viscera and gills removed. The various sections are then thoroughly washed to remove blood and viscera. Following processing and washing, the crabs are cooked in boiling water at  $99\text{--}100^{\circ}\text{C}$  ( $210\text{--}212^{\circ}\text{F}$ ) for 25–30 minutes, then spray-washed to cool the product.

Frozen king crab sections (meat in the shell) are popular with retail and institutional buyers. To provide this product, the processed and cooked sections are chilled, thoroughly washed, trimmed, and

divided into uniform lots. The sections are then frozen and glazed. Extra glazing is necessary at the shoulder end, where the meat is exposed, to prevent dehydration. Yellowing and honeycombing (spongy appearance) of the meat are typical signs of dehydration. The shoulder of the crab is enclosed by a yellowish membrane, so it is important to distinguish between the natural yellow of the membrane and yellowing of the meat due to dehydration and rancidity.

### Dungeness crab

Dungeness crabs (*C. magister*) are large crabs, typically weighing a kilogram (over 2 lb) at harvest. They are caught in circular steel traps commonly called "pots." Only mature male crabs measuring at least 16.9 cm (6.25 in.) across the back of the shell are harvested. Undersized male crabs and females are returned to the ocean to ensure a healthy breed stock. After removal from pots, crabs are sorted and kept alive on board the vessel in tanks with circulating seawater until they are delivered to shore-side processing plants. (Oregon Dungeness Crab Commission, 2010).

Total Dungeness production for the entire region (California to Alaska) averages 19.3 million kg (42.5 million lb) annually. The ocean crab season along the Oregon coast begins on December 1 and continues through August 14. The peak harvest occurs during the first 8 weeks of the season with up to 75% of the annual production landed during this period.

Based on personal communication with Hugh Link, Assistant Administrator, Oregon Dungeness Crab Commission, crabs are received at processing plants either directly from boats or by truck from a receiving station. Some animals are sold live, with the remainder being cooked and sold in various forms. Crabs may be cooked whole or in sections. To cook sections, the carapace and viscera are removed and the crab is cut in half. Whole or sectioned crabs are cooked by either boiling or steaming in saltwater.

After cooking, whole crabs are either sold in this form, or hand picked, and the meat sold fresh in either a vacuum-sealed can or pouch. Because the majority of crabs are harvested in a short-time period (8 weeks), whole crabs are generally frozen for later picking. Sections are also frozen to extend

their shelf life. Freezing is accomplished by placing product in mesh bags and submerging the bags in tanks in which brine, maintained at temperatures close to  $-17.7^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ), is circulated. After removal from brine freezing tanks, the bags are blast frozen at  $-34^{\circ}\text{C}$  ( $-30^{\circ}\text{F}$ ). To prevent the meat from dehydrating, the bags are often glazed with a frozen brine solution. Prior to hand picking, frozen bags are defrosted by removing them from the freezer and placing them in a tank with circulating cold water.

Market forms include the following:

- (1) Live.
- (2) Cooked whole crab, fresh, or frozen.
- (3) Cooked, frozen sections, which are sold in various size lots, including soldier packs (cooked sections lined up in 11.4 kg (25 lb) boxes).
- (4) Canned or vacuum-sealed cooked meat.

### Stone crab

Stone crab (*M. mercenaria*) is found in the western North Atlantic, from North Carolina to Belize, including Texas, the Gulf of Mexico, Cuba, and the Bahamas. The bodies of these crabs are relatively small and are rarely eaten, but the claws, which are large and strong enough to break an oyster's shell, are considered a delicacy. By law, only the claw is sold. Harvesting is accomplished by removing one or both claws from the live animal and returning it to the ocean where it can regrow the lost limb(s). To be kept, claws must be 70 mm (2.75 in.) long, measured from the tips of the immovable finger to the first joint. If both claws are legal size, they may both be taken. Studies by the state of Florida have shown that removing both claws do not harm the Florida stone crab in any way when removed properly. Claws are boiled, graded by size (small, medium, and large), and sold either as precooked fresh or frozen.

### Jonah crab and rock crab

The Jonah crab (*C. borealis*) and rock crab (*C. irroratus*) inhabit the deep water and rocky bottoms in the North Atlantic, from New England to Canada. These crabs are processed much like blue crabs by cooking and hand picking. Meat from walking legs may be removed using a mechanical deboner and

sold as minced meat to the food service industry. Picked meat is primarily sold fresh. Claws are typically sold frozen, either intact or as cocktail claws, which are precut and the tips removed.

## Lobster

Maine is the top producing state for the American lobster (*Homarus americanus*) with the 2009 catch totaling a record 75.6 million lb. The fishery is year-round, with fresh, live product available 365 days a year. In Maine, lobsters are caught via baited wire traps. Those meeting the legal size range are retained with smaller, larger, and marked female lobsters returned to the sea. Outside of Maine, lobsters are also legally harvested as bycatch in groundfish nets. Lobsters are removed from traps and stored live in wooden or plastic crates, usually 90 lb to a crate.

Lobsters are sold live to retail outlets and restaurants, where they are stored inside in a tank room, refrigerator, or floatation pool until sold live or cooked. They are graded and priced according to weight (1.25 lb, 1.5 lb, 1.75 lb, etc.). In the summer months, lobsters are available as either "hard-shell" and "soft-shell" or shedders, the latter being priced lower. In the wholesale market, soft-shell lobsters are usually processed into various parts and value-added products as opposed to being sold whole.

Crates of lobster are delivered via refrigerated truck (or, in some cases, boat) to processing facilities, where they are refrigerated and processed within 24 hours of being caught. Lobsters are cooked in batches, either steamed with a continuous cooker or boiled. They are then cryogenically frozen with liquid nitrogen or other flash-freeze methods, or are left to cool before being frozen. Every step is monitored for temperature.

Market products include the following:

- (1) Cooked, frozen whole lobster in the shell.
- (2) Cooked, frozen, machine-split half lobster in the shell.
- (3) Cooked, frozen claws, knuckles, and tails in the shell.
- (4) Cooked, fresh, or frozen meat hand-picked from the shell.
- (5) Raw (blanched), frozen whole lobster in the shell.
- (6) Raw tails, detached by hand, frozen in the shell.
- (7) Lobster can also be canned or used as an ingredient in a number of value-added products.

One entrepreneur in Maine is using high pressure processing (sometimes called hydrostatic or hyperbaric processing) to extract raw lobster meat. High pressure processing alters the structure of membrane-bound proteins, inactivating pathogens and enzymes. In oysters, a side effect is that it makes the shells easier to open. In lobsters, it separates the shell from the muscle (meat). Raw meat is then packaged for refrigerated sale, frozen, or used in value-added products. This product is not yet available to the US retail market.

## Shrimp

There are over 3000 species of shrimp, which can be roughly categorized as warm-water, cold-water, or paste shrimp. Of these, approximately 300 species are of economic interest worldwide, with approximately 100 species representing the bulk of the annual world catch. Wild caught shrimp come from all three categories. The Food and Agriculture Organization (FAO) maintains statistics on marine shrimp catch worldwide using "species items," which represent a taxonomic group, generally at the species level, but sometimes at the level of genus, family, or suborder. Using the FAO designations, six shrimp species items (four species and two aggregated groups) accounted for 82% of the global shrimp catch in 2005 (Gilbert, 2008). Asia is the most important area for shrimp fishing with China, India, Indonesia, Vietnam, Thailand, and Malaysia accounting for 67% of the world's shrimp catch.

### Paste shrimp

In the Asia-Pacific region, very large quantities of paste shrimp are captured, generally using very small-scale fishing gear such as stow nets, triangular nets, lift nets, scoop nets, and seines. These shrimp are small, with adult body lengths ranging from 1 to 4 cm. *Acetes japonicus* (akiame paste shrimp) is the single most important shrimp species in the world by weight, accounting for 19% of the world harvest in 2005 (Gilbert, 2008). They are typically marketed dried, boiled, salted, fermented with salt, or processed into paste or sauce (Chan, 1998).

## Cold-water shrimp

Cold-water shrimp represent approximately 15% of the world shrimp harvest. Most cold-water shrimp belong to the Pandalidae family and are found in the waters of the North and South Atlantic and the North Pacific. The world catch in 2005 was approximately 500,000 tons (Seafish, 2009).

Northern and pink shrimp (*Pandalus borealis* and *P. jordani*) that are small compared with warm-water shrimp make up the vast majority of cold-water shrimp. Northern shrimp are primarily harvested by Canada and Greenland. Most are sold frozen in a variety of commercial product forms including frozen block whole (raw or cooked), frozen block peeled (raw or cooked), individually quick frozen (IQF, raw, or cooked), canned in brine, smoked, or in prepared dishes such as soups.

Giant spot shrimp (*Pandalus platyceros*) are the largest of the commonly caught cold-water shrimp. They are typically quick frozen at sea or sold fresh. A few are sold live in the United States, primarily in Asian markets.

## Warm-water shrimp

All of the commercially aquacultured species are warm-water penaeid shrimp. Aquaculture accounts for approximately 40% of the total shrimp yield. Some commercially important wild caught warm-water shrimp include southern rough shrimp (*Trachypenaeus curvirostris*), giant tiger prawn (*Penaeus monodon*), fleshy prawn (*Penaeus chinensis*), and banana prawn (*Penaeus merguensis*).

## Shrimp processing on board the capture vessel

Handling of shrimp on board the capture vessel is vitally important. As the catch is brought on board, the contents of the net are dumped on the deck, and the shrimp are separated from the bycatch. Three additional processing steps may occur on board:

- (1) Removal of the head (heading)
- (2) Treatment to prevent melanosis (black spot)
- (3) Icing or brine freezing

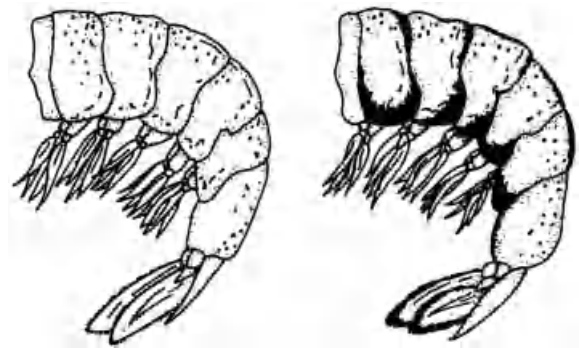
## Heading

When practical, crew members remove the head and the entire cephalothorax section, which contains the gills and many of the organs associated with the digestive tract. This process is referred to as “heading.” Studies have shown that removal of this section eliminates a significant source of bacteria as well as active enzymes that can hasten deterioration of the shrimp. After heading, washing with clean seawater further reduces bacteria and enzymes.

## Treatment to prevent melanosis

Black spot, also called box ring, ice burn, and ringer shrimp, is a dark discoloration that may form on stored shrimp (Figure 13.2). Black spot is caused by a biochemical reaction, called melanosis, which is produced from naturally occurring compounds in the shrimp shell and is similar to the reaction that takes place when a person gets a suntan. Efficient handling on deck, immediate, thorough washing, and either brine freezing or storage on good-quality melting ice are the most natural and effective means of controlling black spot. Rapid handling on deck reduces exposure to sunlight and elevated temperatures, which speed up the chemical reaction leading to black spot.

Additional processing aids to delay melanosis are often employed prior to landing the catch. Bisulfite dips are often used; however, a small percentage of the population exhibits an allergic response to sulfites, which can be quite severe. As a result, any product treated with sulfites must be labeled



**Figure 13.2** The appearance of a normal shrimp (left) and one with black spotting (right).

as such and cannot be sold as “chemical free,” and does not command a premium price. Newer alternatives to bisulfite treatments include antime-lanosis compounds in the form of 4-hexylresorcinol, which does not require labeling and, hence, can command the “chemical-free” designation.

Use of antimelanosis treatments have been shown effective when applied according to manu-facturers’ directions. However, applying this treat-ment on the capture vessel is not necessarily ideal. Haby et al. (2010) conducted an in-depth study of the efficacy of various antimelanosis treatments under different handling strategies to simulate treatment both immediately upon cap-ture and 7 days later after thawing frozen prod-uct. They found treatment after freezing could be effective.

### Icing or brine freezing

Shelf life of shrimp is highly dependent upon prod-uct temperature; hence, once shrimp are headed and washed, they are typically iced or brine frozen. If ice is used, the shrimp should be stored in layers of ice to prevent crushing damage.

Another method of preserving shrimp at sea is the use of brine freezing. The proper use of freezer brines is very important. An effective brine solution should rapidly freeze shrimp or bring them close to freezing, so that they can be completely frozen in the boat’s hold. Proper brine freezing helps pre-vent black spot and dehydration. Salt in the proper concentration (23%) reduces the freezing point of a brine tank to  $-21.1^{\circ}\text{C}$  ( $-6^{\circ}\text{F}$ ). Approximately 22.7 kg (50 lb) of headed shrimp are placed in open-mesh sacks and then submerged in the brine tanks. Shrimp should not be allowed to soak for more than 15 or 20 minutes; otherwise, the shrimp will become too salty and eventually toughen. Once brine freez-ing is complete, the bags are placed in the freezer hold.

At the dock, boats that stored shrimp on ice will flood the hold to melt the ice. The shrimp are then removed by vacuum pumps to wash tanks in the processing plant. Bags of brine frozen shrimp are off-loaded from the boats and emptied into thaw tanks. Shrimp remain in these tanks for 5–10 min-utes to allow the frozen shrimp to separate. At this point, if not previously treated, shrimp may be treated to prevent black spot.

### Shrimp processing after landing

From this point on, whether the shrimp were iced or frozen, warm-water or cold-water species, the process is much the same. The shrimp are dipped in an ice bath and then the shell-on shrimp are machine graded according to size, with grades of shrimp expressed as “count,” meaning the aver-age number of shrimp to the pound. Following are the common commercial size categories: less than 10, 14–15, 16–20, 21–25, 26–30, 31–35, 36–40, 41–45, 46–50, 51–60, 61–70, more than 70.

After grading, if the shrimp were not previously headed, the head will be removed. This step may be done by hand (typical in developing countries) or by machine.

The next step depends on the desired product form. Possibilities for raw shrimp include headless, shell-on (most common form sold in the United States and Japan); head and shell-on; headless and peeled but not deveined; and peeled and deveined. Peeled shrimp may or may not have the tail left on. Cooked shrimp comes in three main forms: peeled and deveined, tail-on; peeled and deveined, tail-off; and cooked in the shell.

Shrimp can be peeled (shell removed) by machine or by hand. In developing countries, hand peeling is most common. After the shell is removed (with or without removing the tail as well), the shrimp intes-tine (vein) that runs down the dorsal side near the surface is removed. This may also be accomplished by machine or by hand. Various machines are man-ufactured to accommodate various shrimp species and sizes. If the cut to remove the vein is almost all the way through the shrimp so that it lays open, it is referred to as butterfly.

Typically, the shrimp will be further processed by freezing raw, cooking, or breading and cook-ing prior to freezing. The cooking may occur prior to or after peeling and deveining. The method and timing of cooking will affect product quality. For unbreaded product, steam cooking is typical. Machines are manufactured specifically for this task (e.g., Laitram Model CTSB Split Hood-pure steam cooker, Laitram Machinery, Inc., New Orleans, LA). For breaded product, raw shrimp in various forms (e.g., tail on or off) are battered, fried, cooled, and then frozen. The battering step can be accomplished by machine or by hand.

Freezing is typically done in blocks in a blast freezer or plate freezer. After the product is



thoroughly frozen, it is removed from the freezer, the top of the box is opened, and about 237 mL (8 oz) of water is sprayed on the shrimp. The lid is closed and the box inverted. This method allows a solid block of ice and shrimp to form, protecting the shrimp from freezer burn. Shrimp may also be IQF by immersing or spraying them with liquid nitrogen or carbon dioxide. This process is extremely effective but has high operating costs.

Kanduri and Eckhardt (2002) provide a much more detailed discussion of shrimp processing.

## Crawfish

Freshwater crawfish, members of the superfamilies Parastacoidea and Astacoidea, are freshwater crustaceans resembling small lobsters. The vast majority of crawfish are farmed using extensive methods, not wild caught. *Procambarus clarkia* (red swamp crawfish) is the single most important commercial species. Because of the low-input farming methods most often employed, harvest can vary dramatically from year to year. Until 2002, the United States (and more specifically Louisiana) was the largest producer of red swamp crawfish in the world (Moody, 2000). In 2003, China started recording significant aquaculture production of crawfish and by 2005 China had become the largest producer worldwide. Global aquaculture production was approximately 105,000 tons in 2005 (FAO, 2010). Historically, in the United States, crawfish were sold whole and live. A processing industry grew to salvage unsold live animals.

### Harvesting crawfish

Both wild and aquacultured crawfish are harvested using wire-baited traps. This is labor intensive, with traps being checked daily to remove crawfish and replenish bait. Typically, 50–75 traps are set per hectare (2.47 acres).

### Handling harvested crawfish

Crawfish are alive and active when harvested and are handled to keep them alive until they are processed. In Louisiana, harvested animals are placed in pliable, mesh sacks, with a sack typically holding about 23 kg (50 lb). Rapidly cooling harvested animals to between 4°C and 10°C (40–50°F) reduces

their metabolism, minimizes stress, and extends shelf life (Moody, 2000).

## Grading

Crawfish are typically machine graded; the grading strategy most commonly employed involves passing the animals over a series of openings that gradually increase in size. When the slot is large enough for the cephalothorax to pass, the animal will fall through the slot. For more detail on grading machine options, see Moody (2000). The crawfish industry has unofficially adopted five basic size grades (Moody, 2000): Jumbo (15 or less/lb), Large (16–20/lb), Medium (21–25/lb), Peeler (26 or more/lb), and Field run (ungraded).

## Cooking

Cooking is necessary to remove the meat from the shell and to minimize enzymatic action that can make the meat mushy. The degree of cooking is important because both under- and overcooking can result in a mushy product. Also, proper cooking is required to assure that the meat slips easily from the shell and that the intestine (which runs the length of the meat) slips easily from the meat, without breaking. Prior to cooking, crawfish are typically washed or cleaned in a washing tank or in the cooking basket.

Many different cooking procedures are used by the industry, including boiling in a cooking vessel or a steam-jacketed kettle, or using a steam chamber for heat processing. The cooking step should be closely monitored to understand the time/temperature treatment being applied. This step is considered a Critical Control Point for Hazard Analysis Critical Control Point (HACCP). Cooking is typically accomplished at the same rate as the peeling step, which follows.

### Cooling and peeling

After cooking, crawfish are generally cooled in open air to allow for hand extraction of the meat. Typically, refrigeration is not used at this step; however, a water spray may be used to speed cooling. To assure product quality, time from cooking until the final product is refrigerated should be minimized.

HACCP policies require careful monitoring of post-cooking cooling procedures.

Hand peeling by skilled workers remains the industry standard, as a mechanical process that yields meat quality equivalent to hand peeled has not been developed (Moody, 2000). Hand peeling is labor intensive and the single greatest cost factor in the final meat price. Most processing plants have a dedicated room for hand peeling of meat from whole, cooked crawfish. Cooked and cooled crawfish are piled onto peeling tables (generally, stainless steel for ease in cleaning) so that workers can selectively peel from the pile. It is recommended that time on the table prior to peeling be kept to a minimum.

## Packaging

Once crawfish are peeled, they are delivered to a packaging room where the meat is inspected for bits of shell or intestines. After inspection, product is placed into its final package. This too is generally a hand operation, with product being placed in bags, weighted and sealed. Because of a concern for *Clostridium botulinum* in packaged crawfish meat, the packaging is generally oxygen permeable. Once packaged and sealed, the product should be rapidly chilled, typically in slush ice. Ideally, time from cooking to final cooling of 0°C should be under 2 hours.

## Other freshwater crawfish products

Fresh, cooked, and peeled crawfish meat is the most important commercial product, but whole, cooked, and frozen crawfish has a significant market in Scandinavia. Local production has not been able to satisfy demand; hence, the Louisiana industry processes this form as well. Only the largest and most select animals (with all legs and claws attached) are processed for this market. The animals must be thoroughly cleaned. Typically, the animals are washed, then cooked (with steam or in boiling water) and rapidly chilled. Cooking water may or may not be seasoned, depending on final product destination. Cooked product is packed by hand into trays (typically 1 kg), and covered with additional water (with or without seasoning as appropriate) and an air-tight lid or cover, which is sealed over the tray. The tray is then rapidly frozen. Cryo-

genically freezing has been shown to produce the highest quality product (Godber et al., 1989), and is considered the industry standard.

Another product form of commercial significance is soft-shell crawfish. Soft-shell are offered raw alive or frozen, to be cooked after purchase. Processing begins by placing live animals in molting trays with recirculating water. Once an animal molts, it must be removed quickly before the exoskeleton hardens. The most typical processing method for molted crawfish is cleaning and freezing whole, using conventional freezing methods such as blast or still-air freezing (Moody, 2000). Cleaning includes removal of the stomach stones or gastrolith by making a small cut just behind each eyestalk and pushing them out.

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# 14

## Freshwater Fish

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Denise Skonberg and Thomas E. Rippen

Freshwater fish make up less than 5% of the commercial harvest of wild fishery stocks in the United States, yet several species find traditional markets, primarily in the Midwest, where they are highly prized. Consequently, seafood firms wishing to serve inland customers should evaluate local consumption patterns prior to introducing unfamiliar products.

Most freshwater fishing in the United States remains centered in the Great Lakes area, despite a dramatic decline in food species in recent years. Great Lakes is the collective name for lakes Superior, Michigan, Huron, Erie, and Ontario, which all drain to the Atlantic via the St. Lawrence River. Combined with the large lakes of central and western Canada, they contain approximately 40% of the world's fresh surface water. This chapter emphasizes these traditional North American fisheries with occasional reference to less important lakes and river systems. The bias toward North American fisheries should not be misinterpreted as suggesting that other freshwater systems are insignificant. Subsistence fishing on Lake Titicaca and the greater Amazon drainage of South America and on the large rivers of China, for example, has had a major economic and historic impact on the people of those regions. Likewise, important targeted fisheries exist

for pike and whitefish in scattered locations in Europe and Asia, as they do for Nile perch in Lake Victoria, Africa. The US experience is highlighted as a study of commercial freshwater fishing, reflecting dynamic social values and market demand.

This chapter is also confined to selected wild freshwater species. Most freshwater trout, catfish, and crayfish are produced under controlled conditions, which will be discussed in Chapter 24. Some species or populations of sturgeon, salmon, eels, shad, and other fish inhabit freshwaters during a portion of their life to spawn or feed, but they are generally considered marine species and as such are discussed in detail elsewhere.

During storage and preparation, fish performance varies according to their physiological and biochemical makeup, which in turn is dictated by their environment. This chapter addresses factors that distinguish freshwater species from their salt-water relatives. We also discuss processing methods, products, and distribution channels.

### Current status

The overall effect of the activities of humans and nonnative fish has been a shift in market products

from large, high valued species to small fish of low value. The successful stocking of salmonids, including coho and chinook salmon, may help control populations of nuisance fish but has little direct impact on regional fishing fleets. Most bordering states are committed to recreational rather than commercial fisheries. Species of trout, salmon, walleye, blue pike, smallmouth bass, and several others are generally not permitted or are limited in the US commercial catch. Access to the commercial fishery is controlled by gear and license restrictions. Wisconsin issues about 200 licenses per year, Michigan and Ohio about 100 each, with another 100 issued by the combined states of Minnesota, Pennsylvania, Indiana, and Illinois. These states plus New York contain 7527 km (4678 mi) of shoreline, equaling Ontario's waterfront.

By contrast, Canada regulates the commercial harvest of most traditional and introduced species including lake trout, walleye, northern pike, sturgeon, splake, and Pacific salmon. Ontario issues about 1000 licenses each year written for a wide variety of gear types including over 11,887 km (13 million yd) of gillnet, a net which has been severely restricted by most states in the US. The Great Lakes commercial fishery comprise primarily of whitefish, yellow perch, rainbow smelt, and chubs. Lake whitefish represent the highest value fish landed in US waters, with total landings of more than 9.5 million lb worth \$8.1 million in 2008. However, yellow perch, walleye, rainbow smelt, and chubs are all higher value species on a per pound basis, with average landed values of \$2.25, \$1.93, \$1.92, and \$1.21/lb, respectively, in 2008. In Canada, yellow perch and walleye account for the high value of the Ontario harvest, with 2006 landed values of Can\$17.6 million and Can\$12 million, respectively.

Most US fishing occurs in the western Great Lakes with only a minor fishery in lakes Erie and Ontario (Table 14.1). Canadian fleets account for nearly all the increased catch in the eastern lakes. Sales of smelt, yellow perch, and walleye have elevated the value of landings from Canadian waters of Lake Erie from \$6 million in the middle 1970s to \$59 million in 1991. Currently, the Lake Erie fishery makes up about two-thirds of the Canadian Great Lakes commercial fishery harvest.

The discovery of DDT, polychlorinated biphenyl (PCBs), dieldrin, mercury, and other contaminants in Great Lakes fish hampered the fishing industry as

**Table 14.1** US landings of selected commercially harvested freshwater fish in 2008.

Species	Weight (lb)	Value (\$)
Blue catfish	3,285,437	1,525,128
Burbot	12,286	5434
Chubs	733,966	888,842
Common carp	1,154,344	204,008
Lake Trout	666,548	240,451
Rainbow Smelt	446,984	858,362
Tilapia	62,576	42,894
Walleye	48,252	93,583
White bass	426,303	320,098
White mullet	318,864	185,817
White perch	1,834,249	1,277,983
Whitefish	9,550,007	8,118,865
Yellow perch	2,191,293	4,934,008

certain species were banned. Several contaminants monitored by state and federal agencies have generally fallen below tolerance levels, permitting the sale of some formerly banned products. Unfortunately, recent research has renewed concerns about contaminants and has led to heightened regulatory activity.

## Other fisheries

Traditional fisheries exist in the Mississippi River and its tributaries, the inland waters of Florida and certain US lakes, notably the Red Lakes and Boundary Lakes of Minnesota, and the large Canadian lakes of the prairie provinces and Northwest Territories. Historically, the Mississippi River system produced landings rivaling the Great Lakes, but now much of the catch has a lower market value. Catfish, carp, buffalofish, and sheepshead still predominate.

The Boundary Lakes (Lake of the Woods and Rainy Lake) have annually produced large yields of walleye, northern pike, and lake herring, although Minnesota has sharply curtailed commercial fishing in these waters with significant reductions on the Canadian side as well. An Indian gillnet fishery on the Red Lakes has historically been highly productive, producing up to 318,000 kg (700,000 lb) of walleye a year, 454,000 kg (1 million lb) of yellow perch, 36,400 kg (80,000 lb) of whitefish, 22,700 kg (50,000 lb) of northern pike, and 454,000 kg (1 million lb) of suckers and sheepshead. A moratorium



was imposed in 1997 on harvesting walleye in this fishery following a crash in the population. A major conservation program resulted in strong recovery of the stock and harvesting resumed in 2006.

Canada's inland fisheries include 11 commercially important lakes in Manitoba, Saskatchewan, Alberta, and the Northwest Territories. Walleye, whitefish, northern pike, lake trout, sauger, lake herring, and arctic char are the most valuable species. They are harvested primarily with gillnets fished in either open water or under the ice and with poundnets, trapnets, and seines.

## Markets/processing

The freshwater industry remains based on traditional products and markets. Most fish are whole-saled fresh, usually whole but also dressed, filleted, or chunked. Typically, family-owned or cooperative fishing operations on the Great Lakes include a simple shoreline facility for cutting, icing, boxing, and storing the catch. The fish are sold locally or shipped (usually contracted with trucking firms) to wholesale distributors in major cities, most notably Chicago.

Many of these small businesses operate a smokehouse for hot-smoking (kippering) drawn, dressed, or chunked fish. Chubs, lake whitefish, lake herring, and imported whiting are the species commonly selected for smoking. Smoked products are mostly consumed locally although a few large volume processors and distributors ship finished products to distant metropolitan centers, including New York and Miami. Some of the most modern processing and distribution plants are located in Canada. They are generally very competitive with US firms, offering buyers attractive prices and relatively stable supplies, although seasonal gluts contribute to periodically suppressed prices.

The historically important salt-cured lake herring trade has virtually disappeared. Years of poor catches and changing consumer attitudes are probably responsible. Efforts by processors to diversify their product lines have met with encouraging but generally modest results. Some whitefish roe is screened, washed, and brined for further processing into caviar; certain underutilized species, including suckers, lake herring, and round whitefish, are mechanically deboned to make mince.

Freshwater fish are the primary ingredient in processed products destined for the Jewish trade, notably gefilte fish, which is made by cooking seasoned fish dumplings in a vegetable/fish stock. Important species include whitefish, carp, and walleye.

## Composition and quality

### Shelf life

In general, spoilage patterns are similar for freshwater and saltwater fish. Bacterial composition may be somewhat different during certain stages of decomposition but proteolytic (protein-consuming) microorganisms lend familiar putrefactive flavors and odors to both groups. As with saltwater fish, enzymatic activity varies with species and season.

Despite similarities, freshwater products, on average, maintain quality longer than do their marine counterparts. This fact is generally attributed to the presence of light-weight compounds known as osmoregulators in saltwater fish. Although important for balancing flesh "salt" content with the marine environment, bacteria readily break down these compounds as a food source. Deterioration of osmoregulators is associated with ammoniacal odors, bitter flavors, and undesirable textural changes during frozen storage of susceptible seafoods.

Freshwater fish must deal with a harsh environment relatively free of electrolytes. As a result, water invades their tissues under osmotic pressure and must be excreted as copious dilute urine. They do not drink. Chemical osmoregulators would be counterproductive. Consequently, related shelf-life problems are notably absent.

### Red versus white muscle

As with saltwater species, freshwater fish have muscle ranging from white to well-defined regions of white meat and dark meat to mostly dark meat. However, few species of freshwater fish contain flesh as highly pigmented as some migratory saltwater fish. The red blood pigment, hemoglobin, and muscle pigment, myoglobin, bind oxygen for transport and storage. These pigments can release

**Table 14.2** Nutrients in selected freshwater fish species (per 100 g wet weight)

Species	Protein (g)	Fat (g)	Water (g)	Mineral (g)	Kcal	Omega-3 (mg)
Burbot	19.3	0.8	79.3	1.2	90	192
Carp	17.8	5.6	76.3	1.5	127	704
Channel catfish	16.4	2.8	80.4	1.0	95	535
Perch	19.4	0.9	79.1	1.2	91	283
Pike	19.3	0.7	78.9	1.2	88	142
Rainbow smelt	17.6	2.4	78.8	1.4	97	760
Walleye	19.1	1.2	79.3	1.2	93	363
Sunfish	19.4	0.7	79.5	1.1	89	152
Whitefish	19.1	5.9	72.7	1.1	134	1604

oxygen for desirable chemical reactions in the tissues while making it unavailable for detrimental reactions.

Saltwater species that require great quantities of energy for swimming rely primarily on metabolism of tissue oils, an oxygen-consuming process. Consequently, most free swimming species are both dark-fleshed and oily. Freshwater species are less likely to expend large quantities of energy for movement. Even species that do, such as migratory freshwater trout, function with little red muscle probably because they frequent well-oxygenated water. A few freshwater fish that are highly pigmented may have adapted to low oxygen environments. Carp and bullhead catfish are examples.

### Nutrient composition

Like their saltwater counterparts, freshwater fish are an excellent source of high-quality protein, with protein contents typically ranging from 16 to 20 g/100 g wet fillet. Fat content of fillet is highly variable, depending on species, geographical location, and season of harvest. Fish harvested in late summer have higher fat contents and correspondingly higher energy values (kilocalories) than fish caught in late winter. The contents of omega-3 fatty acids, including linolenic (18:3), EPA (20:5), DPA (22:5), and DHA (22:6) are also highly variable within freshwater fish species, and are generally somewhat lower than the omega-3 fatty acid contents of saltwater fish. However, wild caught channel catfish, rainbow smelt, and carp all contain more than 500 mg omega-3 fatty acids per 100 g (3.5 oz) serving, and omega-3 fatty acid contents of lake trout and whitefish are considerably higher. Typically, the fat

in cold-water fish has a higher percentage of omega-3 fatty acids than in warm-water fish. Cholesterol contents for freshwater fish are low, ranging from approximately 40–90 mg/100 g. The nutrient values for selected freshwater fish species listed in Table 14.2 were obtained from the USDA National Nutrient Database and represent values averaged from multiple sources of data.

### Consumer preference

Marketing strategies often emphasize oil content, color, texture, and flavor intensity as a basis for classification of fish species. Lake trout, lake whitefish, and similar freshwater species may prove helpful for supplementing light-mild-oily categories not always available from marine fisheries. Other lake fish can be substituted for traditional lean, mild marine fish without compromise. Walleye and yellow perch are highly regarded by mid-western seafood consumers among higher priced lean species. A survey of restaurant managers in the Midwest indicated that walleye and yellow perch outsell halibut, a comparably lean, high-value marine species. Although customer demand for yellow perch or walleye in restaurants is highest in the summer, both products are served year round, despite the fact that the yellow perch commercial fishery is seasonal. Typically, restaurants prefer to select fillets when purchasing yellow perch and walleye. A recent study conducted at the Ohio State University assessed how well consumers liked yellow perch in comparison to its major market competitors, walleye, ocean perch, and imported European zander. Although consumers were able to detect differences between the four species of

restaurant-style deep-fried fish, they liked them all equally with the exception of walleye which was rated somewhat lower. Interestingly, restaurants in the Minneapolis/St. Paul region of Minnesota were investigated by the Food and Drug Administration (FDA) in 2004, when they were reported to be serving imported zander under the name of walleye on their menus. Other freshwater fish including smelt, suckers, sheepshead, and several other inexpensive fish are considered fine eating and serve to round out product lines at lower cost than many comparable saltwater products.

### Off-flavors

When comparing flavor of fresh products, few distinctions can be made between freshwater and saltwater species. However, earthy, musty, or weedy off-flavors, when they occur, are encountered primarily in freshwater fish. These flavors occur more by season and location than by species.

Regional consumer bias against certain fish may be related to poor experiences with local supplies. Even fish normally in high demand such as walleye may accumulate a "muddy" flavor at times, while the same species caught in another location may be unaffected.

The organic compounds geosmin and 2-methylisoborneol are produced by certain microorganisms and algae and are readily absorbed by fish, lending disagreeable flavors and odors to their flesh. Fish need not ingest the plants to become tainted but probably pick up the compounds from the water via the gills and epithelial tissues. Other off-flavors can be traced to decayed organic matter or, rarely, chemical contamination.

Objectionable flavors appear most commonly in fish taken from shallow, weedy lakes and slow-flowing streams. Large bodies of water typical of most commercial fisheries are less affected.

### Parasites

Parasites may be found in nearly all saltwater and freshwater fish, often appearing as cysts or worms in the flesh or viscera. They are characterized by complex life histories typically requiring one or more intermediate host(s). Only parasites that need

both cold-blooded and warm-blooded animals during their life cycles are capable of infecting humans who consume them in fish.

Saltwater seafoods may contain roundworms (nematodes) capable of causing severe but temporary digestive upset in humans. The FDA has expressed concern that pathogenic nematodes may become a problem because of the increased popularity of raw or lightly marinated fish.

Perhaps due to the proximity of freshwater environments to many warm-blooded animals, freshwater fish may represent a greater health concern than do saltwater fish. Also, nonpathogenic but unsightly infestations can be especially troublesome to firms marketing affected products. Tapeworms and flukes occasionally infect consumers of raw freshwater fish.

Northern pike, walleye, and burbot from the northern Midwest United States have the highest incidence of tapeworms. Complete coagulation of fish muscle by cooking, pickling, or salting kills harmful parasites and accounts for the scarcity of clinical cases in the United States. In most cases, frozen storage also destroys parasites. To prevent the migration of roundworms from the viscera to surrounding meat, the fish should be thoroughly iced and problem species marketed in eviscerated forms.

### Contaminants

Pesticides, heavy metals, and other contaminants in fish flesh have adversely affected regional fisheries around the world. The US freshwater industry has been affected by regulatory action and by consumer response to a list of chemicals and trade names, including mercury, DDT, PCB, polybrominated biphenyl (PBB), dieldrin, and Mirex.

An estimated 5000–10,000 new chemicals are produced each year, of which 1000 are introduced into commerce. To protect consumers from possible harmful effects, the Toxic Substance Control Act of 1976 requires that certain classes of chemicals be screened for toxicity before they are cleared for use. In addition, it allows for federal regulation of the production and application of these chemicals. More recent legislation has strengthened enforcement capabilities. Once chemicals are in use, the FDA establishes and enforces limits on the amounts of certain substances that may appear in foods.

State departments of commerce, health, and natural resources also commonly enforce measures to reduce public exposure to contaminants.

Although new contaminants in fish are identified periodically, monitoring programs have documented reduced concentrations of several of these substances in recent years. As mentioned, few products are currently banned from the marketplace by legislation. Concerned consumers should know that commercially sold fish are routinely evaluated for major contaminants. Sport fishermen, who may eat considerable quantities of problem fish without the benefit of such sampling, are at greater risk.

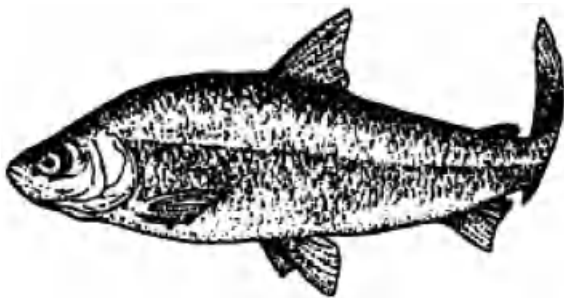
## Selected species

### Whitefish

Whitefish, which account for a significant portion of the trade in inland markets, is a collective name for certain members of the Salmonidae family including true trout and salmon. They are characterized by an adipose fin (a small rayless projection behind the dorsal fin), a small delicate mouth, white flesh, and mild flavor.

### Lake whitefish

Virtually all the whitefish sold under the name are lake whitefish (*Coregonus clupeaformis*) (Figure 14.1). A large, relatively oily whitefish, they grow to more than 5.5 kg (12 lb) but average 0.91–2.27 kg (2–5 lb). They are found from New England to Minnesota



**Figure 14.1** Lake whitefish, the primary species sold as whitefish.

and north to the Arctic and Alaska. In recent years, Canada has increased its percentage of the catch as fishermen work the deep cold lakes of the north-central provinces and Northwest Territories. They produce about  $9.1 \times 10^6$  kg (20 million lb) each year by fishing gillnets even under thick ice.

Lake whitefish are marketed whole, dressed, chunked, and filleted. The roe is fine in texture and remains tender when cooked. Market demand is strong for eggs processed as “golden” caviar or whitefish caviar. Although commonly sold fresh, large quantities of frozen, smoked, and canned lake whitefish (combined with other species as gefilte fish) are also distributed.

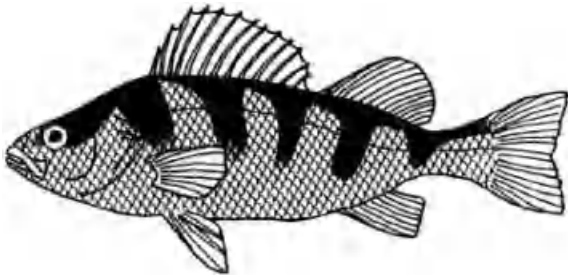
### Chubs (lake herring)

Several species of small whitefish are marketed in the United States as chub, especially when drawn and smoked. Among biologists, “cisco” is the more universally accepted name for this group. Fish sold as “lake herring,” “tullibee,” or “cisco” are usually *Coregonus artedii*. Other chubs, some of which are threatened or extinct, include deepwater cisco (*Coregonus johanna*), longjaw cisco (*Coregonus alpe*), shortjaw cisco (*Coregonus zenithicus*), short-nose cisco (*Coregonus reighardi*), and blackfin cisco (*Coregonus nigripinnis*). Additional market names include bloater and grayback. Sometimes, the term chub implies a smoked product because it is the most common market form. Seafood suppliers and buyers should communicate clearly, due to confusing whitefish nomenclature.

### Other whitefish

Round whitefish or menominee (*Prosopium cylindraceum*) is a common resident to cold lakes of northern New England, the Great Lakes, and Canada. Compared to some members of the whitefish family, round whitefish is lower in oil content and, as the name implies, round in cross section. It is smaller than lake whitefish and finds only limited, usually local, markets despite desirable eating qualities.

Inconnu or sheefish is a very large whitefish of northwestern Canada and Alaska. They are found in large lakes and streams where they migrate to sea. Anadromous (migratory) individuals may



**Figure 14.2** Yellow (freshwater) perch.

reach 27.2 kg (60 lb); landlocked specimens are somewhat smaller. Inconnu (French for unknown) possess white, oily, mild flesh but find few buyers in the United States, possibly due to limited experience with the species. Perhaps  $2.27 \times 10^4$  kg (50,000 lb) are shipped to the lower regions of the United States.

### Yellow perch

Yellow perch (*Perca flavescens*) is among the most valuable species in the freshwater industry, remaining a mainstay of many US and Canadian fishing ports (Figure 14.2). In recent years, imports from Canada have dominated the market. The high value of Ontario landings is largely attributed to perch. Although, landings of yellow perch from Ohio's historically important Lake Erie fishery were sporadic during the 1990s, they have steadily increased to reach the 2008 level of 1.95 million lb of fish with a value of \$4.4 million.

Yellow perch are true perch (family Percidae) closely related to walleye and sauger. They have little in common, either taxonomically or gastronomically, with white perch, ocean perch, or a dozen other species commonly referred to as "perch." The term lake perch may refer to either yellow or white perch. Yellow perch are widely distributed from South Carolina north to Nova Scotia and west to the Great Lakes and west-central Canada.

Although yellow perch average under 0.454 kg (1 lb), their simple skeletal structure and small visceral cavity lend them to commercial filleting, sold fresh or frozen. Other forms include whole and, less commonly, breaded and frozen. Yellow perch are recognized by the presence of two spiny dorsal

fins, a greenish to yellow body with dark vertical bands, and yellow to orange pelvic fins. The flesh is firm, white, lean, and mild but distinctive. Well-handled fresh or frozen perch generally retain quality longer than many species. Gillnetters find they hold up well in their nets and are slow to develop signs of enzymatic softening.

### Walleye

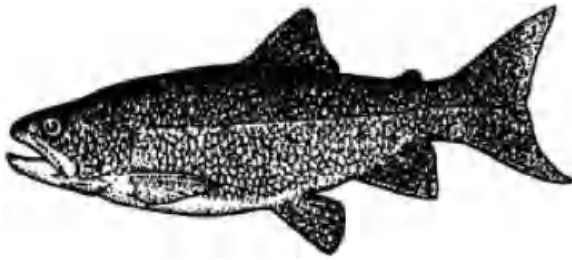
Another member of the perch family, walleye (*Sander vitreum*), is similar to yellow perch both in general appearance and in eating quality. They are larger however, reaching 4.5 kg (10 lb) or more although averaging 0.9–1.8 kg (2–4 lb). Their back is dusky, grading to bronze-gold on the sides. Long recognized for their culinary quality, walleye were known as salmon to early settlers. The meat is fine textured, firm, white, lean, and mild.

Its natural range extends from North Carolina to New England, west to the Rocky Mountains and north to the Hudson Bay. Largely protected as a game fish in the United States, most of the  $5.45 \times 10^6$  kg (12 million lb) available are imported from Canada. Small quantities are available from New York, Pennsylvania, and American Indian fisheries. They are available fresh or frozen, whole, dressed, filleted (skin off or on), and as breaded fillets. They also appear as an ingredient of gefilte fish. Shelf-life characteristics and fillet yield are similar to yellow perch.

Walleye are usually marketed under that name or walleye pike in the United States but are recognized as yellow pickerel by the Canadian government. Suppliers may list them as yellow pickerel, pike-perch, or yellow pike, although as a percid, walleye are unrelated to pike or pickerel. As an adaptation to low light levels, their eyes are naturally opalescent, which negates cloudiness as an indicator of quality. Blue walleye is a walleye color variant, possessing a gray to blue body instead of the typical golden hue. They are almost certainly not true blue pike (*Sander vitreus glaucus*), a Great Lakes species which appears to be extinct.

Sauger (*Sander canadensis*) is a close relative and, though somewhat smaller, nearly identical to walleye in appearance. Look for the absence of a white tip on the lower lobe of the tail fin, characteristic of walleye. Sauger enter markets mostly as an incidental catch of the walleye fisheries. Eating quality





**Figure 14.3** Lake trout, the largest of North American trout.

is similar to walleye and blue pike but is considered by some to be slightly less desirable.

### Lake trout

Lake trout, the largest of North American trout (technically, a char), are found in cool, deep lakes across northern America (Figure 14.3). They are available from Canadian, Wisconsin, and Minnesota sources and certain Midwest American Indian companies fishing under treaty. Lake trout (*Salvelinus namaycush*) are also known as mackinaw, togue, namaycush, forktail, and Great Lakes trout. They average about 1.8–2.3 kg (4–5 lb) in the commercial catch but may reach 22.7 kg (50 lb) or more. Like whitefish and other salmonids they possess a small fleshy adipose fin on their back behind a spineless dorsal fin. They have large mouths and sharp teeth. Coloration is dull but distinctly marked with light spots on a darker background.

Lake trout are among the most oily of commercial fish ranging up to 22% fat for the common species. The closely related siscowet, or fat trout, may contain more than 50% fat. These deepwater trout are only occasionally available on the market, usually in a smoked form. Until the late 1980s, about 600,000 lb of siscowet were harvested annually. A recent study revealed that there are over 600 million lb of this omega-3 fatty acid rich fish in Lake Superior alone. Lake trout populations were decimated by the lamprey invasion of the 1940s and 1950s. Current Great Lakes stocks are maintained by ongoing stocking programs because current cultured varieties cannot reproduce naturally. There is some hope that the wild western brood stock will help reestablish a self-sustaining population in the future. A lake trout/brook trout hybrid known as splake has been introduced and is harvested by Ontario fishermen.

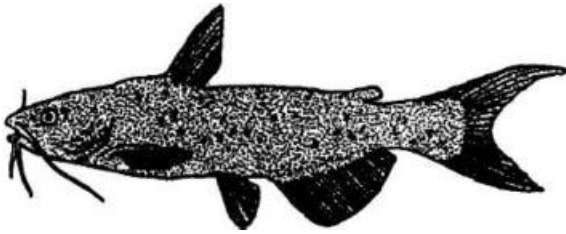
### Smelt

Several small, slender species of fish may be called smelt but the one most commercially important is the rainbow smelt or lake smelt (*Osmerus mordax*). It is a silvery to greenish fish usually under 20.3 cm (8 in.) long with a rather large mouth for its size and characteristically sharp teeth, even on its tongue. Its small silvery scales are easily rubbed off. An anadromous fish by nature, living in saltwater and entering freshwater streams to spawn, it has adapted so well to freshwater habitats that it is often considered a freshwater fish. Smelt are widely distributed in the Great Lakes region and in the Northeast where they are taken by a variety of gear including small mesh gillnets, pound nets, and trawls. Some states manage smelt as forage for game fish and do not issue commercial fishing permits. Much of the supply comes from Canada.

Often labeled as fatty fish, smelt are actually quite lean, about 2% fat, although a much more oily cousin, the eulachon or Columbia River smelt, is locally popular in the Northwest. Some buyers consider lake smelt better than Atlantic or Pacific species. Smelt are available nearly year round either fresh or frozen, headed-and-gutted, or whole. They are nearly always breaded and fried, and eaten bones and all. Although shelf-life properties are generally good, the delicate flavor and texture that smelt are noted for are quickly lost when mishandled.

### Catfish

Originally native to the Mississippi, Missouri, and Ohio River drainage, blue catfish (*Ictalurus furcatus*) have been widely introduced throughout the country, and are most prevalent in central and southeastern United States. They are the largest catfish species in the United States with trophy fish reaching sizes well over 100 lb. Highly prized by anglers for their firm, white, mild-flavored flesh and fighting spirit, these fish are also harvested commercially in numerous states including Louisiana, Virginia, Kentucky, Arkansas, Tennessee, Illinois, and Texas. For many years, the largest commercial harvest has occurred in Louisiana; however, that harvest has gradually dropped from 4.2 million lb in 2000 to 2.8 million lb in 2008. Also known as the humpback blue, forktail cat, chucklehead, and



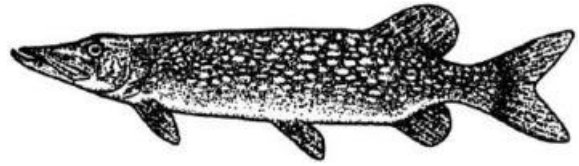
**Figure 14.4** Channel (or spotted) catfish.

Fulton cat, these fish are primarily processed and sold in local markets.

Channel catfish (*Ictalurus punctatus*) are mostly farm raised, but fisheries remain in the Great Lakes, in Mississippi drainage, and in some coastal tributaries of the East and Gulf coasts (Figure 14.4). Flathead catfish, white catfish, and bullheads are also available. In 2008, Louisiana reported the highest catches of catfish, with landings of 578,000 lb and 325,000 lb for channel catfish and flathead catfish, respectively. Catfish tolerate low oxygen levels and are one of the few fish sometimes marketed alive. They may be held in drums or tubs on fishing vessels, and then transferred to aerated tanks at shore-side facilities. They are also marketed dressed (headed-and-gutted, skinned) and, to a lesser extent, filleted or steaked.

### Other species

Small but regionally significant quantities of other wild harvest freshwater fish are also caught in North America, most finding local or ethnic markets. Pike are large, toothy fish that frequent northern lakes and streams from New England to the Midwest and most of Canada. The northern pike (*Esox lucius*), the only species supporting a commercial fishery, grow to 11.4 kg (25 lb) or more, but 1.8–3.2 kg (4–7 lb) is more common (Figure 14.5). They are recognized by their long, slender shape and greenish skin covered with yellow or cream-colored oval spots. Supplies come primarily from Canada since they are protected in the United States. Much of the catch is exported to Europe where the same species is also native but exists in numbers too low to satisfy the strong demand. The name, pike, is occasionally confused with market terms for walleye, yellow pike, blue pike, and yellow pickerel. In fact, walleye are some-



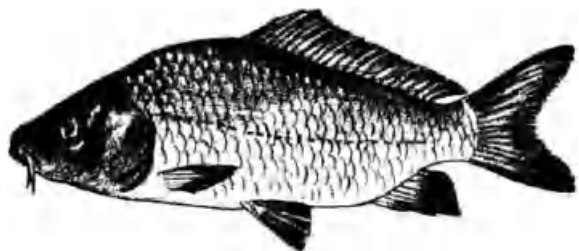
**Figure 14.5** Northern pike.

times called walleye pike. Such confusing nomenclature is unfortunate because the two species are unrelated and dissimilar in appearance and eating quality.

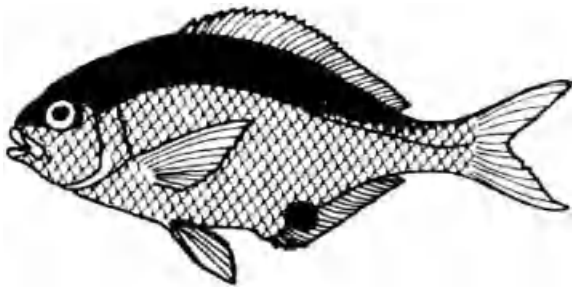
Northern pike are a lean (1–2% fat), very firm and mild fish containing numerous Y bones (forked intermuscular bones). They are sold whole or cut into most market forms, fresh or frozen.

Carp (*Cyprinus carpio*) is popular in many ethnic centers (Figure 14.6). Nearly  $13.6 \times 10^6$  kg (30 million lb) are harvested commercially in the United States each year, mostly from the Mississippi River system, the Great Lakes, and from states issuing permits as part of fish control programs. Because of a propensity for concentrating geosmin compounds, they are best when harvested in winter or from bodies of water where algae are not a problem. The flesh is often oily, ranging from 2% to 25% fat, and has a distinctive but pleasant flavor. Carp are usually marketed whole or in finished products, such as gefilte fish.

White perch (*Morone americana*) is both a freshwater and saltwater species (Figure 14.7). It is not a perch at all but a small relative of the striped bass and sea basses. Lake Erie's white perch populations have increased in recent years as large numbers have migrated from the Atlantic by way of the Welland Canal. The harvest has also increased somewhat in the Mid-Atlantic marine fisheries since 1985. Fillets are sometimes sold as lake perch,



**Figure 14.6** Carp.

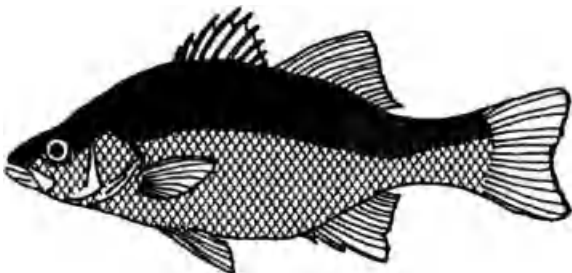


**Figure 14.7** White perch.

a name also used for the higher valued yellow perch. To add to the confusion, white perch is also a market name for freshwater drum, otherwise known as sheepshead or freshwater croaker.

A closely related species, the white bass (*Morone chrysops*), is an important fish in the Lake Erie fisheries both in Canada and the United States (Figure 14.8). It resembles a silvery, panfish-sized striped bass, having narrow dark stripes that run the length of the body. The average size is about 454 g (1 lb) although some individuals approach 1.8 kg (4 lb) especially in southern and southwestern reservoirs where they have been stocked for recreational fishing. White bass produce boneless fillets of good eating quality.

Suckers make up another family of freshwater fish of some importance. The white sucker or freshwater mullet (*Catostomus commersoni*) is probably the most significant commercial species. Although harvested primarily in the Great Lakes, it is widely distributed east of the Rocky Mountains. As with some of the other suckers, it is well known for its numerous fine bones which limit market potential. The fish are sometimes split and scored to reduce bone size, which then soften during cooking. Several processing plants have used this species



**Figure 14.8** White (freshwater) bass.

to produce boneless minces. It is a drab green to nearly brassy-colored fish of about 1 to 1.4 kg (2–3 lb). Other suckers include three species of buffalo (large fish resembling carp harvested in the Mississippi valley south of the Great Lakes); the longnose sucker; ten species of redhorse; two species of quillback or carpsucker; the spotted sucker; and the blue sucker.

Other North American freshwater fish occasionally seen in the markets include crappie, various sunfish, freshwater drum, rock bass, burbot, lake sturgeon from Canadian sources, eel, bowfish, gar, paddlefish, and alewives (smoked or cured). The American paddlefish (*Polyodon spathula*), also known as spoonbill cat or spoonbill sturgeon, provides the roe for much of the “American sturgeon” caviar on the market. It is not related to either sturgeon or catfish. Most alewives, gizzard shad, and goldfish are sold for commercial bait or industrial applications.

As mentioned previously, Pacific salmon species stocked in the Great Lakes are tightly managed for recreational purposes; however, significant quantities are marketed. The State of Michigan awards a contract for sale of adult salmon taken at weirs where eggs and milt (the male’s sperm) are collected for culture, and Canada permits limited fishing.

## Acknowledgments

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# 15

## Nutrition and Preparation

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Doris T. Hicks

### Introduction

Foods from the sea have for hundreds of years been a source of protein. Nutritionists have known for years that seafood is a good source of high-quality protein. We also know now that seafood has a lot more to offer than just high-quality protein and that fish and shellfish can be and should be part of a healthy diet. The US Department of Agriculture (USDA) recommends that we maintain a healthy diet, one that emphasizes fruits, vegetables, whole grains, and fat-free or low-fat milk and dairy products; includes lean meats, poultry, fish, beans, eggs, and nuts; and is low in saturated fats, trans fats, cholesterol, sodium, and added sugars. The USDA and the US Department of Health and Human Services also advises that by adding seafood to your diet, as little as two meals of fish or shellfish per week (and a daily dose of exercise!), you'll be well on your way to a healthier lifestyle. Fish is also a good source of other nutrients. Baked, broiled, steamed, or grilled, seafood is good for you. It is a good low-calorie protein choice for all diets. Seafood is an essential part of a healthy lifestyle. The 2005 Dietary Guidelines Advisory Committee

recommended two 4-oz servings of fish per week. In the new food pyramid ([www.mypyramid.gov](http://www.mypyramid.gov)), the US government prominently features recommendations for Americans to consume two servings of seafood every week to maintain a healthy diet. Proteins, vitamins, and fatty acids found in seafood contribute to improved cardiovascular and neurological health. This chapter examines the major nutrients found in seafood and discusses various preparation methods. The USDA Dietary Guidelines are reviewed and revised every 5 years.

A Commentary in the 2010 November issue of the *Journal of the American Dietetic Association*, Linda Van Horn, PhD, RD, Editor-in-Chief of the Journal, Chair of the Dietary Guidelines Advisory Committee (DGAC), and Professor and Associate Dean, Northwestern University, Feinberg School of Medicine, highlights the key features and noteworthy findings of the 2010 US DGAC Report. In this commentary, Dr. Van Horn indicates that many of the recommendations from the 2005 US Dietary Guidelines are reinforced, new evidence-based findings will help health care providers provide guidance to encourage better eating habits among Americans.



A review of the following will help you understand the measurements referred to in this chapter:

- 1 pound (lb) = 16 ounces (oz)
- 1 ounce = Approximately 28 grams (g)
- 1 gram = 1000 milligrams (mg)
- 1 gram = 1,000,000 micrograms ( $\mu$ g)

### Make smart choices from every food group

The best way to give your body the balanced nutrition it needs is by eating a variety of nutrient-packed foods every day. Just be sure to stay within your daily calorie needs. A healthy eating plan is one that:

- (1) emphasizes on the intake of fruits, vegetables, whole grains, and fat-free or low-fat milk and milk products;
- (2) includes lean meats, poultry, fish, beans, eggs, and nuts;
- (3) is low in saturated fats, trans fats, cholesterol, salt (sodium), and added sugars ([www.cnpp.usda.gov](http://www.cnpp.usda.gov)).

### Nutrient intake recommendations

The Recommended Daily Allowances (RDAs) reflect the average daily amount of a nutrient considered adequate to meet the needs of most healthy people. The nutritional facts label on many different foods reflects Daily Values (DV) for the different nutrients found in food. They help you evaluate how a particular food fits into what you eat for the entire day. DV are average levels of nutrients for a person eating 2000 calories a day. For example, a food item with a 5% DV for fat means 5% of the amount of fat that a person consuming 2000 calories a day would eat.

## Major nutrients

### Protein

- (1) Build and repair body tissues.
- (2) Help antibodies fight infection.
- (3) Supply energy (4 calories per gram) if more is consumed than needed to build and repair body tissues.

Protein is absolutely essential to human diets. It ensures that amino acids are available to build new tissue and maintain old tissue. It forms enzymes, proteins that function to catalyze body reactions. It forms some of the body's hormones, substances that act to regulate some body functions (e.g., regulation of body temperature). Proteins make up the body's antibodies, the body's defense against such things as bacteria, viruses, and toxins. Proteins are also essential for helping to maintain the body's fluid balance, salt balance, and acid-base balance, and it can serve as a source of energy.

Proteins are large molecules composed primarily of amino acids. Our body's digestive enzymes break down the protein we consume to release amino acids that are in turn used to make new proteins the body uses for growth and maintenance. There are nine amino acids that the body cannot manufacture; we must get them from food. They are called essential amino acids. Seafood contains all nine essential amino acids; therefore, it is an excellent choice for meeting our daily protein needs. An added advantage of seafood is that its protein is highly digestible. The protein in seafood is more readily broken down and absorbed than the protein in red meats and poultry. This advantage makes seafood an excellent food choice for people of all ages. Fish contain 17–25% protein with an average protein content of 19 g/100 g.

The amount of protein in fish varies from species to species and even within species. This variation is caused by differences in feeding habits, age and sex of the fish, and fat and water content of the flesh. Generally speaking, in finfish, the muscle contains about 18–22 g of protein in each 100 g of edible meat (a 100 g portion is roughly equivalent to an average-sized serving of 3.5 oz). There is an inverse relationship between fat content and water and protein content in fish. High fat content generally means that the moisture and protein contents are lower. Shellfish that are classified as mollusks (oysters, clams, scallops, etc.) generally contain a little less protein than finfish; crustaceans (crabs, shrimp, lobsters, etc.) tend to contain more protein than finfish.

Fish protein is classified as high quality, that is, it contains all the amino acids necessary for growth and maintenance of body tissues. (Amino acids are molecular units that hook together in various formations to form the chains called proteins.) This protein is also highly digestible, due to the short muscle fibers and lack of tough connective tissues.

## Fat

### (1) Supply energy (9 calories/gram).

Fat performs several essential body functions. It is a major source of energy for the body, making available over twice as much energy per gram as either protein or carbohydrate. (Fat yields 9 calories per gram; protein and carbohydrate both yield 4 calories per gram.) Fat also surrounds and protects the body's organs and helps the body maintain a constant temperature. In addition, fat can be found as an important part of the membranes that surround the body's cells. Finally, many other nutrients are soluble in fat (vitamins A, D, and K), and therefore, fat is a "carrier" for certain fat-soluble nutrients.

Seafood tends to be low in fat content, but what fat it does have differs from that found in many other protein foods. Of greatest interest to most people is that seafood fat contains a great proportion of highly unsaturated fatty acids. (Fatty acids are chains of carbon atoms bonded together; the number of carbons in the chain varies from one fatty acid to another.) The polyunsaturated fatty acids have been shown to help reduce the body's cholesterol level.

The fat content of fish varies with the season, geographical origin, prevailing temperatures of the environment, physiological state of the animal, and the food available to the animal. It is important to realize that the dark flesh of fish has more fat and therefore less protein than the light flesh. Fish are usually categorized as lean, moderately fat, and fat with the percentage of fat being less than 5%, from 5% to 10%, and greater than 10%, respectively.

Though the polyunsaturated nature of fats in fish makes it highly desirable in diets, this same characteristic makes it more susceptible to oxidation and rancidity. This is the reason that bluefish, for example, a moderately fat fish, will spoil more rapidly in your freezer than sea trout, a lean fish.

## Omega-3 fatty acids and cholesterol

### (1) The bonus: long-chained polyunsaturated fatty acids (PUFA).

Because most finfish and shellfish are low in fat, averaging only 1–5% in total fat, most seafood has only 90–100 calories per 3-oz serving. Compare that to the same size serving of ground beef, which has 15–20% fat and about 230 calories, and it's easy to

see why seafood is a healthier choice when prepared in a low-fat recipe. Deep-frying or serving seafood with a cream sauce can add extra fat and calories, but broiling, barbecuing, poaching, microwaving, or steaming on a rack can help minimize the amount of fat in your dish. Adding seafood to your diet also can help you meet the USDA dietary guideline to "reduce cholesterol consumption to 300 mg per day." One serving of fish (3 oz, cooked) averages about 30–90 mg of cholesterol; shellfish have only slightly higher cholesterol content, ranging from 80 to 160 milligrams per serving.

### *The bonus: fish oils*

Consequently, eating seafood is a good idea, it's compatible with optimum dietary practices and recommendations, and it can help you maintain a low-fat diet. The bonus, the consumption of fish oils, provides additional heart and health benefits. Fish oils, like other fats or lipids, are composed of glycerol to which three fatty acids are attached. The fatty acids contain chains of carbon atoms linked by single and/or double bonds. Polyunsaturated fatty acids contain several double bonds between carbon atoms in the chain, the more double bonds, the higher the degree of unsaturation.

Fish oils are unique in that they are rich in essential polyunsaturated fatty acids called omega-3 fatty acids. The fatty acids contain chains of carbon atoms linked by single and/or double bonds. Polyunsaturated fatty acids contain several double bonds between carbon atoms in the chain, the more double bonds, the higher the degree of unsaturation.

The most important omega-3 fatty acids found in seafood are eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). Fish and shellfish ingest and accumulate EPA and DHA through the food chain from microscopic algae and phytoplankton, the primary producers of omega-3 fatty acids. Since our bodies are unable to provide their own omega-3 fatty acids, we need to obtain them through food. The National Institutes of Health recommends that we consume 0.65 g per day of DHA plus EPA. Although all fish contain omega-3 fatty acids, the quantities of EPA and DHA vary among species and depend on diet, environment, and whether the fish is wild caught or farm raised. Oily fish are one of the best sources of these essential fatty acids, particularly salmon, fresh tuna, and trout.

Most nutrition researchers say that eating seafood twice a week may be beneficial in preventing coronary heart disease. Not only may the polyunsaturated fatty acids in seafood reduce the risk of arrhythmia in diseased heart muscle, but they also lower blood cholesterol and triglyceride levels, two important indicators for heart disease. Omega-3 fatty acids help maintain a critical balance of lipoproteins, increasing the levels of high-density lipoprotein that are responsible for carrying cholesterol away from the artery walls. Omega-3 fatty acids also form a different pattern of prostaglandins (hormone-like compounds), which minimizes blood clot formation, reduces the number and stickiness of blood platelets, and makes red blood cells more flexible so that they flow through the arteries more smoothly. Current science also indicates that the nutrients in seafood also substantially benefit neurodevelopment.

Researchers suggest that increasing your intake of omega-3s from seafood provides many other health benefits in addition to preventing heart disease. An excellent anti-inflammatory agent, omega-3 fatty acids can alleviate the symptoms of arthritis, asthma, inflammatory bowel disease, multiple sclerosis, and psoriasis. They also may help counteract Alzheimer's disease, cystic fibrosis, depression, diabetes, emphysema, headaches, and some kidney diseases. Omega-3s also appear to be effective against some types of cancers; they may reduce the body's production of cancer-promoting enzymes, delay or reduce tumor development in breast cancer, and prevent the development of benign polyps into malignant colon tumors (Table 15.1).

## Water

- (1) Is essential for life.
- (2) Represents two-thirds of our body weight.
- (3) Is part of every living cell.
- (4) Is the medium for all metabolic changes (digestion, absorption, and excretion).
- (5) Transports nutrients and all body substances.

**Table 15.1** Cholesterol content of seafood.

Seafood, 3 oz serving	Cholesterol (mg)
Mollusks (clams, oysters, scallops)	48–90 mg
Crustaceans (crabs, lobster, shrimp)	80–160 mg
Finfish (catfish, cod, salmon)	50–70 mg

- (6) Helps maintain body temperature.
- (7) Acts as a lubricant.

Fish and shellfish are very high in water content, averaging 80–85%. Generally, mollusks contain more water than either finfish; or crustaceans.

Water is essential for body functions in fact, it makes up about 60% of body weight. Water performs many functions, among them serving as part of the source of the chemical structures and compounds that form the cells in the body. It is involved in many chemical reactions and is used as a major medium of transportation in the body. Water is also a very good solvent and, therefore, dissolves substances and carries them to the cells. Acting as a lubricant and shock absorber, water protects the body's joints in the form of synovial fluid and also serves in such places as the amniotic fluid surrounding a growing fetus. Water helps the body to maintain a constant temperature of 37°C (98.6°F).

## Minerals

Minerals are inorganic substances that are often referred to as ash when talking about the nutritional composition of a food. To put it simplistically, this term refers to the fact that ashes from the body's minerals remain after the carbon atoms comprising carbohydrate, fat, protein, and vitamins in the body form carbon dioxide. The leftover hydrogen and oxygen from these compounds join to form water, which, with the rest of the water that comprises the body, evaporates. The only thing left then are ashes from the body's minerals. In humans, the minerals weigh about 2.3 kg (5 lb). In the edible portion of fish, the percentage of ash varies from 0.4 to 1.5 g per 100 g. Because there is a large mineral concentration in bones and skin, the percentage of ash is related to the amounts of skin and bone present in the market form consumed.

Seafood includes the following important major minerals (those present in the body in amounts greater than 5 g): calcium, phosphorus, sodium, potassium, and magnesium. Trace minerals of significance are iodine, iron, copper, fluorine, cobalt, and zinc.

## Calcium

- (1) Needed for bone rigidity.
- (2) Helps in blood clotting.

- (3) Aids in muscle contraction and normal nerve functions.

In the human body, calcium is largely concentrated in the bones and teeth with a very small percentage (less than 1%) found in the fluid surrounding the body cells and inside the body's cells. Dietary calcium is essential for the formation of bones and teeth, and helps regulate the transport of ions across cell membranes (Ions are electrically charged particles that function in the body to help regulate water and acid-base balance. Calcium ions carry a +2 charge [ $\text{Ca}^{++}$ ].) It also is important in nerve impulse transmission; it is necessary in order for muscles to contract (e.g., maintaining heart-beat); aids blood clotting; and helps to maintain the body's collagen, a substance that functions to hold cells together.

In children, calcium deficiency can lead to stunted growth. Calcium deficiency leading to bone loss in adulthood is known as osteoporosis. Both of these diseases can also be attributed to a lack of vitamin D that is necessary in order for calcium to be absorbed across the intestinal cell membranes.

Some types of seafood are excellent sources of dietary calcium with values varying from 5 to 200 mg per 100 g. This variability can be attributed to the amount of calcium in the water and/or food, and the age, size, and sexual maturity of the animal. Whole finfish are a very good source of calcium; crustaceans and mollusks tend to contain more calcium than finfish. Especially good sources are canned fishes with edible bones (sardines, salmon) and oysters.

## Phosphorus

- (1) Helps build strong bones.
- (2) Aids in all phases of calcium metabolism.

About 85% of the body's phosphorus is found in the bones and teeth. The remainder is found in small amounts in the body's blood plasma and in larger amounts as phosphoric acid, a constituent of all body cells.

Phosphorus serves many key functions in the body. Along with calcium, it helps give strength to bones and teeth. It is a component of DNA and RNA, both responsible for the cell's genetic code, and as a component of phosphate groups, it is necessary for the activation of some enzymes and the B vitamins. It is a component of ATP, a sub-

stance that carries the cell's energy. It is a structural part of some lipids or fats (called phospholipids) that are responsible for transporting other lipids through the blood. It is a component of cell membranes and is essential in helping maintain the body's acid/base balance by acting as a "buffer."

Because it is so abundant in their cells, the muscle tissue from animals is the best source of dietary phosphorus. Deficiencies of phosphorus are unknown. As a matter of fact, since Americans consume so much animal protein and consequently quite a bit of phosphorus along with it, any excess phosphorus that the body does not use is excreted carrying along with it some calcium, the RDA for calcium is higher here than it is in other countries. Consumption ratios for calcium to phosphorus are recommended to be anywhere from 3:1 to 1:3 with a ratio of 1:1 generally accepted as reasonable.

The phosphorus content of seafood ranges from 100 to 400 mg per 100 g of flesh with the variability dependent on the same factor as listed for calcium. Crustaceans and mollusks tend to have less phosphorus than finfish.

## Sodium, chloride, and potassium (these three work together)

- (1) Regulate the flow of fluids in the body.
- (2) Help regulate the nervous system.
- (3) Help regulate the muscle functions, including heart.
- (4) Help regulate nutrient absorption in the cells.

Of all the minerals, sodium seems to have gained the most attention nationwide. Sodium is the positive ion making up the compound sodium chloride or common table salt. The American public has been advised to reduce sodium intake, and, to this end, manufacturers are introducing new salt substitute products, salt-free and reduced salt products, and are beginning to label sodium contents for various foods.

Some sodium is essential. It is easily absorbed into the body fluids, and the kidneys are thus responsible for filtering excess sodium out of the blood for eventual excretion or, conversely, for conserving sodium when shortages occur in the body. The amount of sodium excreted in a day normally equals the amount consumed. Sodium is the primary positive ion on the outside of the cell helping regulate the total amount of fluid in the body and maintaining a constant ratio of sodium to water. It

also permits nerve transmission and muscle contraction.

Deficiencies of sodium are rare. In the United States, the opposite condition, ingestion of too much sodium, usually is the case. In people who are genetically predisposed to developing hypertension (high blood pressure), consumption of a great deal of sodium can lead to problems. Putting it simply, a higher sodium level in the blood increases the fluid level, which puts a strain on the heart by forcing it to work harder to pump the body's fluids. Americans are being urged to reduce their sodium intake by limiting consumption to less than 2300 mg (1 teaspoon) per day. As salt is about 40% sodium, this would roughly equal about 2000 mg of sodium per day. Sodium is already present in many foods and is added to some processed foods, so this goal can probably be met by reducing the topical addition of salt to foods and the consumption of high salt foods like potato chips and pretzels.

The sodium content of finfish ranges from 30 to 150 mg with an average of 60 mg/100 g of muscle. (Variations in sodium content of flesh within species is attributable to size, season, and in some cases time of life cycle). Finfish, therefore, are quite low in sodium content, and, in fact, are recommended for people on low-sodium diets. The sodium content of mollusks and crustaceans varies with species, but is higher than that of the same portion of finfish. (For a 100 g cooked portion, hard clams have approximately 205 mg, steamed crabs have 456 mg, fresh lobster has 325 mg, scallops have 265 mg, and shrimp have 140 mg of sodium, respectively.) Canned seafood, because of the salt added during processing, can be quite high in sodium content.

Like sodium, potassium is a positively charged ion; potassium ions are the principal positively charged ions inside the body's cells and, as such, they play a major role in maintaining fluid balance in the body. Potassium is essential for maintenance of heartbeat, nerve transmission, muscle contraction, and plays a catalytic role in carbohydrate and protein metabolism. Because of its role in maintaining fluid balance, if excess water should be lost from the body, with the consequent loss of sodium ions, potassium ions would be drawn from within the cells and excreted. This could, in severe cases, cause sudden death from heart failure because of potassium's role in maintaining the heartbeat. The potassium content of fish varies from 250 to 500 mg per 100 g of muscle with an average of 400 mg. The potassium content of shellfish tends to be lower

than that of finfish. Though fish and shellfish are not considered to be principal sources of potassium, they are considered reasonable sources considering that the average diet in the United States supplies 1.5–2.5 g of potassium daily.

## Magnesium

- (1) Helps regulate body temperature, muscle contractions, and the nervous system.
- (2) Helps cells utilize carbohydrates, fats, and proteins.

Magnesium, a mineral found in small quantities (about 1.0 oz in a 59.1 kg (130 lb) individual) in the human body, is important for several reasons. It serves as a catalyst in activating the enzyme system that aids in the metabolism of carbohydrates, and its major role seems to be related to bonding of phosphate groups to ATP molecules. Other functions of magnesium are as a vital constituent in protein making, as an aid to muscle relaxation after contraction, and as a calcium binder in tooth enamel.

Magnesium deficiencies are not likely but can occur in extreme circumstances (vomiting, diarrhea, protein malnutrition, etc.). It is recommended that adult males consume 400 mg of magnesium per day and females 310 mg per day. Fish is generally considered a good source of magnesium with the amount in the muscle varying with species.

## Trace minerals

### Iron

- (1) Combines with protein in the blood to form hemoglobin.

Perhaps no other mineral has received as much attention as the trace mineral iron. Television and radio commercials tout the consumption of iron supplements to prevent such maladies as iron deficiency anemia, a disease in which the red blood cells have less than normal hemoglobin and consequently cannot get enough oxygen for the cells to use.

Hemoglobin and myoglobin are proteins that carry oxygen and release it. Hemoglobin is found concentrated in the blood, and myoglobin in the cells. Iron is a part of both compounds and is responsible for the bonding on or release of oxygen



by each. Iron performs this crucial function because it can assume a +2 or a +3 charge ( $\text{Fe}^{++}$ ,  $\text{Fe}^{+++}$ ), and as needed, the ionized iron can switch from one charge to the other, with the consequent holding onto or release of oxygen that carries a -2 charge.

It is difficult to say how much of the iron consumed is absorbed by the body, but a rough estimate would be about 10%. Iron absorption may be aided by the presence of acid; therefore, it is frequently suggested that citrus fruits or juice (containing ascorbic acid) be taken along with iron-containing food.

Adult males and older females should consume 8 mg of iron per day and females of childbearing age 18 mg per day. Finfish contains about 1 mg of iron per 100 g of flesh, with dark meat containing more than white meat. If this iron is absorbed, then fish is a reasonably good source of iron. Oysters are an exceptionally good source of iron. Three-quarters of a cup (177.9 mL) will provide 10 mg of iron. Other shellfish considered good sources of iron are clams (85 g/3 oz raw have 5.2 mg of iron) and shrimp (which contain about 2.6 mg of iron in 85 g/3 oz of canned product).

## Copper

- (1) Necessary in the formation of hemoglobin.

Copper, like iron, is necessary in the formation of hemoglobin. It also plays a role in respiration and in the release of energy, helping iron change from one ionic state to the other ( $\text{Fe}^{++}$  to  $\text{Fe}^{+++}$ ), and helps maintain the sheath around the muscle fibers.

The amount of copper estimated to be safe and adequate in the daily diet of adults is 900  $\mu\text{g}$ . Shellfish appear to be good dietary sources of copper, generally averaging more than 0.25 mg/100 g.

## Iodine

- (1) Needed by thyroid gland to produce thyroxine, which is essential for the oxidation rate of cells.

Seafoods are the richest natural food source of iodine, a trace mineral that is a component of the hormone thyroxine, which regulates the rate that energy is released. Other good sources of iodine include iodized salt and foods that are grown in soil that has high iodine content.

It is recommended that the adult intake of iodine be 150  $\mu\text{g}$  per day. This RDA is not difficult to meet if seafoods are included in the diet. The iodine values reported for finfish range from 16 to 318  $\mu\text{g}$  per 100 g of flesh with the iodine seeming to concentrate in the oily portions of the fish. Freshwater fish have lower iodine concentration with values ranging from 1.7 to 40  $\mu\text{g}$  per 100 g of flesh.

## Mercury

Mercury occurs in the environment as a result of natural processes and human activity, such as fossil fuel burning. Mercury is transformed by bacteria in water to an organic form of concern called methylmercury (MeHg). MeHg can accumulate in the food chain; so larger and older fish tend to have higher concentrations of MeHg than smaller, short-lived species, such as salmon, pollock, shrimp, catfish, or shellfish. The most commonly consumed seafood in the United States is low in mercury.

## Selenium

- (1) Works in conjunction with vitamin E to protect cells from destruction.

Selenium is essential to good health. The RDA is 55  $\mu\text{g}$  for healthy adults. Selenium is incorporated into proteins to make selenoproteins, which are important antioxidant enzymes. The antioxidant properties of selenoproteins help prevent cellular damage from free radicals.

## Other trace minerals

Fluorine, necessary for healthy, strong teeth and bones; cobalt, an essential component of the vitamin B12 molecule; and zinc, a component of many of the body's enzymes, are found in seafood in varying amounts. The RDA for zinc is 11 mg for men and 8 mg/day for women. Oysters are an excellent source for zinc (a 3 oz portion cooked provides more than the RDA). The elements chromium and vanadium are also found in minute quantities in seafood.

## Vitamins

Vitamins are organic chemical compounds essential for promoting growth, reproduction, and

maintenance of normal body health and function. Vitamins are usually classified into two distinct groups those that are soluble in water, including the B complex of vitamins and vitamin C (also known as ascorbic acid); and those that are soluble in fat, including vitamins A, D, E, and K. Fat-soluble vitamins, because of their nature, are not quickly excreted from the body; therefore, any quantities of fat-soluble vitamins ingested in excess of the body's needs are stored, mainly in the liver and fatty tissues. Excesses of fat-soluble vitamins can reach toxic levels because of the body's storage capacity. Unlike fat-soluble vitamins, excesses of the water-soluble vitamins are normally excreted from the body, although extreme excesses provided by vitamin supplements can be toxic. The vitamin content of fish varies with species, age, season, sexual maturity, and geographical area, and specific information about vitamin content is sketchy at best.

### Fat-soluble vitamins

#### *Vitamin A*

- (1) Keeps eyes healthy and enables them to adjust to dim light.
- (2) Helps keep skin healthy.
- (3) Helps keep lining of mouth, nose, throat and digestive tract healthy and resistant to infection.
- (4) Promotes growth.

Vitamin A deficiency is a serious world health problem, lack of vitamin A impairs several crucial bodily functions. Notably, vitamin A is essential to maintain the health of the outside covering of the eye. Xerophthalmia, an inflammation of the eye that can lead to blindness, can be prevented by proper levels of vitamin A. Other epithelial tissues depend on vitamin A for their health. These epithelial cells normally secrete infection-preventive mucus, but when vitamin A is lacking, they instead secrete a protein called keratin, which causes epithelial cells to become dry and hard and eventually die.

Vitamin A is also known to prevent what is commonly called night blindness, the inability of the eye to quickly adjust from light to darkness. It also plays a role in growth. Lack of vitamin A, causing keratinization of the tongue cells or deterioration of the epithelial tissue of the intestinal tract, can cause a low appetite that results in the cessation of growth.

Vitamin A in fish is found concentrated in the viscera, especially the liver. Fish liver oils like cod liver oil and shark liver oil are excellent seafood sources of vitamin A. As a matter of fact, before vitamin A was synthesized in the laboratory, sharks were caught in large quantities and the oil extracted from the liver to provide vitamin A. Because much of the oil in fish is found in the dark flesh, this flesh has higher concentrations of vitamin A. Among shellfish, oysters appear to be the best source.

The body can derive vitamin A from various retinoids and carotenoids and its recommendations are expressed as retinol activity equivalents, the average male needing 900 µg daily and the average adult female needing about 700 µg daily. The vitamin A content of fish flesh ranges from 0 to 200 µg with, for example, salmon (Coho, farmed, raw) containing 47.6 µg/3 oz.

#### *Vitamin D*

- (1) Helps body absorb calcium.
- (2) Helps body build strong bones and teeth.

As mentioned in the section on calcium, vitamin D is essential for normal bone and tooth development. Proper absorption, movement, deposition, and excretion of calcium and phosphorus is dependent on adequate levels of vitamin D. The estimated safe level of intake for all individuals is approximately 400 IU. Extreme excesses, because it is stored by the body, can lead to toxicity symptoms like diarrhea and nausea. Unique among vitamins, D can be synthesized in the body with the use of the sun's ultraviolet rays. Vitamin D also is found in the lipid portion of food.

The vitamin D content of fish is dependent on the species. Oily fish such as mackerel and herring contain a higher level of vitamin D than leaner fish like flounder and sea trout.

Information on vitamins E (active in maintaining the involuntary nervous system, vascular system, and involuntary muscles) and K (necessary for proper blood clotting) is sketchy. More work needs to be done in determining nutritional values found in seafood.

### Water-soluble vitamins

Water-soluble vitamins can be found throughout a fish's body rather than concentrated in

the viscera like fat-soluble vitamins. Among the important vitamins in this classification are thiamine, riboflavin, pyridoxine, niacin, folic acid, pantothenic acid, vitamin B12, and vitamin C.

There are a number of vitamins in what is known as the B complex. Generally, they are found in the same groups of foods and their function within the cells has to do with energy release.

#### *Thiamine*

Thiamine functions primarily as a coenzyme (a substance that serves to activate an enzyme) to catalyze the breakdown of carbohydrate to glucose and helps store energy in the compound ATP. The lack of thiamine blocks the normal breakdown of carbohydrate and subsequent energy production. The recommended intake for adult males is 1.2 mg per day and for women 1.1 mg. Fish muscle averages approximately 100 µg/100 g of flesh. Oysters, an especially good source of thiamine, contain about 0.25 mg in a 21.3 g (0.75 oz) serving.

Fish muscle is a good source of niacin. Like thiamine, niacin forms part of a coenzyme, which is essential in the production of energy. Specifically, niacin is crucial in the body's formation of energy from glucose. Symptoms of niacin deficiency include diarrhea, dementia, and dermatitis in the form of a rash that occurs on parts of the body exposed to the sun. Niacin in fish muscle ranges from 0.9 to 10 mg per 100 g of tissue. Among shellfish, oysters, with 2 mg/100 g are a reasonably good source of niacin. The RDA for niacin is about 1.0 mg for adult women and 1.4 mg for adult males.

#### *Riboflavin*

Riboflavin, another of the B complex vitamins, is essential in the body's energy production, playing an especially important role in breaking down fatty acids and amino acids that are to be used for energy. The RDA for women is 1.1 mg and for men is 1.3 mg per day. The concentration of riboflavin in fish is quite variable with the dark meat containing more than the white meat. The amount of riboflavin found in many fish, however, is comparable to that found in terrestrial animals (0.03–0.18 mg/100 g of muscle).

#### *Vitamin B6*

Vitamin B6, referred to as pyridoxine, is involved in a number of body functions. It converts one amino

acid to another that is needed by the body; aids in the breakdown of amino acids slated for energy production; converts linoleic acid to arachidonic acid (both fatty acids); aids in the synthesis of such substances as hemoglobin; and helps maintain the blood glucose level. Adults need 1.3 mg per day of pyridoxine. Whole fish is a good source of pyridoxine with values ranging from 0.06 to 0.56 mg per 100 g of fish flesh.

#### *Vitamin B12*

Vitamin B12 is found in significant amounts in seafood, especially fatty fish and shellfish. The potency of the vitamin is higher in dark flesh fish like herring than in white flesh fish like flounder. The amount found in fish muscle varies from 0.6 to 84.1 µg per 100 g in clams, most varieties have 1.0–30 µg/100 g. Vitamin B is necessary for maintaining the sheath around nerve fibers, for promoting growth, and especially for the production of red blood cells. Recommended dietary intake of vitamin B12 for adults is 2.4 µg, a very small amount, so seafood can generally be considered a very good source.

#### *Folic acid and vitamin C*

Two other water-soluble vitamins, folic acid and vitamin C, are found in very small amounts in the edible portions of fish and shellfish. Blue mussels contain 64.6 µg folic acid and 11.6 mg vitamin C representing the high end for these nutrients.

In sum, finfish and shellfish are highly nutritious foods. Additionally, when consumed as part of a well-balanced diet they can add variety in flavor, texture, and color to meals.

## **Nutrition labeling for seafood**

The Nutrition Facts label is required on most food packages. The Nutrition Labeling and Education Act, which amended the FD&C Act requires most foods to bear nutrition labeling and requires food labels that bear nutrient content claims and certain health messages to comply with specific requirements.

For fresh produce and seafood, a voluntary nutrition labeling program covers these foods through the use of the appropriate means such as shelf labels, signs, and posters. In 2004, the Food and

Drug Administration (FDA) and the Environmental Protection Agency (EPA) issued a joint Advisory for Fish ([www.fda.gov](http://www.fda.gov); [www.epa.gov](http://www.epa.gov)).

### What you need to know about mercury in fish and shellfish

2004 EPA and FDA Advice for:

- (1) women who might become pregnant;
- (2) women who are pregnant;
- (3) nursing mothers;
- (4) young children.

Fish and shellfish are an important part of a healthy diet. Fish and shellfish contain high-quality protein and other essential nutrients, are low in saturated fat, and contain omega-3 fatty acids (Table 15.2). A well-balanced diet that includes a variety of fish and shellfish can contribute to heart health and children's proper growth and development. So, women and young children in particular should include fish or shellfish in their diets due to the many nutritional benefits. However, nearly all fish and shellfish contain traces of mercury. For most people, the risk from mercury by eating fish and shellfish is not a health concern. Yet, some fish and shellfish contain higher levels of mercury that may

harm an unborn baby or young child's developing nervous system. The risks from mercury in fish and shellfish depend on the amount of fish and shellfish eaten and the levels of mercury in the fish and shellfish. Therefore, the FDA and the EPA are advising women who may become pregnant, pregnant women, nursing mothers, and young children to avoid some types of fish and eat fish and shellfish that are lower in mercury. By following these three recommendations for selecting and eating fish or shellfish, women and young children will receive the benefits of eating fish and shellfish and be confident that they have reduced their exposure to the harmful effects of mercury:

- (1) Do not eat shark, swordfish, king mackerel, or tilefish because they contain high levels of mercury.
- (2) Eat up to 12 oz (two average meals) a week of a variety of fish and shellfish that are lower in mercury. Five of the most commonly eaten fish that are low in mercury are shrimp, canned light tuna, salmon, pollock, and catfish. Another commonly eaten fish, albacore ("white") tuna has more mercury than canned light tuna. So, when choosing your two meals of fish and shellfish, you may eat up to 6 oz (one average meal) of albacore tuna per week.

**Table 15.2** Omega-3 rich fish.

Type of fish/seafood 3 oz	EPA (mg)	DHA (mg)	Total long-chain omega-3 (mg)
Shrimp	145	122	267
Canned tuna, white Light	198	535	733
	40	190	230
Salmon, wild Farm raised	349	1215	1564
	587	1238	1825
Pollock	77	383	460
Tilapia	4	111	115
Catfish	42	109	151
Crab	207	196	403
Flatfish	207	219	426
Clams	117	124	241
Herring	1058	751	1807
Mackerel	369	677	1048
Sardines	402	433	835
Trout	220	575	795
Anchovies	649	99	748
Mussels	235	430	665
Oysters	372	212	584

- (3) Check local advisories about the safety of fish caught by family and friends in your local lakes, rivers, and coastal areas. If no advice is available, eat up to 6 oz (one average meal) per week of fish you catch from local waters, but do not consume any other fish during that week.

Follow these same recommendations when feeding fish and shellfish to your young child, but serve smaller portions.

According to the Harvard School of Public health ([www.hsph.harvard.edu](http://www.hsph.harvard.edu)), we need to strike a balance between the benefits and risks. The easiest way to avoid concern about contaminants is simply to eat a variety of fish and other seafood.

**So, these recommendations emphasize that women who are or may become pregnant, nursing mothers, and young children should eat fish, avoiding only four specific (and generally rarely consumed) fish species. Importantly, the latter limitation does not apply to the rest of the population, for whom the evidence supports simply choosing a variety of fish and seafood ([www.hsph.harvard.edu](http://www.hsph.harvard.edu)).**

## Allergens

Finfish and crustaceans can cause an allergic reaction in some people. Current regulations require that all foods that contain any of the major food allergens be properly labeled. Patients are often only allergic to a certain species and can safely eat other types of seafood.

## Buying seafood

What should you know in order to purchase high-quality seafood? First, it's important to buy seafood from reputable dealers, those with a known record of safe handling practices, and avoid roadside stands. And since seafood is highly perishable, purchase it last. Make sure the raw juices from seafood do not drip on other foods, especially those that will be eaten without further cooking. (Bacteria in the raw juices can cause cooked foods to spoil, and since these foods are already cooked, there will not be any chance for the bacteria to be destroyed). You can avoid cross-contamination in your shopping

cart by enclosing individual packages of seafood in plastic bags. Note that the word "fresh" refers to seafood that has not been frozen. Yet, "frozen" does not have a bad connotation.

Frozen seafood can be superior in quality compared to fresh seafood, so base your purchase on product quality. Products labeled "fresh frozen" indicate the seafood was frozen while it was fresh, in many instances within hours of harvest. If fishery products were frozen and thawed for retail sale they should be labeled "previously frozen."

How can you determine the quality of fresh seafood in the store? First, look at the display. All fresh seafood should be held as near to 0°C (32°F) as possible, which is maintained by refrigeration and/or ice.

## Whole fish

Whatever the variety, whole fish have certain characteristics that indicate freshness. They should have bright, clear, full eyes that are often protruding. As the fish loses freshness, the eyes become cloudy, pink, and sunken. The gills should be bright red or pink. Avoid fish with dull-colored gills that are gray, brown, or green. Fresh fish should be free of loose or sloughing slime.

The flesh should be firm yet elastic, springing back when pressed gently with the finger. With time, the flesh becomes soft and slips away from the bone. The skin of a fresh, whole fish should be shiny with scales that adhere tightly. Characteristic colors and markings start to fade as soon as a fish leaves the water, but the skin should still have a bright, shiny appearance.

## Fish fillets or steaks

Note that fillets and steaks should have firm, elastic flesh and a fresh-cut, moist appearance, with no browning around the edges. Fillets separate if they are left too long in the case. The flesh should be almost translucent, as if you can almost see through it. There should be little evidence of bruising or reddening of the flesh from retention of blood. Prepackaged steaks and fillets should contain a minimum of liquid. Fish fillets stored in liquid deteriorate quickly.



## Shellfish

They may be sold live, cooked, or fresh shucked. Each form and species has different quality signs to examine. The shells of live clams, oysters, or mussels should look moist and be tightly closed. If the shells gape slightly, have your retailer tap them. If the shells do not close, do not purchase them. Do not purchase live shellfish with cracked shells. The bottom shell of an oyster should be well cupped, a sign that the oyster inside is plump and well formed. The “neck” or “snout” of soft-shelled clams should show movement. The meats of fresh-shucked clams, oysters, or mussels should be plump and covered with their liquor. Their liquor should be clear or slightly opalescent (slightly milky or light gray) and free of shell or grit. There should be no strong odor. Scallops are not usually sold live because they are highly perishable. Typically, scallops are shucked at sea shortly after capture. Occasionally, day boats bring whole scallops to markets or local restaurants. Fresh scallop meats have a firm texture and a distinctly sweet odor. A sour or iodine smell indicates spoilage. The smaller bay and calico scallops are usually creamy white, although there may be some normal light tan or pink coloration. The larger sea scallops are also generally creamy white, although they may show some normal light orange or pink color. Live crabs and lobsters should show leg movement, and the tail of lobsters should curl tightly underneath the body and not hang down when the lobster is picked up. Lobsters and crabs will not be very active if they have been refrigerated, but they should move at least a little bit. Cooked lobsters or crabs in the shell should be bright red and have no disagreeable odor. Picked lobster meat will be snowy white with red tints, while crabmeat is white with red or brown tints, depending on the species or the section of the body it was picked from. Cooked, picked lobster or crabmeat should have good color and no disagreeable odor. Raw shrimp meat should be firm and have a mild odor. The shells of most varieties are translucent with a grayish green, pinkish tan, or light pink tint. The shells should not have blackened edges or black spots, this is a sign of quality loss. Cooked shrimp meat should be firm and have no disagreeable odor. The color of the meat should be white with red or pink tints. Tiger shrimp have bluish colored shells with black lines between the segments of the shell (these are not

black spots). When buying whole squid, look for eyes that are clear and full. The skin should be unturned and the meat very firm. The skin of fresh squid is cream colored with reddish brown spots. As squid ages, the skin turns pinkish and the flesh yellow.

## Label-dated seafood

Buy pasteurized crabmeat and other products only if the “sell by” or “use by” date has not expired. While helpful, these dates are reliable only if the seafood has been kept at the proper temperature during storage and handling.

## Mail-order seafood

Gift seafood is a growing specialty market, mainly for gourmet products. Fresh and frozen seafood are also available to people living far away from the resource. Maine lobsters can be shipped anywhere in the United States. Canned salmon, canned chopped clams, seafood seasonings and marinades, and some smoked products are shelf-stable and require no refrigeration. However, any other fresh or frozen seafood product must arrive as cold as if refrigerated in order to be safe. Before ordering such items, ask how and when the product will be shipped, and whether a cold source will be included to ensure that the product will be received cold. Try to be home when your order arrives, so you can put it right in your refrigerator or freezer. If you are not home, give specific instructions about where it should be left. If you receive a package containing live shellfish or fresh or frozen seafood, check the item upon receipt to see if the shellfish are alive, the fresh product is as cold as if refrigerated, and the frozen product is frozen. If it is not, call the mail-order company for a replacement that will arrive cold or request a refund.

## Handling and storing fresh seafood

The storage life of seafood depends on how well you take care of it, whether it is a whole fish or a live oyster. When your seafood purchase arrives home, store it in the coldest part of your refrigerator at a temperature as close to 0°C (32°F) as possible. Many home refrigerators operate at 4.4°C (40°F);

therefore, fish will lose quality faster. Fish bruises easily, so lift a whole fish with both hands and avoid holding it by the tail. Pack dressed fish on ice in the refrigerator. Seal fillets or steaks in plastic bags or containers; then cover them with ice in trays or pans. Empty the melt water regularly and add more ice as necessary. Fish that is not prepackaged should be washed under cold, running water and patted dry with an absorbent paper towel. The fish should then be wrapped in moisture-proof paper or plastic wrap, placed in a heavy plastic bag, or stored in an air-tight, rigid container until ready for cooking. The shelf life of fish depends on the variety and its quality at time of purchase. In general, you should use fish quickly, within 1–2 days.

### Shellfish

Handling and storage guidelines vary according to the variety of shellfish you purchase. Store live shellfish in a shallow dish covered with damp towels or moistened paper towels. Never put live shellfish in water or in an air-tight container where they could suffocate and die. Scrub live oysters, clams, and mussels just prior to shucking or cooking with a stiff brush such as a vegetable brush. Mussels and clams in the shell (live) should be used within two to three days; oysters in the shell, from 7 to 10 days. Some shells may open during storage. If so, tap them. They will close if alive; if not, discard them. Store shrimp, squid, and shucked shellfish in a leak-proof bag, plastic container, or covered jar. Squid and freshly shucked clams have a shelf life of 1–2 days. Shrimp and scallops have a shelf life of about 2–3 days. And freshly shucked oysters have a shelf life of 5–7 days. Live lobsters and crabs should be cooked the same day they are purchased. Store cooked whole lobsters or crabs in rigid air-tight containers and use them within 2–3 days. Cooked, picked lobster or crabmeat may be stored in a sealed moisture proof plastic bag or air-tight plastic container for 3–4 days. Pasteurized crabmeat can be refrigerated for up to 6 months before opening; use it within 3–5 days after opening.

### Leftovers

Taking care of leftovers is a critical food-handling step and is often where errors can occur, sometimes resulting in food-borne illnesses. To prevent a problem at this step, wash hands before handling left-

overs and use clean utensils and surfaces. Refrigerate or freeze leftovers in covered, shallow (less than 2 in. deep) containers within 2 hours after cooking. Leave air space around containers to allow circulation of cold air and to help ensure rapid, even cooling. When preparing seafood for later use, refrigerate or freeze it immediately after cooking in covered, shallow containers. Refrigerators and freezers are designed to compensate for the addition of a few temporarily hot foods without allowing other foods to warm up. Refrigerate leftovers within 2 hours when the temperature in the food serving area is below 32°C (90°F) and within 1 hour when the temperature of the air is 32°C (90°F) or above. Write the date on your leftovers, and be sure to leave a space around containers to ensure rapid, even cooling. Before serving, cover and reheat leftovers to 71°C (160°F). Soups, sauces, and other “wet” foods should be reheated to a rolling boil. If in doubt, throw it out. Discard outdated, obviously spoiled, or possibly unsafe leftovers in a garbage disposal or in tightly wrapped packages.

### Buying frozen seafood

Commercially frozen fish is quickly frozen at its peak freshness and the consumer can now find a wide choice of top-quality and wholesome seafood in the freezer case. When properly thawed, frozen fish is comparable to fish that was never frozen. Both exhibit the qualities of freshness described previously. Frozen fish and shellfish should be packaged in a close-fitting, moisture-proof package. Select packages from below the load line of the freezer case. Look for packages that still have their original shape and the wrapping intact with little or no visible ice. Seafood should be frozen solid with no signs of freezer burn, such as discoloration or drying on the surface, and have no objectionable odor. The same guidelines apply for frozen prepared seafood, such as crab cakes, breaded shrimp, or fish sticks. Do not allow the package to defrost during transportation. When properly thawed, frozen fish can be comparable to fish that was never frozen.

### Power outages/appliance failure

The following steps provided by the US Department of Agriculture Food Safety and Inspection

Service will help keep seafood safe during power outages or when your freezer or refrigerator is not working. If the appliance will be working again within a couple of hours, minimize opening its doors. A fully stocked freezer will usually keep food frozen for 2 days after losing power. A half-full freezer will usually keep food frozen for about a day. If the freezer is not full, quickly group packages together so they will retain the cold more effectively. In the refrigerator, food will usually keep 4–6 hours, depending upon the temperature of the room. If the power will be out for a longer time, block ice may be placed in the refrigerator. When the freezer is operating again, use the following guidelines to decide what to do with foods that were stored there. If ice crystals are still visible and/or the seafood feels as cold as if refrigerated, it is safe to refreeze, but quality may suffer. If the seafood thawed or was held above 4.4°C (40°F) for more than 2 hours, it should be discarded because bacteria may multiply to unsafe levels under these conditions. When the refrigerator is operating again, fresh or cooked seafood should be discarded if it has been held above 4.4°C (40°F) for more than 2 hours because bacteria can multiply to unsafe levels under these conditions.

### Storing frozen fish

After shopping, immediately store commercially wrapped frozen seafood in your freezer. Put it in the coldest part of the freezer, at a temperature as close to –28.8°C (–20°F) as possible. As with other frozen foods, avoid prolonged storage by planning your purchases, keeping in mind “first in, first out.” Commercially frozen seafood can be stored in the freezer for 6–12 months depending on the type of fish and the amount of fat it contains. Freezing fish at home should be reserved for those times when you end up with more than you can immediately eat, such as after a fishing trip or if someone cancels for dinner. Freezing fish or shellfish in the home or commercial freezer will not improve quality; it only maintains the quality of the food at the time it is frozen. To freeze seafood at home, start with a high-quality and carefully handled product. Fish should be cleaned first under cold water and then patted dry. Wrap with plastic wrap, excluding as much air as possible. Then, overwrap your fish with freezer paper or aluminum foil. There are also specially designed plastic bags for use in the freezer.

These may also be used for fish. Carefully seal all packages and label with contents, amount, and date. Place the packages in the coldest part of the freezer where cold air can circulate around them, freezing them quickly. Shellfish such as shucked clams, oysters, or mussels can be frozen in rigid air-tight plastic containers. Be sure the meats are covered with their liquor and there is a 0.5 in. space between the liquid and the container lid to allow for expansion. Scallops may be frozen in plastic freezer bags. Be sure to exclude air and seal tightly or pack scallops tightly in covered freezer containers. Frozen, shucked shellfish can be stored for 3–4 months. Most shrimp available in the market would have been previously frozen. Be sure shrimp has not been frozen if you plan to freeze it. Refreezing shrimp under noncommercial conditions can significantly affect the flavor and texture, and, in some cases, may make the shrimp unsafe to eat when thawed.

Temperature fluctuations in home refrigerators will affect optimal shelf life, as will opening and closing refrigerators and freezers often. Although these storage times ensure a fresh product for maximum refrigeration storage life at 0°C (32°F), the consumer should plan on using seafood within 36–48 hours for optimal quality. To determine the approximate storage time for species not listed, ask your retailer which category (lean, fat, shellfish, breaded, or smoked) the seafood falls within and refer to the guide.

### Thawing

It is not always necessary to thaw seafood before cooking, depending on how it will be prepared. If thawing is not necessary, simply double the cooking time. But if your recipe calls for coating, rolling, or stuffing, or if the fish is in a block, you will need to defrost it to facilitate handling. Plan ahead; defrost the fish overnight in the refrigerator. This is the best way to thaw fish to minimize loss of moisture. A 1-lb package will defrost within 24 hours. Never defrost seafood at room temperature or with hot or warm water. Bacteria on the surface will begin to multiply and cause spoilage.

If you forget to take your seafood out of the freezer ahead of time, place it in the sink under cold, running water. A 1-lb package will defrost in approximately 1 hour. You may also use your microwave oven to partially thaw your fish. Use the

lowest defrost setting, which is usually 30% of normal power levels, and follow the manufacturer's instructions for time based on amount of fish. (A pound of fillets defrosts in 5–6 minutes.) The fish should feel cool, pliable, and slightly icy. Be careful not to overheat it and begin the cooking process. Foods defrosted in the microwave oven should be cooked immediately after thawing. When thawing frozen fish that comes in a vacuum-sealed package, remove it from the package, cover, or wrap, and thaw it under refrigeration immediately before use. Do not thaw product while it is still inside the vacuum-sealed package.

## Preparation

### Keeping it clean

Finally, it's time to prepare your seafood! But before you begin, remind yourself of these important sanitary guidelines developed by the US Department of Agriculture Food Safety and Inspection Service: be sure the food preparation area and all surfaces and utensils that will touch food are clean. Always wash your hands with soap and warm water for at least 20 seconds before beginning food preparation, before working with new food or new utensils, after finishing food preparation, before serving food, and after going to the bathroom. Do not let juices from raw finfish, shellfish, meat, or poultry come into contact with other foods. Wash cutting board, utensils, counter, sink, and hands with hot, soapy water immediately after preparing raw seafood, meats, or poultry. Also, use a fingernail brush to clean under nails and cuticles. Keep dish-washing sponges and cloths clean. Use cutting boards that are easy to clean, plastic, acrylic, or rubber composition are good choices. Wooden boards may look pretty, but they should only be used for cutting breads because they are porous and difficult to clean thoroughly. Do not taste any food of animal origin (meat, poultry, eggs, fish, or shellfish) when it's raw or during cooking. Serve your cooked seafood on clean plates. Never put it back on the plate that held the raw product.

### Cooking: general rules

Cook fish and shellfish thoroughly. Fish is cooked when it begins to flake and/or loses its translu-

cent (raw) appearance and turns opaque. Cook fish until it reaches an internal temperature of 60–63°C (140–145°F) for 15 seconds. Follow processor's directions when preparing frozen, packaged seafood products such as frozen, breaded fish portions. Seafood is usually baked in a moderate to high oven temperature (218°C/425°F). Do not use recipes that call for cooking without a reliable and continuous heat source. Avoid interrupted cooking, completely cook fish and shellfish at one time. Partial or interrupted cooking often produces conditions that encourage bacterial growth.

## Cooking shellfish

Be careful not to overcook shellfish. So, often, shellfish are in small pieces and can easily be overcooked, becoming tough, dry, and flavorless. Some shellfish, such as canned clams or cooked, picked crabmeat and surimi products (imitation shellfish), are already cooked when purchased. In this case, heat the precooked shellfish or surimi product to the desired temperature without cooking further. Scallops and shrimp turn firm and opaque when cooked. It takes from 3 to 5 minutes to boil or steam 1 lb of medium-sized shrimp and 3 to 4 minutes to cook scallops. Shucked shellfish, such as clams, mussels, and oysters, become plump and opaque when cooked. The FDA recommends that shucked oysters be boiled or simmered for at least 3 minutes, fried in oil for at least 3 minutes at 190°C (375°F), or baked at 232°C (450°F) for at least 10 minutes. Steam clams, mussels, and oysters in the shell for 4–9 minutes from the start of steaming. Use small pots to steam shellfish. If too many shells are cooking at once, it's possible the centers will not cook thoroughly. Discard any clams, mussels, or oysters that do not open during cooking. Closed shells indicate they may not have received adequate heating. Boiled lobsters or steamed crabs turn bright red. Allow 10–12 minutes per pound of lobster, starting to time when the water returns to a boil. Steam crabs 25 minutes when 2–3 dozen, depending on size, have been placed in a large crab pot.

## Microwave cooking

Microwave ovens heat food surfaces rapidly. However, time must be allowed for the heat to penetrate to the center of the food. Take the following steps to ensure that food cooks thoroughly and evenly

in the microwave oven. Cover the food to hold in moisture and facilitate even cooking. Glass cookware, glass ceramic cookware, and waxed paper are safe for microwave cooking. Plastic wrap may be used to cover containers, but should not touch the food. Before using other types of containers or wraps, check to be sure that they are approved for use in the microwave oven. Unapproved materials may melt, burn, or contain chemicals that can migrate into food during cooking.

When following microwave oven cooking instructions on product labels, remember that ovens vary in power and operating efficiency. If the microwave oven does not have a turntable, turn the entire dish several times during cooking. Be sure to stir recipes such as casseroles or soups. Allow seafood cooked in the microwave oven to stand for the recommended time. This is necessary to complete the cooking process. Check for doneness before serving.

Fish are delicious, if cooked properly. Cooking fish develops its flavor, softens connective tissue, and makes the protein easier to digest. Cooking fish at too high a temperature or for too long a time toughens them, dries them out, and destroys their flavor.

How can you tell when fish are cooked? Raw fish and shellfish have a translucent, sometimes watery look. During the cooking process, the watery juices become milky, giving the flesh an opaque, whitish (depending on species) tint. This color change is unmistakable. When the flesh has taken on this opaque whitish tint to the center of the thickest part, fish are completely cooked. At this point, the flesh will easily separate into flakes, and if there are bones present, the flesh will come away from them readily. A general rule of thumb to go by in baking and broiling finfish is the “ten minutes to the inch” (2.54 cm) rule. Measure the fish in the thickest portion and cook it 10 minutes if it is 1 in. thick or whatever corresponding fraction applies if the fish is more or less than 1 in. Today, food safety experts would like us to use thermometers. The guidelines for fish are to insert the thermometer at the thickest portion and insure that it has reached 62.7°C (145°F) for 15 seconds. But, if you do not have a food thermometer, there are other ways to determine whether seafood is done or not:

- (1) *Fish*: Slip the point of a sharp knife into the flesh and pull it aside. The flesh should be opaque

and separate easily. If you cooked the fish in the microwave, check it in more than one spot to help ensure it is completely cooked throughout.

- (2) *Shrimp and lobster*: The flesh becomes pearly-opaque.
- (3) *Scallops*: The flesh turns milky white or opaque and firm.
- (4) *Clams, mussels, and oysters*: Watch for the point at which their shells open, which means they’re done. Throw out the ones that do not open.

Most cooked fish tend to break up easily, so handle fish as little and as gently as possible during and after cooking to preserve appearance.

### Baking and broiling

Baking is a form of dry heat cooking and one of the easiest ways to cook fish. But “bake fish easy.” Fish should be baked in a preheated, moderate medium high oven set at 176–218°C (350–425°F) for a relatively short period of time (depending on the thickness of the fish). This temperature keeps the moistness and flavor in the fish, prevents drying, and keeps the fish tender and palatable. Fish not baked in a sauce or with a topping should be basted with melted fat or oil to keep the surface moist. Fish can be baked from the frozen state, if the cooking time is increased to allow for thawing during the baking process and if the recipe does not call for special handling such as stuffing or rolling.

Broiling, like baking, is a dry heat method of cookery but in broiling the heat is direct, intense, and comes from only one source. Thin foods tend to dry out under the broiler, so when planning to use this method, choose pan-dressed fish, fillets, or steaks which are about 2.54 cm (1 in.) thick in preference to the thinner ones. If frozen, fish should be thawed. Baste fish well with melted fat or oil or a basting sauce before placing them under the broiler. Baste again while broiling to keep the fish moist. Be sure to adequately grease the broiler pan.

The length of time it takes to broil fish depends on thickness and the distance placed from the heat. As a general guide, have the surface of the fish about 7.6–10.2 cm (3–4 in.) from the heat source.

Cooking time will usually range from 10 to 15 minutes for fish to reach the “flake easily” stage. As a rule, the fish do not need to be turned because the heat of the pan will cook the underside adequately. Turn the thicker pieces, such as pan-dressed fish,



when half the allotted cooking time is up. Baste again with fat or sauce. Always serve broiled fish sizzling hot.

Charcoal broiling is a dry heat cooking method over hot coals. Fish, because they cook so quickly, are a natural for this method of cookery. It is quick and, as an extra bonus, adds a delightful flavor. Pan-dressed fish, fillets, and steaks are all suitable for charcoal broiling. If frozen, the fish should be thawed first. Fish are usually cooked about 10.2 cm (4 in.) from moderately hot coals for 10–20 minutes, depending on the thickness of the fish.

Since charcoal broiling is a dry heat cooking method, thicker cuts of fish are preferable because they tend to dry out less than thin ones. Also, the fish should be basted generously with a sauce containing some fat before and while cooking to keep the fish juicy and flavorful.

### Marinades

Follow these guidelines when you use marinades to flavor fish and shellfish. If your recipe calls for basting cooked fish or shellfish with marinade, reserve a portion of it for this before combining the marinade with the raw seafood. Marinate seafood in the refrigerator in a glass or plastic container. Marinades often contain acidic liquids such as wine, lemon juice, or vinegar, which react with metal. Avoid cross-contaminating other foods by thoroughly cleaning any utensils, bowls, or surfaces the marinade comes in contact with after it is combined with raw seafood. Do not save marinades that have been combined with raw seafood, unless they will be immediately cooked in a sauce. Bring the marinade to a rolling boil before adding any other

ingredients. Then, cook the sauce to at least 71°C (160°F).

### Smoking

Smoking (for flavor only) is a simple technique that requires a minimum of effort and equipment, and the fish smoked in this manner can be used in various recipes from appetizers to salads and casseroles. However, it is not a method of preserving fish. Items needed for smoking are a hooded or covered grill (either gas, electric, or charcoal); briquettes (if a charcoal grill is to be used); 454 g (1 lb) of hickory or other hardwood chips; water; salt; oil; and fish. The best smoked fish is produced from “fat” fish like bluefish, mullet, mackerel, herring, and shad to name a few; however, other species can be used.

To smoke fish for flavor:

- (1) Soak the chips in 2 quarts (1.89 L) of water until the fire is ready (or at least as long as the fish marinate).
- (2) Marinate the fish in a brine of 1 cup (236.6 mL) of salt dissolved in 1 gal (3.79 L) of water for the length of time as shown in Table 15.3.
- (3) Start the fire using fewer briquettes than for an average broiling fire. Adjust the temperature on gas or electric grills according to the table. When the coals have burned to a red color, spread evenly over the bottom of the grill.
- (4) Cover the charcoal with one-third of the wet chips, which not only produce the smoke but also lower the temperature.
- (5) Grease the grill generously and keep oil handy for basting.

**Table 15.3** Timetable for smoking fish.

Size and shape	How long to marinate in brine	Cook at °F	Cooking time
Fillets or steaks 1/2 in. thick	30 min	150–175	1 h
		200	30 min
		250	20 min
Fillets or steaks 3/4 in. thick	45 min	150–175	1 h 30 min
		200	30–45 min
		250	30 min
Fillets or steaks 1 1/2 in. thick	1 h	150–175	2 h
		200	1 h 45 min
		250	45–50 min

- (6) Drain and dry *the fish* and place it on the grill skin side down.
- (7) Baste the fish at the start and as needed during cooking to prevent the fish from drying out.
- (8) Cover the grill with the hood.
- (9) Smoke the fish for the amount of time as indicated in Table 15.3.
- (10) Add the remainder of the chips as needed to produce smoke.
- (11) Fish are done when they turn to a golden brown and flake easily when tested with a fork.

## Frying

Frying is a method of cooking food in fat. For frying, choose a fat that may be heated to a high temperature without the danger of smoking: A smoking fat begins to decompose and will give the food an unpleasant flavor. Vegetable oils and fats are preferable to animal fats. Frozen fish generally must be thawed before frying. Separate the pieces and cut to uniform size.

The temperature of the fat is extremely important. Too high heat will brown the outside of the fish before the centers are cooked. Too low heat will give a pale, greasy, and fat-soaked product. The most satisfactory frying temperature for fish is 194–208°C (350–375°F).

After frying, drain the fish immediately on absorbent paper to remove excess fat. Keep the fish warm in a low oven until all pieces are cooked, then serve immediately.

### *Deep-fat frying*

Cooking in a deep layer of fat, deep-fat frying is a quick and excellent way to cook tender foods and precooked foods. Use enough fat to float the fish but do not fill the fryer more than half full. You must allow room for the fish and for the bubbling fat.

The fish may be dipped in a liquid and coated with a breading, or dipped in batter. The coating will keep the fish moist during frying and will give them a delicious crispness.

Place only one layer of fish at a time in the fry basket and allow enough room so that the pieces do not touch. This prevents the temperature of the fat from dropping suddenly and assures thorough cooking and even browning. When the fat has heated to the proper temperature, lower the basket into the fryer slowly to prevent excessive bubbling. If the fat is at the right temperature when the fish are added,

a crust forms almost immediately, holding in juices and preventing the fat from soaking in. Fry until the fish are golden brown and flake easily, usually about 3–5 minutes.

### *Pan frying or pan sautéing*

Of all the ways of cooking fish, pan frying or pan sautéing in a very small amount of fat in a frying pan is probably the most frequently used, and most frequently abused method. It is an excellent way of cooking pan-dressed fish, fillets, and steaks.

Generally, the procedure is to heat about 3.2 mm ( $\frac{1}{8}$  in.) of fat in a frying pan to about 194°C (350°F). Place one layer of breaded fish in the hot fat, taking care not to overload the pan and thus cool the fat. Fry until brown on one side, then turn and brown the other side. Cooking time will vary with the thickness of the fish, generally about 8–10 minutes.

## Poaching

Poaching is cooking in a simmering liquid. The fish are placed in a single layer in a shallow, wide pan, such as a large frying pan, and covered lightly with liquid. The liquid used in poaching may be lightly salted water, water seasoned with vegetables, spices, and herbs, milk, a mixture of white wine and water, or tomato juice, to name a few. This liquid is often cooked before the fish is added in order to extract the flavors from the spices and aromatic vegetables. This liquid is often referred to as a stock or court bouillon. As with other methods of fish cookery, it is important not to overcook the fish. Simmer the fish in the liquid in a covered pan until the fish flakes easily, usually 5–10 minutes. Because the poaching liquid contains flavorful juices, the liquid is often reduced and thickened to make a sauce.

Poaching is a favorite method of cooking fish. As an entree, poached fish can be served simply with a sauce or used as the main ingredient of a casserole or other combination dish. Chilled and flaked, poached fish makes a delicious salad.

## Steaming

Steaming is a method of cooking by means of the steam generated from boiling water. When cooked over moisture in a tightly covered pan, fish retain their natural juices and flavors. A steam cooker is

ideal, but any deep pan with a tight cover is satisfactory. If a steaming rack is not available, anything may be used that prevents the fish from touching the water. The water used for steaming may be plain or seasoned with various spices, herbs, or wine. When the water boils rapidly, the fish are placed on the rack, the pan is covered tightly, and the fish are steamed 5–10 minutes or until they flake easily when tested with a fork. Steamed fish may be served in the same way as poached fish.

### Microwaving Seafood

Microwaving is one of the best ways to prepare seafood. The microwave oven cooks the tender flesh quickly retaining natural juices; in fact, seafood can be more tender and flavorful than when cooked by other methods. Fish and shellfish are less dense than red meats, so microwaves will penetrate them more quickly making your cooking time shorter. Always follow your manufacturer's directions for oven settings when cooking or defrosting seafood and check for doneness at the minimum recommended time.

Here are some additional tips and techniques for microwaving fish and shellfish. Use a shallow microwaveable dish to allow the seafood maximum exposure to the microwaves. Arrange the fish or shellfish in a single layer, overlapping fillets only to even out thickness and cover the dish with plastic wrap. Be sure to vent by turning back one corner to allow steam to escape.

Arrange fillets or large shrimp with the thicker portion pointing toward the outside of the dish. Rolling fillets, especially thinner ones, allows them to microwave more easily than flat fillets.

Allow 3 minutes per pound of boneless fish cooked on high as a guide. Allow 2–3 minutes per pound of thawed shellfish on high at 100% power. Rotate the dish and/or stir shellfish halfway through the cooking time. Allow to stand one-third the cooking time. If you make a sauce to cover the fish, there is no need to cover the dish. Additional steam may make the sauce watery. Handle fish as little as possible to avoid breakage. Be careful not to overcook. When done, seafood will have lost its translucency and just turned opaque or white.

To cook clams, mussels, or oysters in the shell, place them in a single layer in a shallow dish, placing the hinged edge so it faces the outside of

the dish. Cover with plastic wrap, turning back one corner to allow steam to escape and cook on high for 2–3 minutes. Check and remove pieces as they open and continue microwaving until all have opened.

When shellfish is prepared with a sauce, cook the sauce first, and then add the uncooked shellfish to it and complete cooking. Otherwise, you may overcook the shellfish.

Large shellfish such as lobster or several crabs require a vented cover and the addition of water to generate steam for cooking, while small shellfish are steamed without additional liquid in a dish covered with plastic wrap and a corner turned back for venting. Also, a moist paper can be used in place of plastic wrap to cover fish or shellfish in the microwave oven.

### Serving seafood

Seafood can be a delicious addition to your daily meal routine and for special occasions such as buffets, picnics, and bag lunches. To ensure the safety of your seafood, follow the sanitary guidelines listed in the Section "Preparation" of this guide. When serving for a buffet, serve hot food from chafing dishes or warming trays that maintain the internal temperature of the food at 60°C (140°F) or above. For cold foods, nestle the serving dish into a bed of crushed ice. Small platters for replenishing the serving table should be prepared ahead and stored in the refrigerator (at 4.4°C/40°F or below) or kept warm in the oven (at a setting of 93–107°C/200–225°F). Discard any foods that have been held at room temperature for more than 2 hours. Fresh food should not be added to a serving dish or platter containing foods that have already been out for serving.

When going on a picnic or traveling with food, keep all perishables in a cooler with ice or freeze-pack inserts until serving time. Make sure the food is cold or frozen to the touch before placing it in a cooler or cold thermos. When packing a "bag lunch" that will be eaten within several hours, placing ice cubes in a resealable bag or a small freeze-pack insert ("blue ice") in an insulated bag should be all that is necessary to keep the food cold. Be sure to put the cooler or lunch bag in the coolest place possible. Do not leave it in the direct sun or in a warm car.

Seafood is highly perishable and in many cases requires certain precautions when handling for home use. Some seafood products require extra care either because they are more vulnerable to bacteria that can cause food-borne illness or they have unusual characteristics because of the way they are processed.

### Value-added Seafood

Value-added seafood includes battered and breaded seafood, smoked seafood, dried fish, pre-cooked seafood entrees, fresh minced clams, pre-seasoned fish fillets (such as farm-raised catfish), and others. All these products are semiprepared and refrigerated or frozen to save you steps when preparing meals at home. Keep in mind the safe handling guidelines, cleanliness, and proper storage and cooking temperatures, and always read the label and follow the manufacturer's directions, especially as new products are developed and reach the marketplace. To use refrigerated and prepared seafood safely, when purchasing it, make sure the seafood is cold. Also check the "sell by" or "use by" date on the package. Read the label and follow storage and cooking or heating instructions carefully. Use these products within the recommended length of time. When freezing these products, do so as soon as possible after purchase.

### Smoked seafood

Most of today's smoked seafood products are lightly smoked to enhance flavor and not to prolong shelf life. Smoked seafood should be refrigerated at all times and stored no longer than 4 or 5 days. In the store, smoked seafood should be displayed in a refrigerator case, but not directly on ice. It should not be in direct contact with fresh seafood. Some other things to look for when buying smoked seafood include a firm, springy texture, glossy surface, smoky odor, no traces of dried blood or viscera, and no traces of salt crystals. For longer storage, smoked seafood can be frozen for 2–3 months.

### Surimi

Since they are fully cooked, add these products to your recipe in the last minutes of cooking, leaving just enough time to heat through. When buying

imitation seafood, look for opaque off-white body meat and red, cooked-shellfish color on the surface. If the surimi product is frozen, there should not be crystals in the package, they indicate freeze-thaw problems. When thawed, these products should be moist and firm, not wet and soft. Do not buy products with off odors (sour, fermented, or sulfur smells). This indicates spoilage. It is wise to read the ingredient statement on the label if you are allergic to any fish or shellfish. Surimi seafood should be stored in the refrigerator for no longer than 14 days (follow the manufacturers' "use by date" if present on unopened package), or frozen for 9–12 months. Remember, this product is fully cooked. Use sanitary handling techniques to prevent cross-contamination with raw seafood and meat.

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# 16

## Species Identification of Seafood

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Species identification of seafood and seafood products in the US marketplace has become a prominent topic of interest amongst the domestic seafood industry, regulatory agencies, and consumers. The primary issue of concern is related to seafood species substitution that leads to extensive economic losses for the industry and fraud for consumers. Another area where species identification of seafood is important and necessary is in fisheries management where accurate harvest data is required, especially since it relates to monitoring species that are currently overexploited. The tremendous demand for some species of fish has contributed to flagrant overfishing of these species. Fishery Management groups and the US Department of Commerce have mandated strict management practices in an effort to restore the exploited fish stocks to sustainable levels. However, enforcement of these guidelines is challenging at best, especially as most distinguishing morphological cues are lost during the initial processing of the fish. Misidentification or mislabeling of seafood can also put consumers at risk. If inaccurate species identification occurs, consumers could unwittingly purchase and consume species with known toxins or species harvested in areas where toxins are a concern. This chapter focuses predominantly on the

need for accurate and reliable species identification of seafood as it relates to species substitution and economic fraud.

International trade in fishery products has increased dramatically over the past several years. With the elimination of numerous trade barriers, a favorable climate has been created for increased import of fishery products into the United States. The increased demand for seafood, lower cost, and readily available imported products can promote fraudulent branding or species substitution. Either willfully or unintentionally, lower priced products flood the marketplace usurping and compromising the domestic seafood industry and defrauding consumers. Since 2005, there have been numerous media events describing incidences of seafood species substitution and subsequent consumer fraud. Earlier estimates of mislabeled seafood products in the US market were compiled over a 9-year period (FY1988-FY1997) by the National Seafood Inspection Laboratory, National Marine Fishery Service. It was determined that 37% of fish and 13% of other seafood (shellfish, edible seaweed) from randomly selected vendors was mislabeled ([sst.ifas.ufl.edu](http://sst.ifas.ufl.edu)). Today, the percentage of seafood species substitution in the marketplace appears to be significantly higher. Seafood species

identification has become a priority in the United States. In order to combat species substitution, practices and controls are being placed on seafood products in commerce and seafood species identification is the key to the success of these efforts.

## Significance of problem

The inaccurate and misleading labeling of aquatic products is a primary cause of economic loss to the US seafood industry. In addition, seafood industry experts believe at least 20 million consumers are defrauded each year through the illegal practice of seafood product substitution (Jones, 2008). Occurrences of species substitution and economic fraud erode consumer confidence in seafood in general. This may limit Americans' consumption of seafood when public health officials are encouraging people to eat more seafood (Buck, 2007).

The Federal Food Drug and Cosmetic Act, Section 403(b) clearly states, "a food shall be deemed to be misbranded if it is offered for sale under the name of another food." An abuse such as this has a direct economic impact on the consumer and constitutes economic fraud. The Food and Drug Administration (FDA) defines economic fraud in seafood and fish sales "when a less expensive species is substituted for a more expensive species" (21CFR Part 102). Since so much of the seafood consumed in the United States is imported, FDA provides guidance to agency field personnel regarding products of concern related to species substitution. Table 16.1 is a list provided by FDA of commonly substituted species. Table 16.1 also includes potential price differences related to the substitution of some of these items. The price differences are calculated as the difference between average ex-vessel prices of the two listed species (NMFS, Statistics Division, Civera, 2003; Martinez et al., 2005). In addition, some of the price differences were estimated by conversations with importers and suppliers in the US industry.

In addition to defrauding the seafood consumer, some major industries in the United States have suffered extensive economic losses due to species substitution. For example, the Atlantic blue crab industry nearly collapsed in the early 2000s with the flood of imported blue swimming crab from Asia (Seafood Business, 2000). The US Channel catfish industry also has had to fight for survival against

imported Vietnamese *Pangasius* sp. (Catfish Journal, 2002).

## Types of species substitution

Seafood species substitution can occur in many different ways all throughout the distribution chain. There are over 20,000 species of commercial food fish worldwide and it is difficult to correctly identify species of whole fish that swim in similar locations (Martinez et al., 2005). Furthermore, it is nearly impossible to distinguish similar species once the identifying characteristics of the fish have been removed in processing. Unintentional species substitution can easily occur at harvest where bycatch is often mixed with the target species. Foreign suppliers have never before had to carefully and thoughtfully sort species from a single catch. In addition, with increase in demand, importers put significant pressure on foreign suppliers to quickly fill an order. Importers may ask for supplier verification of the product in terms of species identification but until recently the accuracy of these documents was never scrutinized. Importers, domestic suppliers, and distributors are highly motivated by the prices of product received and sold. They are also very dependent on product labels, invoices, and other documents stating that the product is labeled correctly. Employees in restaurants and at retail handle many different types of seafood and seafood products and may or may not be able to distinguish species and recognize discrepancies between labels and actual product.

Blatant seafood species substitution for economic gain has been confirmed in numerous instances in the last few years. A good example of this intentional substitution is the labeling of farm raised freshwater *Pangasius* species from Vietnam as grouper, which are wild caught marine fish. Other examples of blatant seafood species substitution include tilapia labeled as snapper and pollock labeled as cod. Instances of the intentional mixing of imported product with domestic product and labeling as domestic product have also been documented. Examples of this are the mixing of imported blue swimming crab with Atlantic blue crab and labeling as just the latter. Imported shrimp has also been mixed with domestic shrimp and labeled wild caught, product of the United States. Unfortunately, many of the recent media

**Table 16.1** Commonly substituted seafood.

Product label	Product actual identity	Potential price difference
Red snapper	Rockfish	\$5.42–\$6.00/kg <sup>a</sup>
Mahi mahi	Yellowtail	N/A
Swordfish	Mako shark	N/A
Orange roughy	Oreo or John Dory	N/A
Cod	Alaska pollock	\$0.62–\$3.35/kg <sup>a</sup>
Halibut	Sea bass	\$0.71–\$1.79/kg <sup>a</sup>
Dover sole	Arrowtooth flounder	\$0.66/kg <sup>a</sup>
Red drum	Black drum	N/A
Snapper ( <i>Lutjanus</i> sp.)	Tilapia	\$.50–\$2.00/kg <sup>b</sup>
Grouper	Basa or tra	\$1.00–\$5.00/kg <sup>b</sup>
Grouper	Emperor or sweet lips	\$0.50–\$3.00/kg <sup>b</sup>
Lake or yellow perch	White perch or zander	N/A
Caviar (sturgeon species)	Paddlefish or other roe	N/A
Walleye	Sauger or Alaska pollock	N/A
Chum salmon	Pink salmon	\$0.37/kg <sup>a</sup>
Salmon	Steelhead trout	\$0.75–\$3.00/kg <sup>a</sup>
Pacific salmon	Atlantic salmon	N/A
Atlantic blue crab	Asian blue swimming crab	\$.50–\$2.00/kg <sup>b</sup>
Wild-caught salmon	Farm-raised salmon	Up to \$1.74/kg <sup>a</sup>

Source: Modified from [www.cfsan.fda.gov](http://www.cfsan.fda.gov).

<sup>a</sup>National Marine Fisheries Service, Fisheries Statistics Division, Silver Springs, MD.

<sup>b</sup>Seafood Imports, Inc., [info@seafoodimports.com](mailto:info@seafoodimports.com), Edgewater, NJ and industry correspondence.

events referenced numerous incidences of blatant species substitution.

## Background

In the early 1980s, seafood species substitution and economic fraud were rampant in the United States. This issue became a priority for regulatory agencies and the FDA Office of Seafood developed a computer database known as the “Regulatory Fish Encyclopedia” (RFE). This has been used extensively over the years to help ensure that the economic adulteration of seafood could be detected and confirmed by scientific methods. The RFE contains annotated color images of more than 96 authenticated fish species, as well as the unique electrophoretic patterns of the flesh proteins of about half of these species ([vm.cfsan.fda.gov](http://vm.cfsan.fda.gov)). The technology of developing electrophoretic species-specific protein banding profiles, generally generated by isoelectric focusing (IEF), while reliable in some cases, is tedious, laborious, and the interpretation of results extremely subjective. While the RFE

contains protein profiles of numerous species, these profiles are to be used for reference data only. When IEF is run in a laboratory in order to determine the species of an unknown, profiles of the unknown must be run with validated reference material in order to confirm species identification. In other words, for regulatory compliance, a protein profile of an unknown cannot be run using a standard method and simply compared to the protein profiles available in the RFE. The protein profiles generated are influenced by the conditions in which the method is run and even when duplicating a standard method, variations occur. The fact that validated reference material must be available to accurately confirm the identity of a species is also a requirement for all methods of species identification and is a limiting factor in current species identification testing programs.

During this same time period, FDA also created the Seafood List. This Seafood List is a compilation of acceptable market names for imported and domestically available seafood. FDA advises to use either the Acceptable Market Name or the Common Name in labeling seafood. It is not advisable

to use the vernacular name because it may lead to misbranding of seafood and seafood products ([www.cfsan.fda.gov](http://www.cfsan.fda.gov)). Both the RFE and the Seafood List are tools available to regulators and the industry to help monitor and prevent seafood species substitution. The Seafood List is being updated to include a broader range of commercially popular fish such as imported grouper and snapper.

## Comparison of protein- and DNA-based methods

While IEF is an accepted analytical technique for species identification and has official methods status (AOAC Official Method 980.16), it has limitations in today's regulatory and commercial climate. The current IEF method allows the discrimination of related fish species based on their differential protein-banding patterns. While this method is reliable for fresh fish samples, species identification by IEF is complicated by value-added processing techniques such as cooking and the addition of low pH sauces and marinades (Yowell and Flurkey, 1986; Hsieh et al., 1997). A high level of species substitution has been documented in restaurants. Current protein methods of species identification are not reliable methods for species identification where the product has been cooked. In addition, protein profiles of the same species of fish have shown significant differences based on geographical harvest location (Applewhite and Bennett, 2008). The age and sex of the fish at harvest and the quality of the fillet being tested all influence protein profiles, making it extremely difficult to correctly identify the species. Other protein-based methods such as capillary electrophoresis, high-performance liquid chromatography, and immunoassays are also impractical for species identification of processed seafood (Mackie et al., 1999; Akasaki et al., 2006). Protein-based methods are rapidly being replaced by DNA-based methods of analyses. The RFE does include a section for DNA fragments and DNA sequence information for some species, but these sections are headed by the statement (data not available at time of publication). FDA currently has limited resources and updating the RFE with DNA data is not a priority. DNA-based identification techniques have shown to be effective in identifying species in fresh, frozen, and processed meat products. DNA is more thermostable than

proteins and does not vary with sex, age, and status of the tissue (Bossier, 1999). DNA-based methods also provide more definitive genetic information related to the identification of a given species and the data are easily interpreted. The use of DNA-based methods for seafood species identification will eventually be standard practice, but to date, no DNA-based method has official methods status in the United States for fish or seafood species identification.

## DNA-based methods

Genetic species identification is based on the principle of DNA polymorphisms, or genetic variations that take place as a result of naturally occurring mutations in the genetic code (Liu and Cordes, 2004). In order to detect species-specific genetic polymorphisms, DNA is first extracted from the target organism and then the DNA fragment(s) of interest is amplified using polymerase chain reaction (PCR). The resulting PCR amplicons are then analyzed to reveal the characteristic polymorphisms under study. This section describes the aforementioned steps in greater detail, with a focus on the analysis of PCR fragments for species determination.

### DNA extraction

Although the basic steps in the isolation of DNA from tissue are fairly constant, a variety of modifications exist for DNA extraction from aquatic species, including numerous commercially available kits. Oftentimes, the choice of DNA-extraction method is dependent on the status of the starting material, and factors such as tissue type and DNA integrity are taken into account. DNA can be damaged by events such as heat exposure, low pH, and nucleases that cause enzymatic degradation, depurination, and hydrolysis (Marmiroli et al., 2003). DNA found in processed seafoods may have undergone significant damage, with the result being reduced quality and shorter target sequences than those found in a freshly harvested sample. Therefore, a common challenge in the application of genetic methods to the authentication of commercial fish and seafood products is to obtain DNA of sufficient quality and quantity for downstream analysis.

One of the more common methods for extraction of DNA from seafood has been the proteinase K-SDS (sodium dodecyl sulphate or urea) digestion method, reported by Quinteiro et al. (1998) to be effective at extracting DNA from both raw and canned samples. In this method, tissue lysis is carried out using proteinase K and SDS; the proteins are removed with phenol/chloroform; and then the DNA is precipitated with addition of alcohol. Although this method previously involved an overnight lysis, recent improvements involving the use of urea in the extraction buffer allowed for a reduced lysis period of just 1 hour when DNA was extracted from frozen fish muscle tissue and cod roe (Aranishi and Okimoto, 2004; Aranishi et al., 2005a). Furthermore, a recent study on DNA extraction from caviar reported the possibility of extracting sufficient DNA for PCR amplification in less than 15 minutes (Aranishi et al., 2006). In this method, termed the urea-Chelex protocol, samples are mixed with an extraction buffer that contains a chelating resin, and then placed in boiling water for 8 minutes, thereby eliminating the need for an incubation step. A study was recently conducted to determine the optimal DNA-extraction methods suitable for species identification in a variety of canned tuna products (Chapela et al., 2007). Four different methods were considered: Wizard DNA Clean Up with prior digestion with proteinase K, Nucleospin (Clontech), Genomic Prep (Amersham Pharmacia Biotech), and the cetyltrimethylammonium bromide (CTAB) precipitation method (Chapela et al., 2007). Several packing materials used in canned tuna products (e.g., brine, oil, vinegar, and tomato sauce) were also examined in terms of effect on DNA quality and quantity. The study was focused on extraction of DNA from canned light tuna containing yellowfin (*Thunnus albacares*). For all procedures, an attempt was made to amplify five different fragments of the mitochondrial cytochrome *b* (mt cyt *b*) gene ranging in size from 100 to 300 base pairs (bp). Fragments above 250 bp could not be amplified for DNA from tuna stored in brine or vinegar; however, for DNA from tuna stored in oil or tomato sauce, fragments up to 300 bp in length were successfully amplified. The Wizard DNA Clean Up procedure showed the greatest performance in terms of fragment size range and DNA quality from tuna stored in different packing materials. However, the authors reported that the optimal procedure varies

with packing media, where the CTAB method was recommended for tuna canned in oil or vinegar; the Wizard method was recommended for tuna canned in brine; and the Genomic Prep method was suggested to be best for tuna canned in tomato sauce (Chapela et al., 2007).

## DNA amplification

Although early DNA-based identification tests utilized species-specific DNA hybridization probes, the major assays currently used in food inspection are based on PCR amplification, which requires much less starting material and exhibits greater versatility and sensitivity (Lenstra, 2003; Gil, 2007). Amplification of genetic material with PCR requires a thermostable DNA polymerase, two oligonucleotide primers, four deoxynucleoside triphosphates (dNTPs), and magnesium ions (Marmiroli et al., 2003). PCR involves numerous cycles of three reaction steps carried out at different temperatures: denaturation (~95°C), annealing (50–60°C), and extension (~72°C). During these three steps, the template DNA is first separated into two single strands by heat denaturation, then the oligonucleotide primers anneal to complementary sequences on opposing ends of a particular fragment of the template DNA, and next a thermostable DNA polymerase uses the four dNTPs to synthesize copies of the target DNA fragment. Generally, about 20–50 cycles of denaturation, annealing, and extension are performed, and the DNA fragment is amplified into millions of copies. The amplified DNA fragment, called an amplicon, is then present in sufficient amounts for analysis by a variety of PCR-based techniques, including sequencing or restriction fragment length polymorphism (RFLP). A major drawback to conventional PCR, however, is that the DNA is not amplified in a constant manner and, therefore, accurate quantitative information cannot be obtained (Marmiroli et al., 2003). The possibility of using quantitative PCR techniques in fish and seafood authentication will be discussed in subsequent sections.

## Selection of genetic material

Given that most genetic techniques currently used in species identification require the ability to amplify target DNA using PCR, properties such as



the integrity and origin of the DNA can become important determining factors in choosing target DNA fragments (Bossier, 1999). Additional factors that must be considered include mutation rate and sequence length (Cespedes et al., 2000). Determination of fish and seafood species can be carried out using either nuclear DNA (nDNA) or mitochondrial DNA (mtDNA) (Martinez et al., 2005). As an alternative to the amplification and analysis of a specific fragment, some current methods are reliant on random amplification of part of the genomic DNA to produce a genetic "fingerprint" (Rego et al., 2002; Ramella et al., 2005; Zhang and Cai, 2006). These techniques do not require prior knowledge of the DNA sequence and will be discussed in detail in subsequent sections.

### *Mitochondrial DNA*

Animal mtDNA contains 1 major noncoding region, 13 protein-coding genes, 22 genes coding for transfer ribonucleic acid (tRNA), and 2 genes coding for ribosomal RNA (rRNA) (Cespedes et al., 2000). Some major advantages of mtDNA over nDNA are (1) it is relatively simple and small compared to nDNA because it lacks features such as large noncoding sequences (introns), pseudogenes, repetitive DNA, and transposable elements; (2) it is relatively easy to extract; (3) it does not undergo genetic rearrangements such as recombination; and (4) sequence ambiguities resulting from heterozygous genotypes are avoided (Cespedes et al., 2000; Civera, 2003; Aranishi et al., 2005a). Further, mtDNA, which is maternally inherited, exhibits a higher copy number and a faster rate of mutation, making it generally more appropriate in the study of evolutionary genetics and inter- and intraspecies variability (Carrera et al., 2000b; Martinez et al., 2005). Due to the widespread use of mtDNA in genetic research, many universal primers have already been designed, thus facilitating the amplification of mtDNA fragments for fish and seafood species diagnosis (Carrera et al., 2000a; Comesana et al., 2003). However, high intraspecies variation observed in a target DNA sequence can become a disadvantage to species-diagnostic methods that rely on stretches of DNA that are assumed to be conserved within a species (Civera, 2003). Therefore, it has been recommended that several individuals, representing the full range of distribution, are collected and tested for each species

in order to increase the validity of the method (Teletchea et al., 2005). An additional factor to consider is that the maternal inheritance pattern of mtDNA may produce misleading results in the event of species hybridization, in which case analysis of nuclear DNA may be preferable (Lenstra, 2003).

Whether mtDNA or nDNA is employed may also depend on the integrity of the target DNA fragment. When DNA undergoes thermal treatment, it can be degraded into fragments ranging from less than 100 bp up to about 500 bp (Ram et al., 1996; Quinteiro et al., 1998; Jerome et al., 2003; Perez et al., 2004; Chapela et al., 2007). In this case, mtDNA is generally preferred due to its relative abundance compared to nDNA and the theory that the circular structure of mtDNA gives it greater resistance to heat-induced degradation (Borgo et al., 1996; Bossier, 1999; Civera, 2003). Indeed, mtDNA has been used for species identification even in products containing severely degraded genetic material, such as canned tuna (Quinteiro et al., 1998; Rehbein et al., 1999b; Pardo and Perez-Villareal, 2004; Lin and Hwang, 2007).

The most common mtDNA gene exploited in species identification research has been mt *cyt b*, which has been used to identify flatfish, gadoids, anchovies, eels, scombroids, and many others (Sotelo et al., 2001; Rehbein et al., 2002; Calo-Mata et al., 2003; Chow et al., 2003; Pepe et al., 2005; Teletchea et al., 2005; Santaclara et al., 2006). Due to its relatively high interspecies variation and low intraspecies variation, the *cyt b* sequence shows considerable variation and allows for the differentiation of even closely related species (Mackie et al., 1999; Aranishi et al., 2005a). Several studies have also targeted a region of mtDNA coding for both mt *cyt b* and a neighboring tRNA sequence (mt tRNA<sup>Glu</sup>-*cyt b*) for the detection of species such as flatfish, codfish, sturgeon, salmonids, gadoids, and scombroids (Wolf et al., 1999; Wolf et al., 2000; Sanjuan and Comesana 2002; Akasaki et al., 2006).

Some other common mtDNA targets in species identification research are the small 12S rRNA gene (819–975 bp in vertebrates) and the larger 16S rRNA gene (1571–1640 bp in vertebrates), which have been used to identify flatfish, eel, cardinalfish, cephalopods, mackerel, hairtail species, crab, and several others (Cespedes et al., 2000; Chapela et al., 2002; Comesana et al., 2003; Karaïskou et al., 2003; Mabuchi et al., 2003; Imai et al., 2004; Chakraborty

et al., 2005; Itoi et al., 2005). The mitochondrial gene coding for 12S rRNA has been reported to be a good candidate for authentication of fish and seafood due to its acceptable length, mutation rate, and availability of sequence information in databases (Céspedes et al., 2000). This gene experiences less degeneracy than the mitochondrial protein-coding genes; however, it does contain sufficient variation for interspecies differentiation (Comesana et al., 2003). In addition to the *cyt b* and rRNA sequences, there exist several additional mtDNA targets that have experienced limited use in fish and seafood species identification. These include the mt control region, used to identify hake (*Merluccius*) species (Quinteiro et al., 2001); the gene coding for cytochrome oxidase subunit III (COSIII), which has been used to differentiate rainbow trout (*Oncorhynchus mykiss*) and Atlantic salmon (*Salmo salar*) (Carrera et al., 1999a); and the flanking region between COSIII and the ATPase genes (termed ATCO), used to differentiate various species of scombroids (Takeyama et al., 2001; Chow et al., 2003).

#### Nuclear DNA

Despite the advantages of mtDNA in species identification research, a number of nDNA targets have also proven to be successful in the differentiation of fish and seafood species. For example, the nuclear 5S rRNA gene has been used to identify mackerel, gadoids, salmonids, sharks, and others (Carrera et al., 2000a; Aranishi, 2005; Clarke et al., 2006; Moran and Garcia-Vazquez, 2006). This gene consists of a small 120 bp conserved region coding for 5S rRNA and a variable region of noncoding DNA termed the nontranscribed spacer (NTS) that has a species-specific length and sequence (Aranishi, 2005). Due to the rapid mutation rate of the NTS region, 5S rRNA amplicons can often be differentiated by species simply by visualizing the fragment length using gel electrophoresis, without the need for further analysis such as sequencing or RFLP (Moran and Garcia-Vazquez, 2006). This method has been reported to be useful for species recognition in a variety of samples, including larvae, eggs, and frozen or canned foods, and it is simple enough that it can be used in a classroom setting for students investigating molecular methods for fish species authentication, as outlined by Moran and Garcia-Vazquez (2006). Additional nDNA markers that have been used in species identification include

the *p53* gene, the nuclear ribosomal internal transcribed spacer 2 (*ITS2*) locus, the 18S rRNA gene, the gene coding for  $\alpha$ -actin, and a major histocompatibility complex (MHC) class II gene (Withler et al., 1997; Fernandez et al., 2000; Carrera et al., 2000b; Shivji et al., 2002; Klinbunga et al., 2003). Studies on species diagnosis using these genes have been based on species-specific variations in DNA sequence. A two-exon fragment of the *p53* gene was employed for the differentiation of Atlantic salmon and rainbow trout (Carrera et al., 2000b). The *ITS2* locus, which is located between the 5.8S rDNA and 28S rDNA coding regions, has been used to differentiate six common species of shark (Shivji et al., 2002), and variations in the gene coding for 18S rRNA allowed for identification of four species of abalone (Klinbunga et al., 2003). The highly conserved  $\alpha$ -actin gene was reported to be useful in the detection of three species of clams (Fernandez et al., 2000), while an exon and an adjacent intron of the MHC class II  $\beta 1$  gene were used to identify several species of salmonids (Withler et al., 2004).

**Satellite DNA.** In addition to the aforementioned gene targets, nDNA also contains tandemly repeated segments of DNA that occur throughout the genome and exhibit a high degree of polymorphism. These regions of DNA are either rich in adenine and thymine or in guanine and cytosine and can be classified into three categories, based on the length and location of their repeat sequences: (1) satellites, which have long repeat units (hundreds to thousands of nucleotides in length) and are often clustered in the centromeres; (2) minisatellites, which have smaller repeat sequences (9–65 nt) and are dispersed throughout the nuclear DNA; and (3) microsatellites, also referred to as simple sequence repeats (SSRs), that are tandem arrays of 2–8 bp and are also dispersed throughout the genome (Brown and Epifanio, 2003). Polymorphisms in the number of repeated segments (up to 100 repeats) at a given locus allow for differentiation of individuals (Imsiridou et al., 2003). In order to carry out satellite-based research, primers are developed to amplify a specific locus and variations in tandem repeats between individuals can be revealed by size separation using gel electrophoresis. In satellite fragment length polymorphism (SFLP), the amplified satellite DNA undergoes a restriction digest, and the resulting ratio of repeat units with and without restriction sites allows for differentiation

of species and hybrids (Lenstra, 2003). While use of SFLPs has been reported in the identification of several terrestrial animal hybrids (Verkaar et al., 2001; Nijman et al., 2002, 2003), a literature search for SFLP implementation in fish and seafood did not show any published studies in this area.

Thanks to their high levels of degeneracy and variability, mini- and microsatellites, also referred to as variable number of tandem repeats (VNTR), have proven to be very useful in studies on population genetics (Brown and Epifanio, 2003). For example, microsatellite markers have been developed for phylogenetic analyses with numerous marine species, including rainbow trout (Beacham et al., 2000, 2004), smelt (Beacham et al., 2005), channel catfish (*Ictalurus punctatus*) (Waldbieser et al., 2001), sun catfish (*Horabagrus brachysoma*) (Gopalakrishnan et al., 2006), carp (Lal et al., 2004), salmonids (Greig et al., 2003; Bucklin et al., 2007), and many more (Liu and Cordes, 2004). VNTR-based methods may prove to be advantageous for fish species identification due to their sensitivity, speed (variants at two loci can be identified simultaneously), and ability to identify commercially processed samples (Castillo et al., 2003). Indeed, a study on Atlantic hakes reported the ability to use microsatellite markers that had previously been developed for population studies in fish species authentication (Castillo et al., 2003). The authors reported that only two microsatellite loci were necessary to differentiate all hake samples and they emphasized the usefulness of the method on a commercial scale for fish labeling, authentication, and inspection programs. More recently, the use of microsatellite technology was reported to help convict or exonerate individuals in Canada suspected of fish fraud involving salmonids (Withler et al., 2004). VNTRs have also been developed to differentiate four similar eel species (Maes et al., 2006); to identify the sturgeon species *Acipenser stellatus*, a producer of highly prized black caviar (Jennekens et al., 2001); to differentiate wild and hatchery-raised red drum (*Sciaenops ocellatus*) (Renshaw et al., 2006); and to identify three Pacific salmonid species (Greig et al., 2002). Despite the potential advantages of microsatellites, they have not been widely used in fish and seafood species authentication studies. This may be partially due to the high level of cost and effort involved in the initial research that must be carried out to develop appropriate markers and primers (Liu and Cordes, 2004).

**Multigene families.** In addition to microsatellites, multigene families represent another case in which genetic analysis is based on polymorphisms in repeated DNA sequences (Moretti et al., 2003). One example is the actin multigene family, which has been used for the identification of a number of vertebrate species (Martinez et al., 2005). Actin genes contain sequences that code for different molecular forms of the actin protein, along with noncoding stretches of DNA (introns) that vary considerably in length and number. In order to use these genetic polymorphisms to identify species, universal primers are designed to amplify the variable regions and produce a species-specific genetic fingerprint. Although actin multigene families have not been exploited for fish and seafood species identification, they represent yet another potentially valuable genetic marker.

### Selection of PCR primers

PCR primers, which can be either universal or species specific, are responsible for binding specific regions of target DNA to define the PCR fragment to be amplified. Therefore, selection of the appropriate primers for DNA amplification is an important factor to consider for the successful identification of fish and seafood species.

#### Universal primers

Universal primers are designed to anneal to regions of DNA that are generally conserved across species groups and amplify a DNA fragment that exhibits interspecies variation (Carrera et al., 2000b). In order to facilitate universal amplification, these primers are often degenerate at certain nucleotide positions that are known to vary with species. Universal primers are useful for the amplification of a DNA fragment for sequencing and subsequent design of species-specific primers, as in the case of cephalopod species differentiation with a fragment of the mt 16S rRNA gene (Chapela et al., 2002). In other cases, universal primers are utilized to amplify the target DNA and then species-specific differences in sequence are analyzed by RFLP (Sanjuan and Comesana, 2002; Akasaki et al., 2006; Santaclara et al., 2006). For example, a pair of universal degenerate primers (H15149AD, L14735) has been used to amplify a fragment of the mitochondrial gene *cyt b* in over 40 species of fish, which

could subsequently be identified at the species level using restriction enzymes (Russell et al., 2000; Sotelo et al., 2001; Calo-Mata et al., 2003). An alternative to using a single primer pair with degenerate sites for the amplification of a universal gene fragment is the application of a cocktail of primers associated with the gene target. For example, the use of primer cocktails was reported in the amplification and sequencing of segments of the *cyt c* oxidase subunit I (COI) gene for use in DNA barcoding (Ivanova et al., 2007).

#### *Species-specific primers and multiplex PCR*

Species-specific primers are designed on the basis of single nucleotide polymorphisms (SNPs) to anneal only to DNA from a given species (Lockley and Bardsley, 2000). Although this method requires detailed knowledge of the DNA sequences from target species, this information is becoming increasingly available with the use of genetic databases. Also, the use of species-specific primers allows for simple detection of species by the presence or absence of the PCR amplicon on an agarose gel, with no need for traditional analytical procedures such as sequencing, RFLP, or single-stranded conformational polymorphism (SSCP). In multiplex PCR, multiple species can be analyzed in a single run by using a combination of species-specific primers and universal primers, resulting in DNA fragment lengths that vary with species (Apte and Daniel, 2003). The length of the fragments can be predicted if the complete sequence is known and a given species can be identified by the appearance of an amplicon of appropriate size on an agarose gel. Multiplex PCR with the nuclear ribosomal *ITS2* locus and the mt *cyt b* gene has been used for species diagnosis of a variety of pelagic sharks, such as great white (*Carcharodon carcharias*), hammerhead (order *Carcharhiniformes*), basking shark (*Cetorhinus maximus*), and mako (*Isurus paucus* and *Isurus oxyrinchus*), whose fins are commonly sold on the global shark fin market (Shivji et al., 2002; Abercrombie et al., 2005; Clarke et al., 2006; Magnussen et al., 2007). Multiplex PCR assays have also been developed to identify swordfish (*Xiphias gladius*) in processed products (Hsieh et al., 2004); to differentiate sole (*Solea solea*) and Greenland halibut (*Reinhardtius hippoglossoides*) (Céspedes et al., 1999); to identify three species of Pacific salmonids (Greig et al., 2002); and to differentiate fillets of Nile

perch (*Lates niloticus*), grouper (*Epinephelus guaza*), and wreck fish (*Polyprion americanus*) (Asensio et al., 2001; Asensio, 2008). A further advantage of multiplex PCR is that real-time PCR probes, such as TaqMan<sup>®</sup>, can also be applied, which allows for a rapid, quantitative analysis that does not require the use of gel electrophoresis (Marmioli et al., 2003). For example, Trotta et al. (2005) reported the development of a multiplex PCR assay that allowed for the discrimination of grouper from commonly substituted species based on analysis with either conventional gel electrophoresis or a real-time system. Use of real-time PCR will be discussed further in Section “Challenges and emerging trends” of this chapter.

#### Post-PCR analysis methods

Following DNA extraction and PCR amplification, the resulting DNA fragments must be properly analyzed in order to verify the presence or absence of species-specific genetic markers, a variety of methods are available for this purpose. Selection of the most appropriate analytical method is a crucial step in species recognition and involves the consideration of several factors, such as the quality of the starting material and the type and number of species to be differentiated (Table 16.2). For routine use in species identification, these techniques must have a relatively low cost of operation and should be reproducible, quick, and dependable (Bossier, 1999). As mentioned previously, when species-specific or multiplex PCR primers are utilized, analysis may be as simple as visualization of the amplicons with gel electrophoresis. However, in many cases, such as with the analysis of RFLPs, SSCPs, random amplified polymorphic DNA (RAPD), and amplified fragment length polymorphisms (AFLPs), additional procedures are necessary. Despite the wide range of available techniques, the majority of DNA-based fish and seafood identification studies to date have been carried out using either RFLP or sequencing analysis of PCR-amplified fragments of mtDNA (especially *cyt b*). This is fairly consistent with general trends in this field: a literature search of food and forensic molecular identification methods revealed that over 90% of published studies used either RFLP, species-specific PCR or FINS (Teletchea et al., 2005). This section of the review discusses the

**Table 16.2** Comparison of major DNA-based methods used in fish and seafood species identification for prevention of commercial fraud.

DNA-based method	Acronym	Requires prior DNA sequence information?	Quantity of loci analyzed	Robustness to DNA degradation	Potential for interlaboratory reproducibility	Cost	Potential for database construction	Potential for intraspecies variation errors	Examples of fish and seafood species identified with method
Species-specific primers and multiplex PCR	NA	Yes	Single	Medium-high	High	Medium	High	Medium	Flatfish, gadiformes, salmonids, scombroids, percoids, sturgeon, eels, sharks, mollusks
DNA sequencing + phylogenetic mapping	FINS	Yes	Single	Medium-high	High	High	High	Low	Cephalopods, gadiformes, mollusks
Restriction fragment length polymorphism	RFLP	Yes	Single	Medium-high	High	Medium	Medium-high	Medium	Flatfish, gadiformes, salmonids, scombroids, percoids, sturgeon, eels, mollusks
Single-stranded conformational polymorphism	SSCP	Yes	Single	Medium-high	Medium	Medium	Medium-high	Low-medium	Salmonids, scombroids, sturgeon, eels
Random amplified polymorphic DNA	RAPD	No	Multiple	Low-medium	Low-medium	Medium	Medium-high	Low-medium	Percoids, goosfish, mollusks
Amplified fragment length polymorphism	AFLP	No	Multiple	Low-medium	Medium-high	Medium-high	Medium-high	Low-medium	Salmonids, scombroids

Source: This table is adapted from earlier versions by Bossier (1999) and Liu and Cordes (2004).



basic principles, suitable applications, and advantages/disadvantages of the major post-PCR analytical methods currently being employed in fish and seafood species identification research.

### Forensically informative nucleotide sequencing

Forensically informative nucleotide sequencing (FINS) is a DNA-based procedure first described by Bartlett and Davidson (1992). In order to identify a species using FINS, a specific DNA fragment is amplified by PCR, its nucleotide sequence is determined, and the sequence is then compared with related sequences in a database using phylogenetic analysis. The sequence with the lowest genetic distance, or number of nucleotide substitutions, from the target fragment represents the species group to which the original sample belongs (Bartlett and Davidson, 1992). A combination of two mathematical modeling systems is generally employed to carry out the phylogenetic analysis: (1) the Tamura-Nei method, to calculate the genetic distances among sequences (Tamura and Nei, 1993), and (2) the Neighbor-Joining method, to construct a phylogenetic tree based on these genetic differences (Saitou and Nei, 1987).

Since FINS is based on nucleotide sequence substitutions, it is important to select a fragment that exhibits high interspecies variability, but low intraspecies variability in order to avoid ambiguities in the determination of species (Bossier, 1999). A common choice for use in FINS is the mt *cyt b* gene. This method has been used to successfully identify a number of fish samples, including canned salmon, salted cod, partially cooked battered cod, and pickled herring (Bartlett and Davidson, 1992); fresh, frozen, or salted gadoid species (Calo-Mata et al., 2003); frozen or canned sardines and sardine-type products (Jerome et al., 2003); fresh/frozen anchovy species (Santaclara et al., 2006); and fresh/frozen or canned cephalopods and "squid rings" products (Chapela et al., 2003). Extensive phylogenetic research with the mt *cyt b* gene has resulted in the accumulation of a great amount of sequence data that can be used to properly identify species origin, as in the aforementioned studies (Lockley and Bardsley, 2000). Another DNA fragment that has been analyzed with FINS is the mt 16S rRNA gene, which was used to differentiate between a variety of fresh, frozen, or processed (squid rings) cephalopod species (Chapela et al., 2002).

Although sequencing has proven to be the most direct and reliable way to obtain information from PCR fragments, it is also time consuming and expensive, making it impractical for routine use in many laboratories (Lockley and Bardsley, 2000; Chapela et al., 2002; Dooley et al., 2005a). Additionally, sequencing is not appropriate for the analysis of samples containing multiple species (Lenstra, 2003). Therefore, even though sequence analysis with FINS is a valuable technique in phylogenetic and population studies, it may prove to be inappropriate for use in species identification, especially when a large number of samples is involved (Carrera et al., 2000b). On the other hand, numerous studies have shown successful diagnosis of species using FINS, and ongoing technological advances have led to the development of protocols that are simpler and easier than they once were, thus increasing the feasibility of sequencing for species identification (Chapela et al., 2003).

### Restriction fragment length polymorphism

A popular alternative to FINS is PCR-RFLP, which is based on polymorphisms in the lengths of particular restriction fragments of genetic code. As mentioned earlier, species-specific variations in the lengths of particular fragments can sometimes be analyzed simply by PCR amplification and visualization on an agarose gel. However, when the variations are too small to be detected in this way (<100 bp difference), PCR amplicons can be digested with restriction enzymes (endonucleases) and then analyzed using gel electrophoresis to develop species-specific restriction profiles (Liu and Cordes, 2004). In order to establish a protocol for species identification using PCR-RFLP, the target DNA fragment must initially be amplified by PCR and then sequenced to identify polymorphisms among the species of interest. Next, appropriate restriction enzymes are chosen that will be able to recognize and cut specific sequences of DNA, resulting in a pattern of restriction fragments that varies with species (Liu and Cordes, 2004). Once the sequence of the fragment has been established, the initial sequencing step is no longer necessary, as the PCR amplicon of interest is simply digested with the preselected restriction enzymes and then its restriction pattern is compared with reference samples for species identification. This procedure has been widely used in fish and seafood authentication

research due to a number of advantages that it offers over other techniques. To begin with, it is less costly, simpler, and more suitable for routine laboratory analysis than techniques, such as FINS, that are based on nucleotide sequencing analysis (Carrera et al., 1999a; Cespedes et al., 2000; Aranishi, 2005). Additionally, PCR-RFLP is a relatively rapid, reproducible, and robust laboratory technique that does not require expensive equipment (Aranishi, 2005). Due to its many advantages, PCR-RFLP may be a good candidate for large-scale studies involving fish species detection, such as those that might be used by food inspection agencies to enforce labeling regulations (Cespedes et al., 2000; Aranishi, 2005).

PCR-RFLP is one of the most common methods used in fish and seafood species identification and has been carried out with a variety of DNA fragments. As with FINS, the most widely used DNA fragment is mt cyt *b*, which has been used to identify fish and seafood such as scombroids (Ram et al., 1996; Quinteiro et al., 1998; Chow et al., 2003; Horstkotte and Rehbein, 2003), flatfish (Cespedes et al., 1998a, 1998b; Sotelo et al., 2001), gadoids (Calo-Mata et al., 2003; Perez et al., 2004; Pepe et al., 2005; Aranishi et al., 2005a, 2005b), salmonids (Russell et al., 2000), and a number of others. Additional DNA fragments that have been analyzed by PCR-RFLP for species identification include (but are not limited to): nuclear 5S rRNA to differentiate mackerel species (Aranishi, 2005), *p53*, mt 16S rRNA, and COSIII to differentiate Atlantic salmon from rainbow trout (Carrera et al., 1999a, 1999b; 2000b), mt 16S rRNA to identify various species of clams and hairtails (Fernandez et al., 2002; Chakraborty et al., 2005), *ATCO* to differentiate scmbroid species (Takeyama et al., 2001; Chow et al., 2003), and mt 12S rRNA to differentiate sole from Greenland halibut and to identify various flatfish species (Cespedes et al., 2000; Comesana et al., 2003). The results of these studies have shown that PCR-RFLP is suitable for analysis of closely related species, samples containing mixed species, and samples that have undergone various levels of processing, including heat sterilization.

While PCR-RFLP has become a prominent method in the field of species identification, it continues to contain a number of drawbacks. A major disadvantage of PCR-RFLP is the possibility for intraspecies variation, in which individuals from

the same species exhibit different restriction patterns due to degeneracy in the DNA fragment being analyzed (Mackie et al., 1999; Lockley and Bardsley, 2000; Akasaki et al., 2006). Therefore, in order to avoid false negatives, numerous individuals from the same species must be analyzed to verify a lack of intraspecies polymorphisms at the target sites. An additional complication is that there is no guarantee that all species will give unique restriction patterns. Consequently, an unknown sample containing a species that has not yet been analyzed with PCR-RFLP could be falsely identified if its restriction profile matches that of a previously studied species (Sotelo et al., 2001). Due to these limitations, it has been recommended that species identification with PCR-RFLP is carried out with caution if there is not substantial information available concerning sequence polymorphisms within and between species groups (Mackie et al., 1999; Sotelo et al., 2001). One approach for minimizing the identification errors caused by the aforementioned complications is the use of at least two diagnostic restriction sites (Lenstra, 2003).

#### *Lab-on-a-chip capillary electrophoresis*

A recently investigated development in PCR-RFLP has been the replacement of the gel electrophoresis step with microfluidic, lab-on-a-chip technology, which utilizes CE to analyze DNA fragments (Dooley et al., 2005a, 2005b). Lab-on-a-chip CE is considered an improvement to the traditional PCR-RFLP procedure because it is easy to use, and it has been reported to exhibit increased sensitivity, speed, reliability, and safety compared to gel-based methods. Following a typical restriction digest with a PCR-amplified DNA fragment, the resulting restriction fragments are loaded into a microchip (3 cm<sup>2</sup>), separated using CE, and then detected and quantified using laser-induced fluorescence (Dooley et al., 2005a, 2005b). The microchips are single-use units that contain etched capillaries attached directly to sample loading wells. Recently, lab-on-a-chip was demonstrated to be effective in fish authentication studies, including the differentiation of rainbow trout and Atlantic salmon (Dooley et al., 2005a) and identification of a number of whitefish species (Dooley et al., 2005b). This technology has also been utilized in the authentication of genetically modified soy (McDowell et al., 2001), olive oil (Dooley et al., 2003), and a variety of meat species

(Dooley and Garrett, 2001). The high level of sensitivity displayed by lab-on-a-chip allows for the detection of DNA fragments that may be too small for visualization using gel electrophoresis. Also, fish species that are present at a level of just 5% in a fish admixture have been detected by lab-on-a-chip analysis (Dooley et al., 2005b). Despite the many advantages that lab-on-a-chip offers in the field of DNA-based species identification, it continues to possess some of the drawbacks mentioned earlier for PCR-RFLP, including the need for predetermined RFLP profiles for species determination.

### Single-stranded conformational polymorphism

SSCP is an alternative to methods such as FINS or RFLP for the detection of interspecies polymorphisms, especially when closely related species are being analyzed (Bossier, 1999). Although RFLP has been reported to be simpler and more robust, SSCP is a highly sensitive technique that is less problematic than RFLP or RAPD in regards to intraspecies variation (Rehbein et al., 1997; Mackie et al., 1999; Akasaki et al., 2006). Analysis with SSCP begins with PCR amplification of a specific DNA fragment in all species being examined (Lockley and Bardsley, 2000). The resulting amplicon is then denatured into a fragment of single-stranded DNA that has a secondary structure dependent on its sequence. Variations in sequence, which may be as small as a single nucleotide, can be detected by differences in electrophoretic mobility with PAGE (polyacrylamide gel electrophoresis). SSCP patterns are visualized by silver staining and then compared to the profiles of authentic species in order to correctly identify an unknown sample (Mackie et al., 1999). SSCP has been reported to be capable of both analyzing small DNA fragments (~100 bp) and detecting species in mixed samples (Mackie et al., 1999; Rehbein et al., 1999b).

In general, SSCP analysis has been based on variations in the sequence of the mt *cyt b* gene. Although not as widely used as PCR-RFLP or sequencing methods, PCR-SSCP has been utilized to identify a variety of fish species, including salmonids, sardines, herring, eel, tuna, bonito, and sturgeon (Rehbein et al., 1997; 1999a, 1999b; 2002). Despite its success, SSCP analysis is more demanding than RFLP and continues to have a number of setbacks.

For example, the high sensitivity of PCR-SSCP also commands a high level of reproducibility, with no differences in the conditions from one analysis to the next (Lockley and Bardsley, 2000). Also, reference samples must always be run on the same gel as the unknown, and the level of information obtained from SSCP is much less than that obtained through sequencing (Rehbein et al., 1997).

### Random amplified polymorphic DNA

Unlike the aforementioned methods, RAPD does not target predetermined DNA fragments. Instead, an arbitrary primer is designed without previous knowledge of the target DNA sequence, and during PCR this primer randomly amplifies segments of DNA (Williams et al., 1990). Due to variations in the genetic code, RAPD analysis on different species results in unique patterns of DNA fragments. In order to carry out RAPD, a short primer around 10 nt in length is constructed and then added to a PCR reaction with the target DNA. Next, the PCR amplicons are analyzed using gel electrophoresis and, if the resulting band patterns are species-specific, the DNA fingerprint for that species is established. When an unknown sample is analyzed using the same primer, its band pattern can be compared with that for known samples in order to verify the species.

RAPD has the potential to be used as an accurate, rapid tool for exposing commercial fraud (Ramella et al., 2005). The method is relatively cheap, fast, and simple; it does not require prior knowledge of the genome sequence; and primers are commercially available (Lockley and Bardsley, 2000; Rego et al., 2002; Liu and Cordes, 2004). Additionally, RAPD requires minimal DNA and allows for both intra- and interspecies differentiation (Ramella et al., 2005). Compared to other available methods, such as RFLP and AFLP, RAPD has been suggested to be the least expensive and the most reliable for species identification when there is no prior knowledge of the genome sequence (Liu and Cordes, 2004). RAPD protocols have been developed for both agricultural animals (Lockley and Bardsley, 2000) and marine organisms, including catfish (Liu et al., 1998b), tilapia (Ahmed et al., 2004), mussels (Rego et al., 2002), Asian arowana (dragonfish: *Scleropages formosus*) (Yue et al., 2002), and blackfin goosefish (*Lophius gastrophysus*) (Ramella et al., 2005). However, most fish research with PCR-RAPD

has been focused on mapping out population genetics rather than revealing commercial fraud through species identification (Ali et al., 2004).

Despite its advantages, PCR-RAPD has a number of disadvantages. A major concern is reproducibility of the method, especially when the target DNA is limited or slightly degraded (Lockley and Bardsley, 2000; Rego et al., 2002). For example, if the template DNA is of poor quality, some of the larger fragments common to specific fingerprints might be absent. Also, reaction conditions must be constant and stringent, in order to ensure that the DNA fingerprints produced accurately reflect the corresponding species. An additional complication is the possibility of false matches occurring when different DNA regions from two different species produce PCR fragments of similar length (Liu and Cordes 2004).

### Amplified fragment length polymorphism

First described by Vos et al. (1995), AFLP is a novel fingerprinting technique that draws upon aspects of both RFLP and RAPD (Bensch and Akesson, 2005). AFLP analysis begins with digestion of whole genomic DNA with two restriction enzymes, one that has a shorter sequence and cuts more frequently and another that has a slightly longer sequence and cuts less frequently. The most commonly used enzymes in AFLP are *MseI* (4 bp recognition sequence) and *EcoRI* (6 bp recognition sequence) (Liu and Cordes, 2004). Adaptor molecules that recognize the restriction sequences are then ligated to the DNA restriction fragments and then PCR amplification is carried out with primers that anneal to the adaptor molecules (Bleas et al., 1998). These primers contain an additional base at the 3' end and, therefore, amplify only a subset (1/16) of the available DNA fragments (Bensch and Akesson, 2005). The resulting amplicons are then used as template DNA for a second, more selective, PCR amplification that involves primers containing two additional overhanging bases. This PCR step further reduces the number of available DNA fragments by 1/256, resulting in a total of about 100 fragments. These fragments are separated by size using gel electrophoresis and detected by a fluorescent or radioactive label on the *EcoRI* adaptor-specific primer (Bossier, 1999; Bensch and Akesson, 2005). The overall result is a specific DNA fingerprint, where inter- and intraspecies polymor-

phisms are revealed by the presence or absence of specific fragments.

AFLP has a number of advantages that make it an attractive tool for species diagnosis. The method can be carried out independently of the source or complexity of the target DNA, and AFLP banding patterns are highly complex and information-rich (Bleas et al., 1998; Bossier, 1999). Although it is similar to RAPD in that it does not require prior knowledge of the DNA sequence, AFLP analysis shows greater levels of reproducibility and polymorphism (Bossier, 1999; Liu and Cordes, 2004). Since there is no need for sequencing, AFLP has relatively low start-up costs and time requirements. This allows for the examination of many loci (>1000) at a moderate cost, compared to other species identification techniques, such as SNPs, microsatellites, and multigene sequencing, that are generally restricted to <50 loci due to high costs and long start-up times (Bensch and Akesson, 2005). Although AFLP analysis results in numerous informative markers and complex banding patterns, information on individual DNA fragments is not as specific as with other techniques. This may be considered a drawback when genetic information is desired on a per-locus basis (e.g., differentiating recessive from dominant genotypes) rather than an overall fingerprint. Furthermore, the development of AFLP markers is fairly labor intensive and requires DNA of high quality and high molecular weight.

Even though AFLP analysis has been extensively utilized for genetic research involving plants, fungi, and bacteria, it has experienced limited use in the field of animal research (Bensch and Akesson, 2005). AFLP markers have been developed for a few aquatic species, including catfish (Liu et al., 1998a), oysters (Yu and Guo, 2003; Li and Guo, 2004), trout (Young et al., 1998), bass, and tuna (Han and Ely, 2002). However, the majority of studies have focused on the use of AFLP for constructing genetic linkage maps rather than species differentiation in commercially available food products. According to Zhang and Cai (2006), AFLP has yet to be exploited in fish fraud research because it is relatively time consuming and has not been adapted for large-scale applications. In order to overcome these setbacks, the authors used AFLP analysis on rainbow trout to develop a species-specific AFLP marker. Primers were designed that would amplify a segment of this marker termed the sequence characterized amplified region (SCAR).



Use of the AFLP-derived SCAR allowed for differentiation of rainbow trout from Atlantic salmon and was reported to increase the overall speed, reliability, and ease of the method for applications in commercial fraud detection (Zhang and Cai, 2006).

## Others

### *Expressed sequence tags*

Expressed sequence tags (ESTs) are short stretches of transcribed nucleotide sequences that can be used to identify gene transcripts and analyze SNPs (Nagaraj et al., 2007). ESTs with polymorphisms are currently valuable in genome mapping (Liu and Cordes, 2004), and EST sequencing projects are being carried out for numerous organisms (Nagaraj et al., 2007). For example, a recent study used ESTs to identify microsatellite regions in channel catfish that were reported to be useful for genetic linkage mapping (Serapion et al., 2004). However, there has been very little research into ESTs for commercial species identification, and aquaculture genetics in general, most likely due to a need for greater bioinformatics capabilities (Liu and Cordes, 2004). In particular, the large volume of data generated in EST research has proven challenging to organize and analyze efficiently (Nagaraj et al., 2007).

### *Single-nucleotide polymorphisms*

Single nucleotide polymorphisms (SNPs) are variations in a single base pair and represent the most common polymorphism that occurs in organisms. They have gained popularity in genetic research because they can reveal differences between individuals that would not be detected using other genetic markers; they are abundant and evenly distributed throughout the genome; and they are adaptable to automation (He et al., 2003; Liu and Cordes, 2004). The most accurate and commonly used technique to analyze SNPs is direct DNA sequencing; however, SNPs can be analyzed using SSCP or heteroduplex analysis. SNPs were recently identified in catfish by comparative analysis of 849 ESTs in blue catfish (*Ictalurus furcatus*) and >11,000 ESTs from channel catfish (He et al., 2003). The authors reported ESTs to be a rich source of SNPs, which could then be used in genetic linkage mapping.

Although SNPs have proven valuable to the field of genomics, their discovery is quite challenging

and can be very costly, with the need for specialized equipment (Liu and Cordes, 2004). Despite these drawbacks, analysis of SNPs with TaqMan probes was recently employed to successfully differentiate two eel species (Itoi et al., 2005). The TaqMan probes were designed to be species-specific based on SNPs, and PCR with these probes revealed differences in fluorescence intensity levels that could be used to verify the presence or absence of species. This method was reported to be a rapid, powerful tool for species identification using either fresh or processed samples.

## General summary of DNA-based methods

As noted, there are numerous DNA-based methods available and many have been investigated for use as accurate and reliable tools for monitoring and testing seafood products in commerce to validate species. The majority of food authentication studies have relied on the DNA database GenBank<sup>®</sup> as a source of sequence information. GenBank is an expansive collection of all publicly available DNA sequences for genes in a multitude of species. This database is produced by the National Center for Biotechnology Information (NCBI) and can be accessed online at the NCBI website ([www.ncbi.nlm.nih.gov](http://www.ncbi.nlm.nih.gov)). However, while GenBank is freely accessible and provides sequence information for many species, this database has been criticized for its susceptibility to misidentification of species or population, missing information, and inconsistent terminology. In addition, there is minimal monitoring of the DNA information entered into GenBank. Many sequences in this public database are not referenced to a voucher specimen. While an excellent source of information, utilizing GenBank alone for regulatory compliance issues may lead to the misidentification of seafood and seafood products.

## Current regulatory activity

While FDA's Office of Seafood no longer exists as it once did, FDA still develops regulations, compliance policy, position papers, regulatory guidelines, and advisory opinions on seafood. As of December 2006, FDA still relied on the protein IEF method for species identification to confirm



regulatory compliance (Randolph, 2006). As mentioned earlier, this protein-based method is based on confirmations utilizing taxonomically validated reference standards. FDA clearly realizes the need to move toward DNA-based methods for seafood species identification. As stated, there are numerous DNA methods suitable for species identification. However, most of the current sequencing methods utilize sequence data in public databases rather than validated specimens as reference standards. In order to eliminate problems associated with the use of nonqualified databases, FDA is participating in the Fish Barcode of Life (FISH-BOL) initiative to develop a qualified database based on authenticated fish samples. FDA is also evaluating a DNA-Barcoding method for species identification of fish and fish products for FDA regulatory compliance. This barcoding method is also the method used in the FISH-BOL initiative.

FISH-BOL is a global effort to coordinate an assembly of a standardized reference sequence library for all fish species. This sequence library will be derived from voucher specimens with authoritative taxonomic identifications. "The Fish Barcode of Life effort is creating a public resource in the form of an electronic database containing DNA barcodes, images, and geospatial coordinates of examined specimens. The database contains links to voucher specimens, information on species distributions, nomenclature, authoritative taxonomic information, collateral natural history information and literature citations," ([www.fishbol.org](http://www.fishbol.org)). DNA barcoding is a technique for characterizing species of organisms utilizing a short DNA sequence from a standard position in the genome ([barcoding.si.edu](http://barcoding.si.edu)). One of the initial challenges of FISH-BOL was the establishment of an easily recovered and standardized region of the genome (genetic material) that provides good taxonomic resolution with a single sequence read to designate as the barcode. Based on the availability of broad range primers for the amplification of the 5' region of *cyt c* oxidase subunit I (COI) from diverse phyla and the fact that this gene sequence is an easily recovered segment of the mitochondrial DNA, it has been established that this gene region is highly appropriate for discriminating between closely related species (Hebert et al., 2003a, 2003b). Thus, the "DNA barcode" locus for identifying animals, including fish, is the 5' end of *cyt c* oxidase subunit I (Ward et al., 2005). FISH-BOL is a section within the Consortium for the Bar-

coding of Life (CBOL) that focuses on fish species identification. The mt COI gene sequences from taxonomically verified fish are added to the Barcode of Life Database (BOLD).

Since the FISH-BOL initiative is a global effort, specimens from all over the world are being collected, taxonomically validated, sequenced, and the COI barcode entered into the database. It will be several more years before this database is complete and available for routine species identification and verification. In addition, there is currently less information on COI than on the molecular marker *mt cyt b*, which is supported by more sequence data from a greater number of species (Dawnay et al., 2007). Standardizing the species identification approach to the COI gene sequence could potentially be a major source of controversy, as it has become in the field of taxonomy (DeSalle et al., 2005). On the other hand, the compilation of sequence information for a specific gene in all species could greatly improve genetic identification techniques and provide a focused effort for fraud prevention. To this effect, FDA researchers have recently been investigating the possibility of incorporating DNA COI Barcodes in the RFE. Yancy et al. (2008) recently reported the development of DNA COI Barcodes for 72 species of fish that may be used as an additional identification resource available in the RFE. The accuracy of this method was also tested for use with commercial samples. A blind study was carried out with 60 unknown fish species that were all identified correctly using the online identification engine BOLD, which is provided by the Barcode of Life data system. The supplementation of the RFE with results from the Barcode of Life project might help to provide a focused, nationwide effort for the development of species differentiation methods. Additionally, the availability of DNA Barcodes in a publicly accessible format could greatly facilitate efforts to enforce regulatory labeling laws for fish and seafood species. A recently published study reported the use of DNA barcoding to identify species in a variety of smoked fish products (Smith et al., 2008). An approximately 600 bp fragment of the COI gene was amplified from each sample, sequenced, and then matched against reference COI sequences from BOLD and GenBank. This method allowed for species identification in products representing fish species spanning ten families and four orders, and it was predicted to become a standard tool for identification of fish species

in food products (Rasmussen and Morrissey, 2008).

## Current commercial applications

Applied Food Technologies (AFT), a private research and development company in the United States, has been working with FDA and FISH-BOL for several years. AFT's focus has been to procure specimens of interest specifically as it relates to commercial species substitution. AFT has created their own database of COI sequences from over 500 validated reference specimens including numerous species of grouper, snapper, pollock, shrimp, crab, catfish, *Pangasius* sp., and so on. In addition, AFT has developed Authenti-Kit™ technology platforms for several species of fish and shellfish that utilizes species-specific primer sets in a multiplex PCR reaction. The major advantages of the Authenti-Kit platform are the ease in which the diagnostics can be utilized in various laboratory settings and the fact that mixed samples can be distinguished. This distinguishing of mixed samples is critical in species identification of products such as canned crabmeat, shrimp on display at retail, and processed products such as grouper fingers. The foundation of AFT and species identification programs is based on taxonomically verified reference specimens.

Another species identification company that offers testing services for fish and seafood products is Therion International, LLC ([www.theriondna.com](http://www.theriondna.com)). With analyses such as mtDNA sequencing and amplification of species-specific microsatellite loci, Therion International is able to identify commonly substituted species in food products, including grouper, red snapper, mahi mahi, tuna, Chilean seabass, walleye, and zander.

On the other hand, a number of companies offer commercial test kits that can be purchased for the purpose of fish species identification. The biotechnology company Bionostra ([www.bionostra.net](http://www.bionostra.net)), located in Madrid, Spain, offers the Fish ID Kit, which is a fish species identification kit based on amplification and analysis of mtDNA. Another Spanish biotechnology company, Biotools ([www.biotools.net](http://www.biotools.net)), offers two kits based on genetic markers for the detection of fish species in fresh and processed samples: (1) the BIOFISH Cod Kit, which utilizes RFLP analysis to identify cod (*Gadus*

*morhua*), Alaska cod (*Gadus macrocephalus*), *Pollachius virens*, pollack (*Pollachius pollachius*), and Arctic cod (*Arctogadus glacialis*), and (2) the BIOFISH Salmon Kit, which allows for identification of Atlantic salmon and two trout species (*O. mykiss* and *Salmo trutta*). Biotools also offers a series of BIOFISH SEQ kits, which allow for species identification based on DNA sequencing for the following groups of fish: flatfish (seven species), sardines (seven species), hake (ten species), and tuna (ten species). The UK-based company Tepnel Life Sciences ([www.tepnel.com](http://www.tepnel.com)) also offers a series of fish species identification kits that allow for the detection of cod, hake, coley, haddock, pollock, whiting, trout, and salmon in most raw and processed products. Tepnel utilizes magnetic bead technology for DNA extraction, followed by a multiplex PCR and analysis of the results with gel electrophoresis. In addition to the aforementioned diagnostic methods, a DNA microarray chip has also been utilized commercially for fish species identification by the European company bioMérieux. This DNA chip, called the FoodExpert-ID<sup>®</sup>, will be discussed further in the section dealing with challenges and emerging trends.

## Online resources

In addition to FISH-BOL (BOLD) and GenBank, previously mentioned databases for species identification, another project that has been focused on sequence information for specific genes is the FishTrace Consortium ([www.fishtrace.org](http://www.fishtrace.org)), which comprise 53 members from several European institutions (Sevilla et al., 2007). The FishTrace Database provides detailed information on a number of fish species common to Europe, along with DNA barcoding data for the genes mt cyt *b* and nuclear rhodopsin. The sequence data have been obtained from referenced FishTrace specimens and the database provides online tools that can be used to predict restriction enzyme cutting sites, carry out Basic Local Alignment Search Tool (BLAST) searches, and construct phylogenetic trees. The barcoding information used by FishTrace includes a longer DNA sequence than that used in COI studies, and it has been argued that the use of DNA barcodes longer in length will allow for increased efficiency of identification labels (Sevilla et al., 2007). Also, the combination of two genes that exhibit

different genomic positions and rates of evolution, such as mt *cyt b* and rhodopsin, was reported to be valuable for the efficiency of DNA barcoding.

A promising resource for mitochondrial sequence information of commercially important fish species in Europe is a database launched by AZTI-Tecnalia ([www.azti.es/dna\\_database](http://www.azti.es/dna_database)). This DNA database was produced in association with the traceability research sector of SEAFOODplus, an integrated seafood research project. The AZTI-Tecnalia database allows for rapid access to sequence information for fish species from five different families: Engraulidae, Gadidae, Merlucciidae, Scombridae, and Zeidae. More than 700 mitochondrial DNA sequences are available from different regions, including *cyt b*, D-loop, 16S RNA, 12S RNA, tRNA-Val, along with sequence information for one nuclear DNA site (tropomyosin). In addition to offering sequence information, AZTI-Tecnalia and SEAFOODplus are currently developing plasmidic standards to help with the validation of DNA methodologies for identifying fish and seafood species.

Another genetic database is being created by a group in Ontario, Canada, for the purpose of enforcing laws that protect endangered and exploited aquatic species (Kyle and Wilson, 2007). This database, which is not yet available online, aims to compile sequence information for a 500 bp portion of the mt *cyt b* gene in a variety of fish species. Molecular identification of species can be achieved through sequence comparisons utilizing phylogenetic analysis and a BLAST search algorithm. In order to initiate development of the database, the gene fragment was sequenced for 26 fish taxa harvested in Ontario, including fish from the families Salmonidae, Centrarchidae, Percidae, Esocidae, Acipenseridae, and Gadidae (Kyle and Wilson, 2007). This method was reported to be a highly effective tool for discrimination of harvested fish species, with great potential in the field of fisheries enforcement. In order to increase the value of information in the database, a validation system was suggested. Under this system, sequences entered for reference specimens would have to be verified by repeated analyses in an independent laboratory before they could be relied upon in forensic work.

Fish and seafood species authentication could also benefit from the development of a database that incorporates information on reference materials generated from a variety of DNA techniques.

For example, a compilation of the results of RFLP analyses on scombroid species could show genes of interest, recommended restriction enzymes, and the expected restriction profiles for reference species. The chance of misidentification due to intraspecies variation would be reduced by allowing multiple laboratories to enter results from studies on scombroids from a variety of geographic locations. To this effect, a prototype database termed Genetics for Identification of Fish Origin was developed that allows for the diagnosis of fish stocks based on a variety of DNA-based methodologies, including RFLP, DNA sequencing, DNA microsatellites, and allozyme electrophoresis (Imsiridou et al., 2003). The database was created by the Joint Research Center of the European Commission, with the primary motivation being the ability to determine place of origin for commercial fish in order to prevent illegal harvests ([fishgen.jrc.it/welcome.php3](http://fishgen.jrc.it/welcome.php3)). The database includes information on genetic identification studies for 11 different species, including Atlantic cod (*G. morhua*), European hake (*Merluccius merluccius*), Chinook salmon (*Oncorhynchus tshawytscha*), and Atlantic salmon.

## Challenges and emerging trends

Some of the major challenges facing genetic food authentication research are the recovery of DNA in highly processed or complex matrices; development of methods that are more simple, rapid, and inexpensive for routine use in a regulatory setting; simultaneous identification of a wide range of species in a food; and quantification of a species in a mixed sample (Mackie et al., 1999; Woolfe and Primrose, 2004; Martinez et al., 2005; Teletchea et al., 2005). Currently, several genetic authentication methods are being investigated to meet these challenges. For example, the use of multiplex PCR with species-specific primers can increase the speed and simplicity of analysis because it does not require additional steps, such as a restriction digest, and it allows for the simultaneous detection of multiple species. Some feasible approaches that may eliminate the need for gel electrophoresis include the use of lab-on-a-chip technology with capillary electrophoresis (Dooley et al., 2005a) and HPLC (Horstkotte and Rehbein, 2003). Another option for reducing time spent in post-PCR procedures is offered by Lonza

Group Ltd. ([www.lonzabioscience.com](http://www.lonzabioscience.com)). This company has developed the FlashGel<sup>®</sup> DNA System, which uses a precast agarose gel run at high voltage to separate DNA in just 2–7 minutes. It also allows for DNA migration to be observed in real time and does not require UV light.

## DNA chips

DNA chips (also known as DNA microarrays or DNA macroarrays) may prove to be a valuable tool in the coming years because they have the potential to simultaneously identify up to hundreds or thousands of species (Teletchea et al., 2005). On a smaller scale, a DNA chip was developed that allowed for differentiation of six animal species commonly consumed in Europe (Peter et al., 2004). Universal primers were used to amplify a 377 bp fragment of the mt *cyt b* gene, and the resulting fragments could then be identified in a microarray with species-specific oligonucleotide probes. This DNA chip was able to detect species present at only 0.1% in an admixture and could identify up to four different species simultaneously in mixed commercial food samples. Interestingly, a commercial DNA chip-based product called the FoodExpert-ID was launched in France in 2004 by the biological diagnostics company bioMérieux ([www.biomerieux.com](http://www.biomerieux.com)). According to the company, this product contained the first high-density DNA chip for use with species identification in food and animal feeds, and it was able to detect 33 different species of vertebrates, including 15 species of fish. However, the company does not have plans to launch the product in the United States and may actually discontinue the product line, as it has not yet found a strong market. Despite their potential advantages, array-based methods have not yet been heavily exploited for species identification in foods; they are still fairly inaccessible due to high costs and long start-up times. In spite of these setbacks, research in this direction has continued, and a DNA microarray was recently developed to differentiate 11 commercially important fish species based on a 600 bp fragment of the 16S rDNA gene (Kochzius et al., 2008). On the basis of these results, a “Fish Chip” for identification of approximately 50 species found in European Seas is currently being developed for authentication and research purposes in the fisheries industry.

## Quantitative PCR

PCR-based techniques that allow for the quantification of target DNA include quantitative competitive PCR (QC-PCR) and real-time PCR. In QC-PCR, the same primers are used for the coamplification of the target DNA along with an internal standard (the competitor), which differs by either having a small intron or a mutated restriction site (Gilliland et al., 1990). The relative amount of each product can then be determined based on the density of the PCR bands on an ethidium bromide-stained gel. QC-PCR has been reported to be useful in the detection and quantification of genetically modified soybean and maize in food products (Hubner et al., 1999) and porcine DNA in meat products (Wolf and Luthy, 2001). Although QC-PCR has been widely used in other fields, very few studies have utilized this technology for the detection and quantification of animal species in food products, and no published studies were found regarding QC-PCR protocols for the detection of commercial fish and seafood species.

Another way to quantitatively measure DNA is through real-time PCR methods, which use fluorescent probes to obtain results during the reaction and do not require gel electrophoresis. A number of fluorescence-based methodologies have been outlined, including the use of primers with fluorescent tags (Amplifluor<sup>™</sup>), a probe with a reporter fluorophore at one end and a quencher fluorophore at the other end (TaqMan), “molecular beacons” that fluoresce when bound to a specific amplicon, Scorpion<sup>™</sup> primers, and LightCycler<sup>™</sup> technology (Lockley and Bardsley 2000; Marras et al., 2006). These methods are advantageous not only in their speed and simplicity, but also in the ability to quantify targeted genetic material. In fact, TaqMan probes have been investigated for their ability to detect and quantify DNA from fish species (Sotelo et al., 2003; Hird et al., 2005) and canned meat products (Laube et al., 2007a). Hird et al. (2005) reported the first successful development of a real-time PCR assay with TaqMan probes for the quantification of whitefish. This method could be used to detect haddock in a complex food matrix containing other fish species. The methodology was optimized specifically for haddock and was able to quantify samples to within 7% of the true percentage of haddock. Because of DNA degradation during processing, this method was only reported to



be useful with raw or lightly processed food products. The application of real-time PCR to multiplex assays has been reported to be effective for the differentiation of three species of gadoids (Taylor et al., 2002), two eel species (Itoi et al., 2005), and two tuna species (Lopez and Pardo, 2005). Real-time PCR was recently utilized in the development and design of a "ready-to-use" reaction plate for the detection of small fragments ( $\leq 212$  bp) of DNA from seven different animal species commonly found in processed foods (Laube et al., 2007b). Despite the advantages of real-time PCR, some limitations remain. For example, multiplex real-time reactions are generally restricted to four fluorogenic probe colors per tube; the size of PCR products cannot be monitored in a closed system; and some systems are not compatible with the chemical properties of fluorogenic probes (Arya et al., 2005).

### Electrochemical DNA sensors

An innovative method for the detection of PCR products was recently described by Lai et al. (2006). This method was based on the use of electrochemical DNA (E-DNA) sensors to detect *Salmonella typhimurium*. An advantage of E-DNA technology is its potential for use in a field-portable, hand-held species identification device. This application is not as feasible in other emerging techniques, such as lab-on-a-chip CE and fluorescence-based methodologies due to analytical needs such as power-intensive laser light sources, high numerical aperture optics, and use of relatively high voltages. Despite the potential for the use of E-DNA sensors in the detection of mislabeled fish and seafood products, analytical protocols for this purpose have not yet been developed.

### Conclusions

Species identification and verification of seafood and seafood products in commerce are dominating topics of interest for the seafood industry and consumers. While federal and state regulators remain focused predominantly on food safety issues, the increasing evidence of significant seafood mislabeling and subsequent economic fraud is not being ignored. FDA and State regulatory agencies are working with researchers and private laboratories

in order to validate and standardize DNA-based methods for seafood species identification. In addition, efforts are focused on the development of public databases of DNA sequences derived from taxonomically validated specimens for use in species identification testing. Members of the food industry are also monitoring the species of product in commerce. Several restaurant chains, distributors, importers, and suppliers have implemented their own seafood species identification programs to minimize unintentional species mislabeling and eliminate blatant species substitution for economic gain.

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# 17

## Packaging

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Joseph E. Marcy

Packaging innovation has been slow to come in the fishing industry but the challenges of a changing international fish trade are bringing significant changes to the packaging of fish products. The international fish trade has grown from US\$8 billion in 1976 to approximately US\$78.4 billion in 2005. Fish, seafood, and fish products are widely transported internationally with more than 75% of the exported fish and seafood going to three major markets: the United States, Japan, and the European Union. Demand by consumers for safe and high-quality fish and seafood have made packaging an increasingly important element in food safety and quality assurance delivery systems. Globalization of the fish trade has increasingly been met with technology advances in handling, processing, distribution, and packaging (FAO, 2007).

One result of globalization and expansion of the international food trade has been significant consolidation and concentration of the food industry in developed countries. This has led to food firms that have substantial and important roles in fish distribution in many countries. Increasingly, the decision on how fish and seafood will be packaged is established by the end point of the supply chain, the retailers. Retailers as the last link in the supply chain have been more active in transmitting consumer

desires and concerns to producers and processors. Fish and seafood consumption has changed with global changes in lifestyles, household incomes, and population changes. Retailers are demanding the ability to trace the origin, safety, and quality of products sold. As a result, retailers have developed standards that seek to protect the consumer and their reputation (FAO, 2007). Changes in fish and seafood packaging are an important component in providing the quality and safety demanded by global customers.

Today, a large quantity of seafood is still moved to market with essentially a minimal amount of packaging. Whole or gutted fish are iced in fish holds, deiced, and sorted upon landing, and then re-iced in bulk containers to be hauled to local fish markets. At the market, whole, dressed, or filleted fish are displayed and offered for sale on a bed of ice. A switch from wooden to waxed or plastic-coated corrugated boxes as the bulk shipping container has been seen as a packaging improvement in this marketing scheme. But the folded newspaper, once the most common form of final product protection is being replaced by packaging methods comparable to retail packaging of meats and poultry in supermarkets. Frozen seafood products are being packaged in a variety of materials to provide

a large selection of attractively packaged raw and processed fish products in supermarket frozen food sections.

## Why package?

Packaging plays an important role in the safe and efficient delivery of most foods including fish and seafood. Packaging protects the contents from contamination and spoilage, makes the product easier to transport, and provides uniform measure of the contents. Packaging makes advertising at point of sale and branding possible especially when combined with large-scale distribution of seafood.

Several definitions of packaging have been proposed to capture the functions that packaging serves. Packaging has been defined as a socioscientific discipline that operates in society to ensure delivery of goods to the ultimate consumer of those goods in the best conditions intended for their use. The Codex Alimentarius Commission in 1985 defined packaging as follows: "Food is packaged to preserve its quality and freshness, add appeal to consumers and to facilitate storage and distribution." Many describe the four primary functions of packaging as containment, protection, convenience, and communication. These four functions are interconnected and all must be considered essential to the packaging process (Robertson, 2006).

Before discussing the many types of packaging materials available for use with seafood, it is important to consider how each of these important functions pertains to the packaging of fishery products.

## Containing and protecting the product

While containing the product is often overlooked because it is so obvious, all product must be contained to move it from place to place. Containment prevents product losses and protection from unintended pollution.

## Product protection

### Chilled product

Even when chilled, fishery products are among the most perishable food products known. They have

high water activity and a relatively high (>6.0) pH that encourage spoilage. Three factors contributing to this rapid loss of quality are bacterial growth, fishery products are an excellent source of nutrients for bacteria, which convert these nutrients into foul-smelling compounds; fat oxidation, the fats and oils of fishery products are unsaturated and tend to break down easily into rancid compounds; and enzyme attack, several digestive and muscle enzymes of fish and shellfish actively break down muscle proteins, which may result in soft, mushy textures.

The action of enzymes can be controlled only by maintaining the product at temperatures as low as possible. Rapid cooling to 0°C or even slightly lower is recommended. Control of temperature during the distribution and marketing of fresh fish is important to both the quality and safety of the product. The package can be an insulator during shipment and increasingly time-temperature indicators (TTI) are being used to monitor the temperature of fish products during distribution.

TTI are being incorporated into fish packaging to measure the overall temperature exposure in distribution and retail handling systems. The use and dependability of TTIs has been well established through scientific studies and practical commercial operation. TTI or smart labels generally respond to temperature change in a dynamic way to alert the user to possible temperature abuse and potential safety. Skinner and Larkin (1998) compiled the existing time and temperature data for production of *Clostridium botulinum* toxin in anaerobically packaged seafood products and concluded that there was a distinct boundary for the time and temperature needed for toxin production. They suggested that TTIs could be used to warn against time and temperature combinations where toxin would be formed. Welt et al. (2003) made additional recommendations for TTI design to minimize false readings. Mendoza et al. (2004) demonstrated TTIs could be used to warn of conditions necessary for toxin production in reduced oxygen packaged seafood products. TTI use is now a routine part of many quality assurance programs for storage and distribution of seafood. However, regardless of the application, it is important to subject the TTI to routine verification and validation (Ronnow, 2006).

Using packaging to control the atmosphere surrounding fish to improve shelf life has been investigated since the 1930s. In general, these modified

atmosphere packaging (MAP) techniques try to change the atmosphere from 78% N<sub>2</sub>, 21% O<sub>2</sub>, <1% CO<sub>2</sub> to a defined set of gases that extends shelf life. In most cases, a gas mixture containing air (or oxygen) and carbon dioxide (CO<sub>2</sub>) is injected into a package or shipping container either on a one-shot (modified atmosphere) or continuous (controlled atmosphere) basis. Effective gas composition varies according to fish species with lower O<sub>2</sub> concentrations being used with fatty fish that are subject to fat oxidation. Robertson (2006) reports that generally gas mixtures for nonfatty fish and shellfish are 25–35% O<sub>2</sub>, 35–45% CO<sub>2</sub>, and 25–35% N<sub>2</sub>. Generally, gas mixtures for fatty fish and smoked fish are 35–45% CO<sub>2</sub> and 55%–65% N<sub>2</sub>. Extremely high levels of CO<sub>2</sub> do not seem to result in significantly more shelf life and may acidify the product, resulting in flavor or color changes (Robertson, 2006).

Although not currently accepted in some countries, the use of carbon monoxide (CO) is currently being used in some MAP applications in the United States. Use of CO produces an attractive red or pink color that is more stable than the oxygen reaction with the same fish muscle. Oxygen combines with the fish heme pigments, myoglobin, and hemoglobin to form red pigments, but these pigment naturally darken to form shades of brown as the pigment oxidizes during storage. When CO combines with heme pigments, carboxymyoglobin is formed. Studies have shown carboxymyoglobin to be stable during refrigeration and frozen storage. Because the pink color is stable, there are concerns that CO-treated fish could mask thermally abused fish that is previously or partially decomposed. Concerns of potential food safety and product deception issues are the primary reasons use of CO-treated fish is presently limited to US use only (Otwell, 2006).

A barrier-type film must be used to prevent loss of the intended gas mixture from the package if the modified atmosphere and vacuum packaging are to be effective. Many manufacturers claim merely exposing the product to CO<sub>2</sub> will result in increased shelf life, but controlled studies have disproved this claim. The use of a barrier film with this type package again led some researchers to question its safety, even when air or oxygen is incorporated into the gas mixture. Those bacteria, which survive the inhibiting effect of the CO<sub>2</sub> may use up the remaining oxygen in the package, thus again possibly favoring toxin formation if the product is temperature

abused. For these reasons, it may be advisable to use MAP only with bulk containers for shipping and storage in which the temperature can be rigidly controlled.

Equally effective to MAP is vacuum packaging to remove most of the available oxygen needed by spoilage bacteria. Removing oxygen also inhibits fat oxidation and rancidity. For such packaging to be effective in inhibiting spoilage, a high-barrier packaging film is necessary to prevent the leakage of oxygen into the package. The gas permeability of a particular film is determined by its chemical composition. Materials such as polyethylene, polyvinyl chloride (PVC), and polypropylene allow a relatively high rate of exchange of gases between the inside and outside of a package, whereas materials such as nylon and polyvinylidene chloride (Saran) and ethyl vinyl alcohol (EVOH) are excellent barriers to gas transmission. Films may be laminates or coextruded to consist of two or more layers of materials that differ in composition (Figure 17.1). In this way, several properties such as gas permeability, heat-sealing ability, and flexibility at cold temperatures may be built into the same film to meet packaging needs.

Unfortunately, removing oxygen from a package may favor the growth of *C. botulinum* bacteria that can produce toxin. In MAP or vacuum-packaged fresh fish or seafood, the hazard would be from nonproteolytic *C. botulinum* types B, E, and F that can potentially grow and produce toxin without characteristic off-odors associated with temperature abuse and spoilage. It has been shown that nonproteolytic *C. botulinum* can grow with temperatures as low as 3.3°C. As previously noted, Skinner and Larkin (1998) compiled literature data to indicate the time and temperature needed for toxin production. The “FDA Fish and Fisheries Products Hazards and Controls Guide” (FDA, 2001) states the packaging that provides an oxygen transmission rate of 10,000 cc/m<sup>2</sup>/24 h can be regarded as

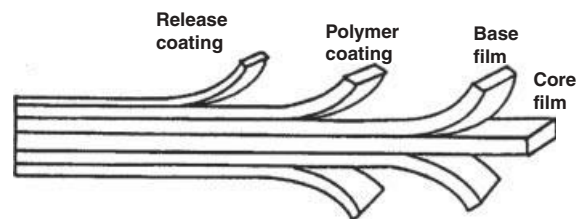


Figure 17.1 An example of a laminated film.



an oxygen permeable packaging material for fishery products. Permeability of 10,000 cc/m<sup>2</sup>/24 h was chosen to be high enough to ensure product spoilage and consumer rejection prior to botulinal toxin production. Vacuum packaging in permeable films that allow gas exchange with the air does not seem to offer any increased safety risk over conventional meat wraps. Such a package would not by itself, however, increase the shelf life of the product, except by preventing further contamination of the product (from hands, air, dust, etc.). Vacuum packaging of frozen fish in oxygen-impermeable (high barrier) films is highly recommended, provided the package is removed or opened prior to thawing. Research is ongoing to establish lower permeation packaging materials for safe MAP packaging of fisheries products.

### Frozen product

Although frozen fish are not subject to spoilage by bacteria, fat oxidation, enzyme activity, and moisture migration do contribute to quality loss in many cases. Maintenance of a low storage temperature with few temperature fluctuations (such as may be caused by cycling of refrigeration equipment) helps control these factors. The enzyme effect, which in this case produces a rubbery texture rather than the mushiness caused by protein breakdown, would not be significantly affected by the type of package used. Packaging can, however, control fat oxidation and moisture migration very effectively.

Glazing fish “packages” in a protective coating of ice prevents moisture from leaving the meat causing so-called freezer burn. In addition, it slows the movement of oxygen into the meat, thus preventing oxidation of the fats.

A skintight vacuum package (obtained by using a shrink film, which we discuss later) of high-barrier film performs the same function as a glaze. However, it is generally preferable to a glaze because it is more durable in rough handling, offers better protection against fat oxidation, is more attractive, and can function as the final consumer package when printed with appropriate label information. The film should be skintight to avoid the creation of voids in the package to which moisture could migrate from the fish causing product damage, and frost accumulation under the film that detracts from product attractiveness. Tightly sealed wax or plastic-impregnated cartons may provide

some protection against fat oxidation, but do little to protect the product from freezer burn.

### Communication

Many processors understand that a package needs to protect the product but do not realize the important role that packaging plays in selling the product.

### Consumer

The consumer is more interested in the product than the package; therefore, a primary function of the package is to provide information about the product. Some consumers, accustomed to evaluating fish quality by smell as much as by sight, may sniff a package in an effort to detect off-odors. To allow for this inspection, packaging film of intermediate gas permeability (more permeable than barrier films but less permeable than conventional meat wraps) may be the best choice for many seafood products. It allows the normal odors of good quality seafood to escape the product at such a slow rate that sniffing the sealed package would reveal little odor. Its limited permeability, however, allows odors to escape sufficiently to prevent accumulation of odors that might be objectionable when the package is first opened, regardless of the freshness.

For a chilled product, visibility is important. Clear films with no fogging and dry, fresh-looking product make the best first impression. Consumers like to inspect as much of the product as possible to determine quality. When packaging many fish species, lay fillets with both skin side up and meat side up so the buyer can make a rapid species identification and an adequate quality inspection.

Transparent films also may be used with frozen fish to heighten the visual impact and quality image. The film should be skintight with no frost accumulation within the package.

Product information may be printed on a separate label or directly on the film and should contain points as follows:

- (1) *Brand name and logo*: To assure the purchaser that the product can be easily identified and, depending upon its quality, either repurchased or avoided in the future.
- (2) *Product description*: The product should be clearly described, with common species names

used to avoid confusion. Any special attributes of the product (coating, sauces, etc.) should be brought to the consumer's attention.

- (3) *Open dating*: An open date is a "use by" or "good until" date used by many consumers to judge quality shelf life of packaged, perishable products. Open dating has become almost mandatory for chilled products, but may be coded for frozen products to avoid consumer discrimination against products that are high in quality but have less remaining shelf life than products recently stocked.
- (4) *Price*: As seafood prices increase, it is often advisable to package smaller quantities to avoid the shock of a high price on individual packages.
- (5) *Product usage information*: Many consumers are afraid of preparing fishery products. They have enjoyed seafood in restaurants but doubt their own ability to prepare it at home. Easy directions for preparation can enhance sales of many seafood products. Printed pictures of "serving suggestions" can add eye appeal and suggest new recipes, which also can be included in the package information.
- (6) *Nutrition information*: Consumers are often concerned with good nutrition. Although not necessarily expected or required, including nutrition information is a good idea, particularly on packages of frozen, specially prepared seafood. Packages making nutritional claims for the product are required by law to give a full nutritional label stating serving size, calories, and US Recommended Daily Allowance of several major nutrients supplied by each serving.
- (7) *Inspection labeling*: Federal inspection is highly regarded by most consumers and, if used by the packer, the inspection and Grade A labeling should be prominently displayed. Regional private inspections should also be featured when performed or in order to bolster consumer confidence in product quality.
- (8) *Convenience*: Aspects of the package or product should be brought to the consumer's attention.

## Convenience

Convenience is not just a function of how the product is prepared prior to sale (whole, fillet, breaded portion, etc.) but also of the package construction

and function. Packages that are easy to open, resealable, or have portions individually wrapped can make using the product a more pleasant experience. Packages can protect, help the product sell, and contribute to easy handling and preparation as well. A final note of caution concerning packaging and merchandising, consumers have developed clear ideas about which types of packages "go with" which product forms. To illustrate this point, consider one manufacturer's attempt to market peanut butter in squeeze tubes. The product was a complete failure because consumers had come to associate this type package with toothpaste, not food. In a similar manner, it has been found that retail packages for chilled seafood should mimic closely the appearance of the conventional foam tray-film overwrap meat package to which customers have become accustomed. Such variations as blue trays instead of white, or vacuum film bags instead of film overwrap are acceptable, but substantial variations from this theme have met with consistent consumer resistance. Through long experience, consumers have come to associate wax board cartons, plastic bags, and cello wrappers with frozen foods; semirigid vacuum pouches and window cartons with processed and cured meats; and foam-tray overwraps with fresh meats. Introducing new package design usually requires strong promotion and clear labeling to overcome consumer resistance to change.

### *At retail*

A bulk package can provide retailers with certain conveniences of storage and handling, which may sell them on the product or program. The retail consumer package may also offer the convenience of having the product prepackaged, weighed, priced, and dated.

### *Institutional*

Institutional users of seafoods prefer packaging that fits their particular type and size operation. Oven-safe trays, single portion packaging, or a wide variety of other specialized packages may be used to meet their needs. Proper packaging eliminates the need to handle fish, with drip and/or odor problems that have come to be associated with fishery products.

## Package selection

### Consumer/retail packaging

#### Chilled products

Most chilled seafoods are raw, with the exception of some smoked seafoods and the newer category of simulated shellfish. These simulated products may be packaged similarly to cured or processed meats, such as country ham and hot dogs, in vacuum-type (tight fill) pouches. Certainly, rigid temperature controls are necessary to assure a safe product when such packages are constructed of oxygen-impermeable film. Such packages can be made several ways. For drawdown mold packages, for instance, a bottom layer of semirigid film is heated and drawdown into a mold the size of the package base to form the cavity in which the product is placed. Alternatively, the heated film may be drawdown over the product itself, with the product serving as the "mold." After filling, a cover sheet of film is stretched tightly across the open side, usually under vacuum, and heat-sealed to the molded film's edges. The sealed package may then be passed through a "shrink tunnel" where it is heated to allow the specially treated film to shrink and form a skintight package around the product.

Other skintight vacuum packages may be made by enclosing the product either between sheets of flexible film or in a preformed flexible film bag, followed by heat sealing under vacuum and passage through a shrink tunnel. When bags are used, either a vacuum chamber heat-sealing machine or nozzle-type vacuum-draw sealer may be used. Sealing between sheets of flexible film is accomplished on equipment similar to that described for the drawdown mold packages.

Most chilled fish and other raw fishery products are commonly prepackaged on shallow clear or foam plastic trays overwrapped with a transparent plastic film. An absorbent paper pad, covered with plastic to avoid sticking to the product, is sandwiched between the product and the tray to absorb moisture. A film overwrap, a single sheet of transparent film, encases the tray and the product. Usually, the film used for this application is polyethylene or PVC of the same type as used for wrapping red meat cuts. These films have a high oxygen permeability to maintain the bright red color of meats, which is stabilized by oxygen. The films pose no

problem with fishery products, although the product can be smelled through the film. Conversely, some fatty fish may absorb off-odors through such films. Vacuum bags of a less permeable (but not barrier) film are being evaluated for fresh fish in trays. The overall appearance of the product in trays is reported not to be noticeably different from the traditional overwrap package. Care should be taken, however, to avoid overheating the film in the shrink tunnel that may cause the foam trays to warp or break.

Recent attempts to incorporate modified (CO<sub>2</sub>-containing) atmospheres into consumer chill packages have used both the tray-bag package just mentioned and a rigid container. These rectangular containers, normally of clear plastic, may be preformed or formed on a draw mold machine. The package is filled and then sealed with a flexible, transparent top sheet heat sealed to the flanges of the rigid container. The CO<sub>2</sub>-containing gas is purged into the container just prior to sealing the top film. Such a package is currently being marketed, although there has been some consumer resistance to this new package design for chilled fish.

With almost any package of chilled seafood, a dry appearance improves the quality image. Product drip loss is best controlled by constantly maintaining the product near 0°C (32°F) or below and using an absorbent pad. "Fog" accumulation, which hides the product from view, can be controlled by coating the underside of the package film with a wetting agent to prevent water droplets from forming.

Wet packs of seafoods such as oysters and scallops commonly consist of round containers of either metal, plastic, or coated paperboard, with snap-on or crimped lids. The product should be visible through the lid or a side window made of a clear plastic. The rectangular, rigid, heat-sealed containers previously mentioned also make an attractive wet pack. These may be clear or opaque with the product clearly visible through the top film.

#### Frozen products

Retail packages of frozen fishery products may be raw (shrimp, fillets, etc.) or processed/convenience foods (breaded portions, stuffed clams, etc.). Packaging for the raw seafoods is generally simpler in design and more functional (protecting the product) than eye appealing. Raw products traditionally have been packed by smaller production-oriented

seafood firms. Most larger marketing oriented food processing companies market processed and prepared seafoods.

High barrier, shrink-film vacuum packaging certainly offers the most protection to frozen seafoods and are increasingly common for retail applications. Whereas a glaze may reduce the likelihood of freezer burn (moisture loss) in loose-filled carton- or wrapper-packaged seafoods, rough handling of the package can result in shattering or flaking of the glaze and a lack of protection. High-barrier vacuum shrink films provide a tougher protective coat.

Rupture of the film at any point may cause only a small surface area of product being exposed to oxidation or freezer burn. It is reported that some packers are concerned about the safety of such packaging in cases of severe temperature abuse. On consumer package labels, it is wise to include a statement such as "open wrapper before thawing" to ensure proper handling.

Still a popular type of package used today for frozen seafoods is the plastic-coated paperboard carton. When properly sealed, these cartons can provide both a good oxygen and moisture barrier. A protective overwrap of plastic, coated cellophane, or coated paper may be used, and the product may be encased in an inner bag for additional protection. The greatest disadvantage of these packages is the presence of voids when the package is loose-filled. In such cases, frost accumulation occurs from moisture migration within the package, and freezer burn can result. In addition, these cartons do not always provide a good oxygen barrier and rancid flavors may develop. For solid blocks of frozen fillets or other block-frozen seafoods, however, such a package can provide good protection and stacks neatly and compactly both in the store and home freezer. For added convenience, fillets are often layer-packed with sheets of plastic film sandwiched between fillets to ease removal of separate fillets and to facilitate rapid thawing.

Many frozen seafoods are also packaged in plain or coated cellophane or polyethylene bags or wrappers. These are some of the least costly packages available and can provide a good moisture vapor-oxygen barrier with the correct film selection and proper sealing. Again, frost accumulation is a problem and is especially troublesome when less flexible films such as cellophane, which cannot adhere tightly to other than rectangular-shaped products, are used. However, cellophane films are

known to handle well on automatic packaging machinery, having fewer machinery problems than many films.

Foil laminates (metal foil bonded to a plastic or other flexible film) provide excellent barrier or protective properties also. These packaging materials are again more costly, and do not allow a view of the packaged product, but for frozen items they may provide a higher quality image. In addition, they may be useful in some "cook-in-the-package" applications. The ultimate in convenience packaging for frozen seafoods are those packages that may be used directly as containers for cooking the product. One such package is the so-called boil-in-bag pouch, which may be of nylon or a similar transparent, flexible film or a foil laminate. They are excellent for such heat-and-eat products as sauces, stews, bisques, and chowders, as well as some chunky-type dishes. For processed seafoods of a less fluid form, such as fillets in sauce, stuffed items, and so on, aluminum or the newer oven-safe paperboard trays are popular. The selection of oven-safe paperboard as opposed to aluminum allows easier preparation in either microwave or conventional ovens. Convenience of preparation is becoming an increasingly desirable factor with today's busier lifestyles. It may be a particularly important factor in marketing seafoods, which traditionally have been viewed as difficult or distasteful to prepare at home.

### Freeze-thaw products

"Slacking out" of frozen products for sale as chilled products has been a widely used, though seldom advertised, practice in the seafood trade. Recent research and commercial experience have shown that such a practice, properly controlled, can produce a product of high quality and similar saleable life as most so-called fresh fish. In addition, marketing studies indicate that consistent high quality is more important in consumer purchasing decisions of chilled fish than is the handling method employed. Freeze-thaw handling can help alleviate seasonable market gluts and the associated variable pricing and availability, which can hamper successful supermarket retailing of chilled fish. Two methods may be employed successfully to merchandize freeze-thaw handled fish. First, the fish may be glazed or, preferably, vacuum packaged for bulk frozen storage until markets are available. Fish

are then rapid thawed and packaged for retail in a manner identical to fresh fish. In the second method, the fish are frozen in the retail consumer package, thawed, and sold chilled in the same package. This method requires special packaging to achieve good quality maintenance in both the frozen and thawed-chilled product. One solution has been to glaze the fish, prior to packaging, in an air-permeable film of the fresh meat type. The glaze provides protection to the product while frozen. A specially designed foam tray with grooves and an extra-absorbent pad removes all traces of the glaze from the package upon thawing, leaving a dry, fresh appearance to the chilled, packaged product. Such techniques are equally adaptable to many shellfish and could help fishery product sale.

### Bulk packaging techniques

The master carton is an important part of the bulk shipping container (Figure 17.2). These cartons are normally of wax- or plastic-coated corrugated paperboard, and may be strapped shut for added protection. If the product is frozen or an internal refrigerant (ice, CO<sub>2</sub> snow, etc.) is to be contained in the package, an inner wall consisting of a rigid foam box or panels may be used to insulate the container. If ice is to be used in the container, a plastic inner lining may be necessary to prevent leaking. Variations on this general design may include the following:

- (1) Corrugated dividers in the package interior to protect individual retail packages from shock and stacking pressure.
- (2) Use of a barrier-type inner bag for MAP of the retail packages within.

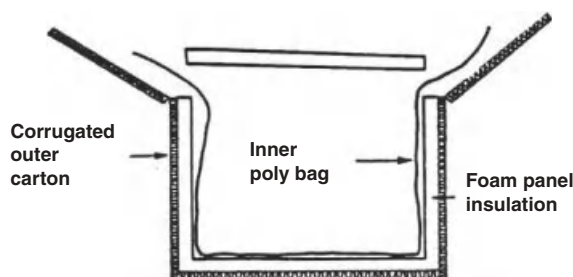


Figure 17.2 Insulated master shipping carton.

- (3) Use of a long, low-profile master carton to eliminate crushing of the inner packages caused by their being stacked too high.
- (4) Coating the outside of the master carton with shiny metallic foil to shield the package from rising temperatures when in direct contact with the sun's rays.

The remaining components of a bulk shipping container are the inner (bulk or retail) containers and an optimal refrigerant such as ice or dry ice when mechanical refrigeration is either not used or is used as supplement for added safety. With frozen foods, the outer master carton is often omitted when the inner containers hold 4.5 kg (10 lb) or more of product. Chilled product also may be packaged either in bulk (4.5–9.1 kg or 10–20 lb), or retail-sized (0.45–1.36 kg or 1–3 lb) inner containers within the master carton.

### Chilled products

As mentioned, large quantities of chilled seafoods are still shipped loose, packed in ice, in wooden or wax/plastic-coated corrugated boxes. The seafood is usually in direct contact with the ice; however, some delicate products such as fillets may be contained in metal trays or plastic bags immersed in the ice. Although packaging with ice maintains product quality reasonably well, it has several drawbacks, which are as follows:

- (1) *Product temperature*: Melting ice maintains the product temperature at 0°C (32°F). A more ideal temperature to prolong shelf life would be near -1.7°C (29°F), just below the freezing point.
- (2) *Leakage, leaching*: Ice packs are leaky and normally must be isolated from other food shipments. Although melting ice may have benefits in terms of “washing” bacteria off the product, leaching of the tissues can also result in significant product weight shrinkage.
- (3) *Weight of ice*: Shipping products on ice increases the shipping weight by 30–50% and thus is more expensive.

Bulk shipping containers that rely on mechanical refrigeration or nonice refrigerants avoid these problems. The simplest of these may consist of the same types of inner packs as are used for isolating the product from the ice in iced packs, but they are



contained in a master package with no ice. Besides the metal trays and plastic bags mentioned earlier, one well-known system recently introduced is a high-density polyethylene deep tray with a flexible film heat-sealed on the top lid. This package is leak and odor free and quite strong. The containers are normally made to hold either 4.5–9.1 kg (10–20 lb) of seafood and are sized to fit inside a master corrugated carton. They are actually larger versions of the rigid plastic trays previously described for retail packaging. The seafood from such containers must be repackaged in smaller quantities for supermarket sale or may be simply displayed on ice in fish retail outlets.

Some refrigerants other than ice, which may be used in master cartons of chilled fish, include CO<sub>2</sub> snow (dry ice) and the reusable “blue ice” refrigerant packs. CO<sub>2</sub> snow has been widely used to top-coat master cartons of chilled poultry. It may be conveniently generated by expanding liquid CO<sub>2</sub> through special nozzles. This “snow” is very cold (−78.9°C) and the crust freezes the product that is in direct contact with it. As the snow “melts” (sublimates), it forms a CO<sub>2</sub> vapor, which inhibits bacterial growth when the master carton or shipping container is sealed. However, care must be exercised to exhaust CO<sub>2</sub> from the packing and storage areas to prevent suffocation of the workers.

Reusable refrigerants may be constructed to melt at temperatures below 0°C (32°F), thereby maintaining a lower temperature than ice. These products must be reused to be economical, however.

A unique freeze-thaw approach to handling chilled fish, developed by National Marine Fishery Service scientists, involved freezing fish and allowing them to thaw slowly in transit. Such a system might require an absorbent foam or similar material to take care of the thaw-drip associated with such a handling method.

## Frozen product

Master cartons for frozen seafoods which are glazed or packaged in smaller bulk or retail-sized containers may often have many openings to allow free exchange of cold air with the packaged product. Within the inner bags or cartons, the product may be individually quick frozen (IQF) and loose filled, or tightly frozen together in either blocks or layer packs. Layer packs separate the seafood layers by pliofilm, parchment, or waxed paper. A satisfac-

tory layer pack would ensure easy removal of each product yet be less expensive than producing IQF products.

## Handling characteristics of packaging materials

Handling characteristics include the performance characteristics of the packaging materials during the actual packaging process (often called machinability characteristics of the material) as well as the strength and durability of the material when it is in contact with irregular product surfaces and/or when it is subjected to physical abuse in normal distribution.

Machinability characteristics that may be important, depending on the type of packaging equipment used, could include tear strength, stretchability, shrinkability, slippage, and heat-sealing or closure-sealing capacities.

If the material is to bear printed information, its inking characteristics would be important, although the type of printing process is often more important than the material being printed upon. Tack strength is often important with flexible films, which must bond easily to each other or to another material. Machinability is influenced by both machine design and package material characteristics; both should be well matched for satisfactory performance in high-speed packaging operations.

The toughness of the packaging material is usually a function of cost for a given category of packaging materials, whether clear film, paperboard, metal foils, or rigid plastics. For cost-effectiveness, the materials selected should only be durable enough to provide the level of package protection needed at a particular stage of distribution. For example, master cartons of corrugated paperboard, possibly with dividers to compartmentalize the retail packages, can be much cheaper protection during shipping than the highly durable clear packaging films for the retail package. Keep in mind, however, that products in self-service counters are often roughly handled by both store personnel and consumers. Frozen products receive especially rough treatment, so packaging materials for frozen products must remain pliable and be able to withstand shock at low temperatures. Packaging films used to

overwrap or bag chilled seafoods with sharp fins or bones must also be especially tough unless the package is designed to avoid contact between the film and the product.

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# 18

## Freezing

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Donald E. Kramer, Lyn D. Peters, and Edward Kolbe

When fish are frozen and stored at subfreezing temperatures, bacterial growth is arrested, and both enzyme and chemical action are slowed to a rate that is commensurate with the freezing temperature. Thus, the fish are preserved, and their shelf life is extended until the retarded chemical/enzymatic reactions eventually produce undesirable quality changes in flavor, texture, or appearance.

Bacteria, like all other living cellular forms, require free water for growth and multiplication. The reason that their growth is suppressed in frozen foods is that most of the water has been frozen and is not available as free water. Dehydration, another method of food preservation, is similar to freezing in that there is insufficient free water available to permit the bacteria to grow and multiply.

Freezing may destroy from 50% to 90% of the bacteria on fish. During frozen storage, there is a continued slow steady die-off of bacteria, with the rate of decrease depending on the temperature and bacterial species. Results of a study showing the effect of freezing and frozen storage on bacterial content of haddock are presented in Table 18.1.

That portion of the original microbial population that does survive freezing and storage will remain viable, but in a dormant state. Upon defrosting, these surviving microorganisms will begin to

grow and reproduce. If the fish are held for a sufficiently long period at temperatures above freezing, these bacteria will ultimately cause spoilage. However, thawed fish do not spoil faster than never-frozen fish. In a study with cod, frozen-thawed portions were found to have as long or a slightly longer iced-storage life compared with nonfrozen portions. Freezing and frozen-storage conditions are much more critical for seafood than for other foods.

### Factors affecting frozen shelf life

The most important factor governing the storage life of frozen fish is storage temperature. The lower the temperature, the longer the shelf life. As a general rule, the rate of chemical reactions doubles for every 10°C increase in temperature. Quality deterioration in frozen foods is a result of chemical reactions, so the importance of decreasing the storage temperature to as low as is economically feasible is essential. For many chemical reactions to take place free water is required, and although most of the water in fish has been frozen at a temperature of  $-7.8^{\circ}\text{C}$  ( $18^{\circ}\text{F}$ ), a small amount of unfrozen water remains even at temperatures below  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ).

**Table 18.1** Effect of freezing and storage on total bacterial counts of haddock.

Time at which counts were made	Total bacterial count per gram		
	Fresh sample	Slightly stale sample	Stale sample
Just before freezing	25,000	500,000	12,000,000
Immediately after freezing	1,500	28,000	950,000
After 1 month at 0°F (−18°C)	900	16,000	430,000
After 6 months at 0°F (−18°C)	0	14,000	300,000
After 12 months at 0°F (−18°C)	600	11,000	270,000

Table 18.2 shows the reported proportion of water frozen in fish at various temperatures.

Frozen storage has several important advantages:

- (1) Fishing vessels that freeze at sea can harvest on grounds farther from the port where they will be landing the catch, and they can fish longer when necessary to get a large enough catch to make the trip profitable.
- (2) The large increase in storage life allows processors and wholesalers to hold inventories for a longer time.
- (3) The increased storage life allows products to be shipped greater distances, with the potential of opening up new markets at a seasonally optimum price.
- (4) Frozen storage allows year-round marketing for species such as salmon, shrimp, and crab, which are harvested over a short time period each year.
- (5) If freezing is carried out soon after harvest, a higher quality product results than for fish kept in chilled storage until marketed.

In today's world market, competition from farmed fish and shellfish as well as competition

from other protein foods (in particular, poultry products) make it necessary for frozen fishery products to be the highest quality, especially frozen salmon and frozen shrimp. Storing seafood below −9.4°C (15°F) stops the growth and multiplication of bacteria. Enzyme action, however, is not slowed sufficiently to make this a good temperature for storing frozen seafood. For very short storage periods, −18°C (0°F) or lower is needed. For longer storage times or for fishery products that do not have very good storage characteristics, a holding temperature below −29°C (−20°F) is necessary.

## Composition

The proximate composition (moisture, fat, protein, and ash) of fish is species related. The attribute most closely associated with frozen-storage shelf life is probably the fat content because of its susceptibility to oxidation and concomitant rancid odors/flavors. Although there is no official definition for lean or fatty fish, an arbitrary definition would classify fish with less than 2% fat as "lean," between 2% and 5% fat as "moderately fat," and greater than 5% as "fatty." Table 18.3 provides a list of the average fat content of various seafoods and their classification based on average fat content. Rancidity is not usually a major problem with lean fish. Rancidity is more of a problem with fatty species such as mackerel, herring, and salmon. It should be noted that with some species, particularly the pelagic fish, fat content varies seasonally. For example, mackerel can have a fat content of 20–25% prior to spawning, and about 5% immediately following spawning. Fatty fish do not undergo serious textural changes during frozen storage.

One of the other major losses of quality in fish muscle during frozen storage is the development

**Table 18.2** Percentage of water frozen in fish as a function of temperature.

Temperature °F (°C)	Percentage of water frozen
30.3 (−0.9)	0
30 (−1.1)	32
28 (−2.2)	61
26 (−3.3)	76
24 (−4.4)	83
22 (−5.5)	86
18 (−7.8)	89

**Table 18.3** Average percentage of fat content and range for various types of seafood.

Lean	Average fat content	Range
Clam, soft shell	2.0	1.4–2.5
Cod	0.5 ± 0.2	
Crab, blue	1.0 ± 0.1	0.4–1.5
Crab, king	0.7 ± 0.2	0.2–1.4
Flounder	1.0 ± 0.2	0.1–2.9
Grouper	0.8 ± 0.2	0.2–2.3
Haddock	0.5 ± 0.2	0.1–1.2
Hakes ( <i>Urophycis</i> )	0.7	
Halibut (Pacific)	1.1 ± 0.2	0.6–3.6
Ocean perch	1.3 ± 0.2	0.6–2.2
Oysters	1.5 ± 0.1	0.7–2.6
Pollock (Atlantic)	0.5 ± 0.1	0.2–1
Scallop	0.7 ± 0.2	0.3–1.6
Squid	1.0 ± 0.2	0.5–1.4
<b>Moderately fat</b>		
Barracudas	3.2 ± 0.4	0.2–10
Bluefish	3.8 ± 0.8	2–5
Halibut (Atlantic)	2.4 ± 0.9	0.7–5.2
Scup	3.7 ± 0.8	1.2–5.9
Smelt	3.9 ± 0.7	2.3–6.7
Swordfish	4.1 ± 0.7	2.0–6.4
Tuna (yellowfin)	2.2 ± 0.5	1.0–9.5
Turbot	2.9	
Weakfish	3.2 ± 0.4	1.4–4.3
Whiting (Atlantic)	2.4	0.7–5.0
<b>Fatty</b>		
Albacore	5.4 ± 0.9	0.7–18
Butterfish	7.2 ± 1.9	1–24
Dogfish	14.5 ± 2.2	
Eel	17.3 ± 2.6	13–22
Herring (Atlantic)	15.7 ± 1.9	2.4–29
Mackerel	16.3 ± 2.1	1–24
Salmon (Chinook)	11.5 ± 2.4	2.2–19
Salmon (Coho)	5.7 ± 0.5	3.1–9
Shad	8.3 ± 1.7	1.7–15
Trout (Rainbow)	11.7	

of a toughness and dryness that is related to protein denaturation (Sikorski et al., 1976). It is the major cause of quality loss during frozen storage of lean fish. Taste panels describe the cooked fish as tough, fibrous, chewy, and rubbery. The cause of the toughness is protein denaturation, or unfolding, and later aggregation accompanied by loss of water-holding capacity. This results in high thaw drip loss and cook drip loss. Ice crystallization contributes to denaturation of the protein by disrupting the water structure around hydropho-

bic areas of the protein and by breaking up the water-mediated hydrophobic–hydrophilic interactions (Sikorski and Kolakowska, 1990). Maintaining this water structure is important to retaining the texture and juiciness of the cooked fish. It is also important in retaining compounds that provide good flavor.

Reducing the rate and amount of protein denaturation depends on good-quality raw material, low storage temperatures with minimum temperature fluctuation, and proper packaging to prevent desiccation. The rate of protein denaturation decreases as storage temperatures decrease. Seafood studies have shown that a storage temperature of  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ) or lower is needed to provide long-term storage.

### Condition of the fish

Fish to be frozen should be as fresh as possible because freezing and frozen storage cannot improve quality. At best, frozen storage will only maintain fish in about the same condition as it was just prior to freezing. The frozen-storage life of poor-quality fish will not be as long as that of good initial quality fish. For example, silver hake stored 2 days postmortem in ice prior to freezing were found to have a storage life of 12 months at  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ) whereas fish held 4 days in ice only had a frozen-storage life of 6 months. In addition, poor initial quality frozen fish will drip more upon defrosting, which will affect the texture of the cooked fish. There are two aspects of raw material quality: (1) intrinsic quality and (2) prefrozen treatment.

Intrinsic quality is the quality or value of the fish when it is harvested. The harvester cannot change or control intrinsic quality. Important factors that affect intrinsic quality are species, sex, fishing ground, nutritional condition, size, maturity, season, food consumed, parasites, and environmental contaminants. They all affect the raw material quality and the price the fisherman gets for the catch.

Prefreezing treatment is the handling and storage of raw material between catching and freezing. The fisherman and fish processor control the prefrozen treatment, which includes:

- (1) length of time between harvesting and freezing;
- (2) holding temperature;



- (3) stage of rigor mortis when freezing;
- (4) processing procedures (product form).

These factors are just as important as intrinsic quality factors. Fish subjected to improper prefreezing treatment will not be of high quality even if they get excellent treatment during freezing and frozen storage.

Seafood treatment should be as good for fish intended to be frozen as for fish intended for the fresh market. All fish and shellfish should be chilled quickly and completely immediately after catching, using ice, chilled, or refrigerated seawater. Once the product is chilled, the allowable holding time will vary with the species. For example, hold raw herring and other small or fatty fish at 0°C (32°F) for no longer than a day. Hold raw halibut and other species with good-to-excellent frozen characteristics at 0°C (32°F) for no longer than 3–5 days.

It is important to keep the chilled storage temperature as close to 0°C as possible (32°F), and to keep the chilled storage time as short as possible. Doyle (1989a, 1989b) has summarized research data to show how storage temperatures exceeding 0°C (32°F) will affect spoilage. Table 18.4 shows how spoilage rate (*r*) is expected to vary with temperature, compared to an assigned rate of 1.0 at 0°C (32°F). The right-hand columns in Table 18.4 express this in terms of “equivalent days on ice.” For example, holding seafood at 0°C (32°F) for 24 hours is 1 day on ice; holding the product at 10°C (50°F) for 18 hours would produce the same spoilage as if it were held on ice for 3 days.

Only the highest quality raw material should be used to prepare frozen products. Poor-quality frozen seafood is too often caused by freezing stale fish. The practice of freezing seafood near the end of its chilled storage life must be eliminated. When lower quality frozen seafood is the result of a delay in freezing, the product should be labeled and sold as cheaper brand in markets where lower quality is acceptable.

### Season of year

During spawning and immediately thereafter, the energy reserves (stored fat) of the fish are at their lowest. To compensate for this depletion of fat, the flesh contains more water than normal and is relatively soft. Fish that have been frozen in this condition will have a less desirable texture after freezing because of excessive water drip upon thawing.

### Rigor mortis

Immediately after death, fish muscles are limp and pliable, but soon afterward they contract and become rigid, at which time the fish is said to be in rigor. After a period of time, depending on the temperature, the muscles relax, once again become soft, and rigor is said to be resolved. Fish muscle contains a carbohydrate (glycogen), which serves as an energy source of muscular activity. The more glycogen present at the time of death, the longer the fish remain in rigor. This characteristic is desirable in that bacterial growth is retarded while fish

**Table 18.4** High-quality shelf life (months) of various frozen seafood at three different temperatures.

Seafood	Storage temperatures		
	0°F (−18°C)	−13°F (−25°C)	−20°F (−28.9°C)
Cod	3–5	6–8	8–10
Haddock	3–5	6–8	8–10
Flatfish	4–6	10	
Fatty fish	2–3	3–5	6
Lobster, crab	2		
Clams	3–4		
Oysters	2–4		
Scallops	3–4		
Shrimp	6		

are in rigor. Fish that are in poor physical condition, such as after spawning, or fish that have struggled hard during capture will have depleted most of their glycogen and will consequently undergo a short period of rigor. The state of rigor has an important bearing on the quality of frozen fish in that it can cause gaping, excess thaw drip, and toughness. Gaping is a condition when individual muscle flakes have become separated and the fillet appears ragged. This condition can result when the fish muscle undergoes rigor at a high temperature, particularly if the glycogen content is high. In this situation, the muscle contraction is so great that the bonds of connective tissue holding the muscle flakes together are broken. The drastic muscle contraction that occurs at a high rigor temperature will also be responsible for a greater drip loss and toughness after thawing and cooking. Gaping can also result when an attempt is made to straighten out bent fish in rigor in order to facilitate filleting. This action forces muscle fibers to break and separate.

If a fish has been filleted prerigor, the fillet will shrink when rigor does develop, more noticeably if the temperature is high; due to muscular contraction, the texture will probably be tough. In addition, the frozen fillet may show a gray discoloration, which is a physical effect resulting from cutting across prerigor muscle fibers. When whole fish undergo rigor, shrinkage is at a minimum because the muscles are anchored to the skeletal frame. Nevertheless, if a fish is frozen before the onset of rigor, the process of rigor will take place slowly during frozen storage, and resolution will eventually occur. But if the frozen flesh is cooked before rigor has been resolved, the muscle will contract during cooking, lose cellular fluid, and be tough. This phenomenon is known as thaw rigor and it can be a problem with high-quality fillets frozen aboard freezer trawlers within a few hours after capture before the fish have passed through rigor. Even fish sticks made from prerigor fish can undergo distortion during cooking. To avoid thaw rigor, it is recommended that the fish be conditioned prior to thawing or cutting into sticks by holding for a period of time at a relatively high temperature in the freezer, thus inducing rigor.

Throughout this discussion, we have stressed the adverse effect of excess thaw drip on the texture of cooked fish. Thaw drip can be mitigated somewhat by a brief dip in a salt solution prior to freezing. This treatment solubilizes the surface protein,

forming a skin on the cut surface and thus helping seal in the moisture. A 10- to 20-second dip in 3–6% brine should suffice. Brine dips should not be applied to fatty fish because of the possibility that this treatment may promote rancidity. This danger can be averted by using one of the phosphates, such as sodium tripolyphosphate or sodium hexametaphosphate, in the dip solution in lieu of the salt. However, either of these treatments increases the sodium content of the fish flesh, which may be undesirable in this age of dietary salt consciousness. In employing dips for fish fillets, the processor should be ever aware of the potential hazards of increased bacterial buildup in the brine solution unless proper temperature control is maintained and the solution is changed often.

### Freezing rate

Depending on the fat content, the water content of various fish species can range from 60% to 90%. For the most part this moisture is located within the tissue cells along with dissolved salts and soluble proteins, all of which make up the sarcoplasm. Some water is present in the interstitial spaces between the cells, and some is chemically bound to the muscle proteins. The ability of proteins to bind water is referred to as water-holding capacity. When this capacity is impaired in frozen flesh foods, such as through denaturation or damage to the proteins, the product will exude some fluid (drip), and the texture will toughen. When fish muscle is subjected to a subfreezing temperature, the muscle temperature drops at a steady rate until it reaches about  $-2.2^{\circ}\text{C}$  to  $-1.8^{\circ}\text{C}$  ( $28^{\circ}\text{F}$  to  $30^{\circ}\text{F}$ ), which is the freezing range for fish muscle. At this point, ice crystals begin to form within the tissues, and the temperature remains relatively constant. When most of the cellular water has been frozen, the muscle temperature begins to drop rapidly once again, until it eventually equilibrates with the temperature of the environment. With a fast freezing rate, ice crystals that form within the muscles will be numerous but small, resulting in little damage to the tissues. If the freezing rate is slow, a few ice crystals will form, but these will be large and can disrupt tissue cells. The ensuing damage will be evident upon thawing as drip loss. In addition, enzymes, which had been contained in compartments in the intact cell, may now be released to react with

suitable substrates to produce undesirable changes in flavor or texture. Other changes besides ice crystallization are also going on within the cells as the cellular water freezes. The naturally present salts are becoming increasingly concentrated in the remaining unfrozen fluid. This concentrated solution damages the proteins and impairs cell permeability as a result of intracellular pH changes and what is referred to as a "salting-out effect." As a consequence, there is a reduced water-holding capacity by the proteins, with large amounts of fluid exuded from the frozen fish upon defrosting or cooking.

Loss of a large quantity of cellular water after thawing results in loss of nutrients, flavor, and succulence. The texture will usually be tough, stringy, and fibrous. To help preserve texture during freezing, it is imperative that the fish muscle temperature pass through the critical freezing zone ( $0^{\circ}\text{C}$  to  $-5^{\circ}\text{C}$ / $32^{\circ}\text{F}$  to  $23^{\circ}\text{F}$ ) as rapidly as possible. This way, the formation of large ice crystals within the tissue cells can be avoided. Residence time of concentrated salt solutions with the proteins and effects of intracellular pH changes can be minimized as well. The critical freezing rate is defined as the time required for the internal temperature of a fish product to drop from  $0^{\circ}\text{C}$  to  $-5^{\circ}\text{C}$  ( $32^{\circ}\text{F}$  to  $23^{\circ}\text{F}$ ), the critical freezing zone. It is within this temperature region that most of the cellular freezing damage occurs.

There are three general categories of freezing rates: (1) slow or sharp freezing, (2) quick or fast freezing, and (3) ultrarapid freezing. These are discussed in the forthcoming sections. Figure 18.1 shows the freezing curves for a block of fish fillets frozen by each method.

### Slow freezing

In slow freezing, or sharp freezing, the temperature of the product remains within the critical zone for more than 2 hours. The term **deep freezing** refers to freezing a food to  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ) and storing it at or below that temperature, without regard to the rate at which the product was frozen. Slow freezing is accomplished by placing the fish, usually on trays or on shelves, in a freezer room or cabinet with little or no air circulation. In this situation, the freezing rate is slow because of the poor heat transfer characteristics of still air. If the freezer room temperature is not sufficiently low, the product, if thick, may remain in the critical zone for a relatively long time. Figure 18.1 shows that the 5.7-cm (2.25-in.)

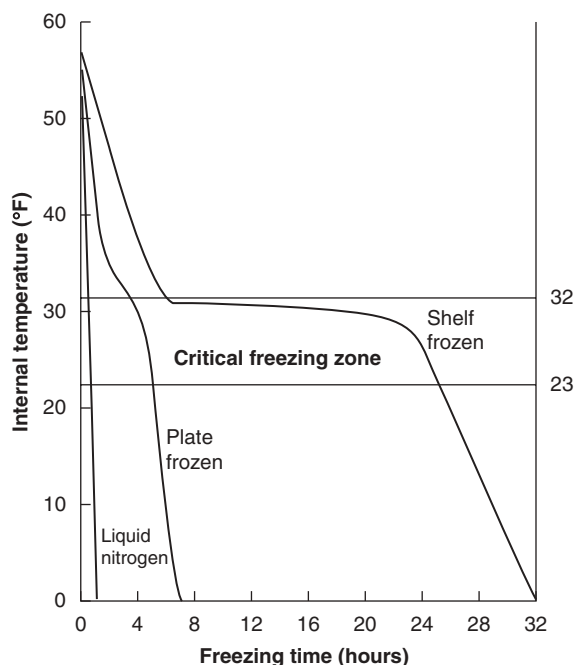


Figure 18.1 Critical freezing time.

thick block of fillets frozen in still air at  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ) (shelf frozen) remained in the critical zone for about 19 hours.

### Quick or fast freezing

A method in which the internal temperature of the product passes through the critical zone in 2 hours or less is classified as quick freezing or fast freezing. By increasing the flow of cold air over the fish, as in a tunnel blast freezer, the removal of heat from the fish is accelerated, and quick freezing can be attained. Placing the product to be frozen in direct or indirect contact with the refrigerant is a still more efficient method for removal of heat. The plate freezer is an example of an indirect contact freezer. Plate freezers can be of the horizontal type, which is preferred for the freezing of blocks or cartons of fish, or the vertical type, developed for freezing whole fish at sea. Fish to be frozen, usually packaged in cartons, are placed in a metal or wooden frame between two parallel movable hollow plates through which a refrigerant is circulated. The product is frozen while under pressure between the plates. The pressurized contact with the plates not only speeds up the rate of freezing, it also

produces a smooth flat surface on the faces of the block of fish by preventing the normal expansion that occurs during freezing. It also eliminates voids or air spaces that could be a focal point for oxidation (rancidity) and that could result in irregular-shaped fish sticks cut from these blocks.

In direct contact freezing; fish are frozen either by being submerged in or sprayed with a suitable refrigerated liquid, usually a brine solution. A disadvantage of this method is that prolonged contact of the fish flesh with brine will lead to a high salt uptake. Excessive salt absorption not only results in an undesirable salty taste, it may also promote rancidity during frozen storage. Generally, salt uptake is serious only when the fish are kept in the brine (23% NaCl) in excess of 4 hours at a brine temperature below  $-12.2^{\circ}\text{C}$  ( $10^{\circ}\text{F}$ ). Oily fish do not absorb as much salt in brine freezing as do the lean species; however, rancidity is more of a problem with oily fish. Small fish take up more salt during brine freezing than do large fish because of their greater surface to volume ratio.

Immersion brine freezing is generally employed aboard West Coast tuna boats for at-sea freezing. In this application, when the temperature of the fish has been lowered close to  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ), the freezing brine is drained and the fish are kept frozen in air maintained at  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ).

### Ultrarapid freezing

Spraying fish fillets or whole fish with or submerging them in either liquid nitrogen ( $-195^{\circ}\text{C}/-320^{\circ}\text{F}$ ) or liquid carbon dioxide ( $-78^{\circ}\text{C}/-109^{\circ}\text{F}$ ) results in ultrarapid freezing. Freezing rate is a function of the temperature difference between the surface temperature of the product to be frozen and the temperature at the center of the product. This temperature differential is the driving force in the removal of heat, and with these liquefied cryogenic gases it can be very large and thus conducive to very rapid freezing. Another variable associated with freezing rate is the heat transfer coefficient. This parameter is small in the case of cryogenic freezing, which again promotes very rapid freezing. In actual practice, a fish fillet can be hard frozen in liquid nitrogen within several minutes. The disadvantage of this method, disregarding economics, is that the frozen fillet may have a chalky appearance (a physical phenomenon resulting from the light scattering by the numerous small ice crystals

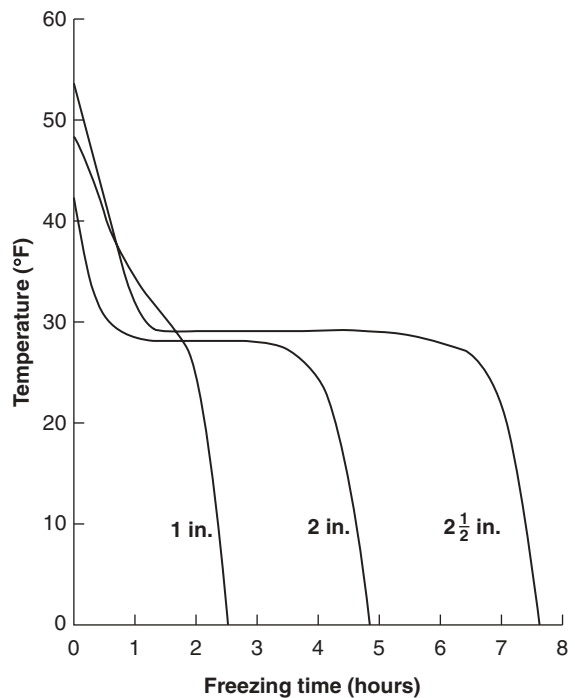


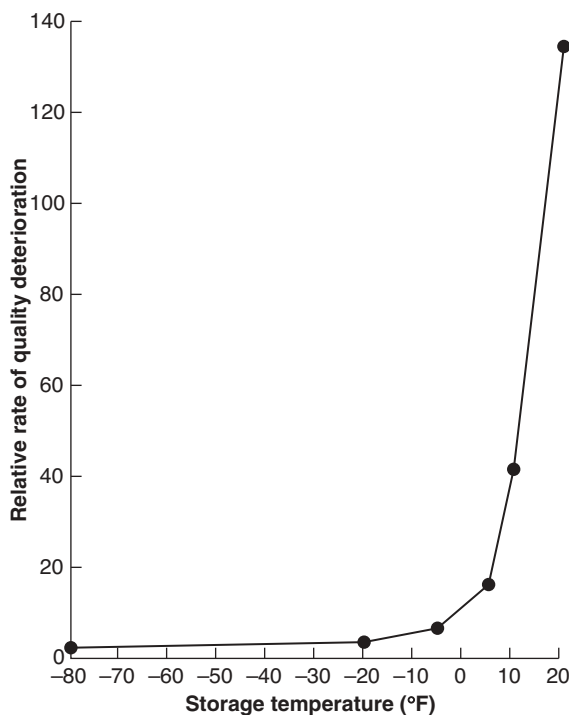
Figure 18.2 Freezing time/thickness.

formed), a ragged surface, and may be brittle and shatter easily if dropped. The advantage is that the flavor and texture of ultrarapidly frozen fish will more closely resemble that of fresh fish. Freezing time is also a function of the product thickness. Figure 18.2 presents freezing curves that show how long it takes fish fillet slabs of different thickness to reach an internal temperature of  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ). Note the critical freezing time for a 6.4-cm (2.5-in.) thick block compared to a 2.5-cm (1-in.) block. It has been observed that a portion of fish twice as thick as another will require two to four times as long to freeze.

The amount of heat that can be removed from a load of fish per unit of time depends mainly on the horsepower rating of the freezer compressor. Overloading a freezer with product will only serve to lengthen the time required to freeze the entire batch. Overloading a freezer will also restrict air circulation, which can reduce the freezing rate. Unfrozen product packaged in individual retail cartons or in master cartons should not be placed in the freezer storage room to be frozen, because the container material will act as an insulator, slowing the freezing rate.

## Storage temperature

Many variables influence the storage life of frozen fish, but the single most important factor is storage temperature. The rates of quality deterioration for frozen red hake fillets over a wide range of storage temperatures are shown in Figure 18.3. There is a dramatic difference in spoilage rate between fillets stored at  $-6.7^{\circ}\text{C}$  ( $20^{\circ}\text{F}$ ) and fillets stored at  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ). A further  $6.6^{\circ}\text{C}$  ( $20^{\circ}\text{F}$ ) drop in storage temperature produces a significant but much lesser effect. In the temperature region of  $-29^{\circ}\text{C}$  to  $-62^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$  to  $-80^{\circ}\text{F}$ ), the difference in spoilage rate appears to be so small as to probably not warrant added cost. It should be pointed out that these data were obtained with a lean fish species and may not apply exactly to a fatty fish. The Association of Food and Drug Officials of the US code of handling practices for frozen foods recommends that frozen foods be stored at a temperature of  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ) or below. For fishery products, a storage temperature of  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ) may be adequate for short-term storage where a fast turnover is expected, but for long-term storage this temperature would be inad-



**Figure 18.3** Relative rate of product deterioration as a function of storage temperature.

equate for maintaining quality. The recommended temperature for long-term storage of frozen fish is  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ).

It is a difficult task to assign absolute storage-life values for different fish species at various temperatures because many variables are involved. Some of these variables such as season of year, condition or quality of fish at time of freezing, and freezing rate have already been discussed. Factors not discussed include fishing ground, product style (whole fish, fillets, minced, etc.), and packaging mode. Even the method of preparation or cooking the product can mask subtle storage changes and affect shelf life. For example, a fish fillet fried in oil would have a longer acceptable storage life than the same product baked or steamed. Moreover, the stage of quality at which a frozen fish may be considered unacceptable is highly subjective, varying among individuals, particularly on a regional basis. Nevertheless, based on published scientific data, an attempt has been made in Figure 18.4 to illustrate the effect of storage temperature on shelf life of several common marine fish species. Note the relatively shorter frozen shelf lives of the fatty fish (herring, mackerel) compared to the lean fish (haddock, whiting, pollock). As previously indicated, quality deterioration in frozen-stored fatty fish is due to oxidative rancidity, whereas in lean fish protein denaturation initiates textural changes that eventually terminate shelf life. The gadoid fish (cod, haddock, pollock, etc.) are especially prone to protein denaturation during frozen storage because they contain an enzyme whose activity produces compounds that cause the muscle fibers to cross-link, resulting in a tough, fibrous texture. This enzyme activity is greatest in the hakes.

The shelf lives depicted in Figure 18.4 are based on product acceptability. However, it is often of interest to a manufacturer to determine the storage time at a given temperature at which the product retains a high quality. Table 18.5 shows some estimated (by the International Institute of Refrigeration) high-quality shelf lives for various seafoods at different storage temperatures.

Tables 18.6, 18.7, and 18.8 were developed from a study by Alaska Sea Grant and represent time and temperature values derived from the literature using a variety of methods (chemical and sensory). These values are approximates and should be used as reference only.



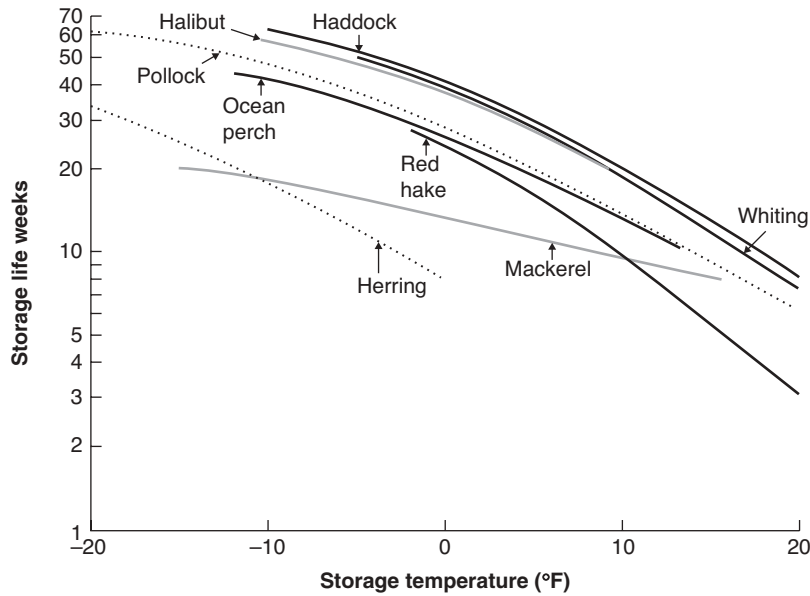


Figure 18.4 Storage life/temperature.

Packaging

Almost as important as temperature control in obtaining maximum shelf life is protection by some type of packaging. The functions of packaging include the following:

- (1) Envelope the product to assist in moving it to market.
- (2) Protect the product from dehydration, oxidation, contamination, and mechanical damage.
- (3) Identify the product to assist in storage management and to provide consumer information.

Table 18.5 Relative rates of seafood spoilage for different temperatures and times.

Equivalent days on ice									
Holding temperature (°F)	Relative rate of spoilage (r)	Time at elevated holding temperature							
		4 h	8 h	12 h	18 h	24 h	36 h	48 h	72 h
28.4	0.6	0.1	0.2	0.3	0.5	0.6	1.0	1.3	1.9
32.0	1.0	0.7	0.3	0.5	0.7	1.0	1.5	2.0	3.0
35.6	1.4	0.2	0.5	0.7	1.1	1.4	2.7	2.9	4.3
39.2	2.0	0.3	0.6	1.0	1.5	2.0	2.9	3.9	5.9
42.8	2.6	0.4	0.8	1.3	1.9	2.6	3.8	5.1	7.9
46.4	3.2	0.5	1.1	1.6	2.4	3.2	4.9	6.5	9.7
50.0	4.0	0.7	1.3	2.0	3.0	4.0	6.0	8.0	12.0
53.6	4.8	0.8	1.6	2.4	3.6	4.8	7.3	9.9	14.5
59.0	6.3	1.0	2.1	3.1	4.7	6.2	9.4	12.5	18.7

A relative spoilage rate (*r*) is a comparison to the rate for a product held at 32°F (where *r* is equal to 1). Because of biological variability within a species, numbers are approximate.

**Table 18.6** Frozen-storage temperature and storage life for marine fish and fish products that are low to moderate in lipid concentration.

Product		For highest quality <sup>a</sup>		For good quality <sup>b</sup>		References
		Maximum storage temperature (°F)		Storage life (months)		
		2 months to consumption	6 months to consumption	0°F	−20°F	
H&G salmon	Chinook	−10	−20	8	14	Heerdt and Stansby, 1955; Doyle, 1989b; Gerasimov and Antonova, 1972; Yu et al., 1973; Banks et al., 1977; FAO, 1977; Löndahl, 1981
	Chum	−15	−20	4	8	
	Coho	−10	−20	6	10	
	Pink	−15	−30	3	6	
	Sockeye	−10	−20	7	12	
	Farmed	−10	−20	7	12	
	Atlantic salmon					
Pacific cod	H&G	−5	−15	9	18	Kelly, 1969; Tomlinson et al., 1969; Doyle, 1989b; Gerasimov and Antonova, 1972; Banks et al., 1977; FAO, 1977; Graham, 1977; Löndahl, 1981, Graham, 1984; Jul, 1984; Learson and Licciardello, 1986
	IQF fillets	−10	−20	7	12	
	Fillet blocks	−10	−20	8	15	
Pacific whiting	H&G	−10	−20	8	15	Doyle, 1989b; FAO, 1977; Graham, 1977; Licciardello et al., 1980; Löndahl, 1981; Graham, 1984; Learson and Licciardello, 1986; Licciardello, 1990
	IQF fillets	−20	−30	6	10	
	Fillet blocks	−10	−20	7	14	
Greenlings	Surimi	−15	−25	6	12	Tomlinson et al., 1969; Doyle, 1989b; FAO, 1977; Graham, 1977; Graham, 1984
	Atka mackerel	−5	−15	9	18	
Alaska pollock	Lingcod	0	−10	10	20	Iwata et al., 1971; Umemoto et al., 1971; FAO, 1977; Graham, 1977; Dassow, 1982; Graham, 1984; Learson and Licciardello, 1986; Babbitt et al., 1987
	H&G	−10	−20	8	14	
	IQF fillets	−15	−20	6	10	
	Fillet blocks	−10	−20	7	12	
Pacific halibut	Surimi	−22	−22	6	12	Tomlinson et al., 1969; Doyle, 1989b; Tomlinson et al., 1973; FAO, 1977; Graham, 1984; Learson and Licciardello, 1986; Licciardello, 1990
	H&G	0	−10	10	20	
	Fletches	−10	−20	8	16	
Flounder/sole	Arrowroot	−10	−20	6	10	Tomlinson et al., 1969; Banks et al., 1977; FAO, 1977; Graham, 1977; Löndahl, 1981; Graham, 1984; Licciardello, 1990
	Dover	0	−10	10	18	
	Flathead	0	−15	10	18	
	Green-land turbot	−10	−20	8	14	
	Rock	0	−10	10	18	
	Yellowfin	−5	−20	9	16	
	Petrale	0	−10	10	18	
	English	−5	−15	8	14	
	Rex	0	−10	9	16	
	Sand	−5	−15	8	12	
	Starry	−10	−20	6	10	

(Continued)

**Table 18.6** (Continued).

Product		For highest quality <sup>a</sup>		For good quality <sup>b</sup>		References
		Maximum storage temperature (°F)		Storage life (months)		
		2 months to consumption	6 months to consumption	0°F	−20°F	
		2 months to consumption	6 months to consumption	0°F	−20°F	
Rockfish/ thorny-head	Pacific Ocean perch	0	−10	8	14	Tomlinson et al., 1969; Doyle, 1989b; Gerasimov and Antonova, 1972; Banks et al., 1977; Löndahl, 1981; Learson and Licciardello, 1986; Licciardello, 1990
	Yelloweye	0	−10	8	14	
	Dusky	−20	−30	5	9	
	Bocaccio	−10	−20	6	12	
	Black	−15	−25	5	10	
	Yellowtail	−10	−20	6	12	
	Widow	−10	−20	6	12	
	Northern	0	−10	8	14	
	Thorny-head	0	−10	9	16	

<sup>a</sup>Storage temperatures given are the highest that will still allow minimal loss of quality. At the end of the frozen-storage period, the product will be almost as good as fresh fish that has been held properly chilled and is frozen within a few days after harvest. This level of quality is termed HQL (high or highest quality life). No quality changes will be detected by a trained sensory panel.

<sup>b</sup>Practical storage life is defined as the length of time the product remains in a condition that can be described as good quality. At the end of good-quality life (practical storage life or PSL), quality has diminished but consumers purchasing this product would be likely to purchase it again. At longer storage times, the product will be of fair-to-poor quality; although it may still be edible, it is not the quality of seafood that the industry should be marketing.

Frozen product not packaged prior to freezing should be packaged as soon as possible after freezing. The packaging should be strong, waterproof, and stain-resistant, and should not contaminate the product. Closeness of fit is also an important property. The packaging material should be impermeable to fats and oils. To reduce the rate of dehydration, the material should have a low permeability to water vapor. To reduce the rate of oxidation, the material should have low oxygen permeability. A good packaging material is strong, tight-fitting, low in permeability to water vapor and oxygen, and inexpensive (low labor and material costs). The following types of packaging are discussed here:

- (1) Glazing
- (2) Hydrocarbon polymer films
- (3) Films made from cellulose
- (4) Chlorinated polyvinyl chloride films
- (5) Hermetically sealed metal cans

Glazing consists of adding a layer of ice to a product by dipping, spraying, or brushing. It is inexpensive, provides a tight fit, and has low permeability to both water vapor and oxygen. Consequently, it provides good protection against dehydration and oxidation. However, glazing is lost by sublimation, and periodic inspection and reglazing are necessary. The glaze is not very strong and will crack off if the product is mishandled. Additives such as sugar, cornstarch, salt, sodium alginate, and carboxymethyl cellulose can be added to the glaze water to strengthen the glaze. Antioxidants such as ascorbic acid and sodium erythorbate are sometimes added. Glazing is now used primarily for individually quick frozen (IQF) fillets and whole fish. Fish or fish fillets packed as a shatter pack are protected with an interweaving of waxed paper or plastic sheeting between fish or fillets so that they can be taken apart without thawing.

Hydrocarbon polymer films such as polyethylene and polypropylene are strong and inexpensive, but

**Table 18.7** Frozen-storage temperature and storage life for marine fish and fish products that are moderate to high in lipid concentration.

Product		For highest quality <sup>a</sup>		For good quality <sup>b</sup>		References
		Maximum storage temperature (°F)		Storage life (months)		
		2 months to consumption	6 months to consumption	0°F	−20°F	
Sablefish		−10	−20	8	14	Doyle, 1989b; FAO, 1977; Tomlinson et al., 1969; Graham, 1984
Tuna	Albacore gutted head on	−10	−20	6	14	Dassow et al., 1956; Tomlinson et al., 1962; FAO, 1977; Anonymous, 1984; Graham, 1984; Craven et al., 1997; Ben-Gigirey et al., 1999; Staruszkiewicz et al., 2004
	Albacore steaks	−10	−20	7	12	
	Albacore loins	−10	−20	8	16	
	Skipjack gutted head on	−15	−25	5	18	
	Yellowfin gutted head on	−15	−25	6	10	
Herring		−20	−30	2	12	Banks et al., 1977; FAO, 1977; Bilinske et al., 1979; Bilinske et al., 1981; Graham, 1984; Jul, 1984; Learson and Licciardello, 1986
Herring roe		−10	−20	8	6	Atkinson, 1985
Smelt	Capelin	−10	−20	8	14	Doyle, 1989b; Banks et al., 1977; Löndahl, 1981; Anonymous, 1984; Graham, 1984; Atkinson, 1985
	Eulachon	−20	−30	4	16	
	Rainbow smelt	−10	−20	6	8	
	Surf smelt	−10	−20	6	9	
	Pacific sardine	−15	−25	5	9	
Shark	Salmon	−10	−20	9	9	Anonymous, 1984
	Thresher	−10	−20	10	12	
Skate	Whole wings	−10	−20	2	14	Otwell and Crow, 1978; Anonymous, 1984

<sup>a</sup>Storage temperatures given are the highest that will still allow minimal loss of quality. At the end of the frozen-storage period, the product will be almost as good as fresh fish that has been held properly chilled and is frozen within a few days after harvest. This level of quality is termed HQL (high or highest quality life). No quality changes will be detected by a trained sensory panel.

<sup>b</sup>Practical storage life is defined as the length of time the product remains in a condition that can be described as good quality. At the end of good-quality life (practical storage life or PSL), quality has diminished but consumers purchasing this product would be likely to purchase it again. At longer storage times, the product will be of fair-to-poor quality; although it may still be edible, it is not the quality of seafood that the industry should be marketing.

**Table 18.8** Frozen-storage temperature and storage life of shellfish and other marine invertebrates.

Product		For highest quality <sup>a</sup>		For good quality <sup>b</sup>		References
		Maximum storage temperature (°F)		Storage life (months)		
		2 months to consumption	6 months to consumption	0°F	−20°F	
Spot shrimp	Raw in shell	0	−10	10	15	Peters and McLane, 1959; Dassow, 1968; Doyle, 1989b; Banks et al., 1977; Löndahl, 1981; Atkinson, 1985; Licciardello, 1990
	Cooked meat	−20	−30	4	8	
Pink shrimp	Raw in shell	−10	−15	8	12	
	Cooked meat	−20	−30	3	6	
Sidestripe shrimp	Raw in shell	0	−10	9	14	
	Cooked meat	−20	−30	4	8	
King crab	Cooked in shell	−10	−20	9	15	Dassow, 1968; Doyle, 1989b; Löndahl, 1981; Atkinson, 1985
	Cooked meat	−10	−25	6	9	
Dungeness crab	Cooked in shell	−15	−20	4	8	
	Cooked meat	−20	−30	2	6	
Tanner/snow crab ( <i>Chionoecetes bairdi</i> )	Cooked in shell	−15	−20	6	12	
	Cooked meat	−15	−30	4	8	
Tanner/snow crab ( <i>Chionoecetes opilio</i> )	Cooked in shell	−15	−20	6	12	
	Cooked meat	−15	−30	4	8	
Pacific oyster	Whole in shell	−10	−20	5	9	Dassow et al., 1956; Doyle, 1989b; Banks et al., 1977; Graham, 1984; Atkinson, 1985; Licciardello, 1990; Andress and Harrison, 1999
	Shucked meats	−15	−25	4	7	
Manilla clam	Whole in shell	−5	−10	8	14	Dassow et al., 1956; Cox, 1997; Doyle, 1989b; Banks et al., 1977; Licciardello, 1990; Andress and Harrison, 1999
	Shucked meats	−10	−15	6	10	
Razor clam	Whole in shell	−10	−15	7	12	
	Shucked meats	−15	−20	6	10	
Geoduck clam	Neck meats	0	−10	12	24	
	Breast meats	−5	−15	10	18	



**Table 18.8** (Continued).

Product		For highest quality <sup>a</sup>		For good quality <sup>b</sup>		References
		Maximum storage temperature (°F)		Storage life (months)		
		2 months to consumption	6 months to consumption	0°F	−20°F	
		2 months to consumption	6 months to consumption	0°F	−20°F	
Mussel	Cooked meats	−10	−20	5	11	Waterman, 1963; Graham, 1984
Scallop	Raw meats	0	−10	10	18	Dassow et al., 1956; Banks et al., 1977; Graham, 1984; Atkinson, 1985; -Licciardello, 1990
California squid	Dressed	0	−10	13	22	Wilson and Gorham, 1982; Dewees and Price, 1983; Atkinson, 1985
Sea cucumber	Raw	0	−5	8	14	Slutskaya, 1973
	Boiled	0	−10	6	12	

<sup>a</sup>Storage temperatures given are the highest that will still allow minimal loss of quality. At the end of the frozen-storage period, the product will be almost as good as fresh fish that has been held properly chilled and is frozen within a few days after harvest. This level of quality is termed HQL (high or highest quality life). No quality changes will be detected by a trained sensory panel.

<sup>b</sup>Practical storage life is defined as the length of time the product remains in a condition that can be described as good quality. At the end of good-quality life (practical storage life or PSL), quality has diminished but consumers purchasing this product would be likely to purchase it again. At longer storage times, the product will be of fair-to-poor quality; although it may still be edible, it is not the quality of seafood that the industry should be marketing.

they do not provide a good barrier to water vapor and oxygen. Therefore, they do not prevent dehydration and oxidation. Polyethylene bags are often used to hold glazed seafood products like IQF fillets or shrimp. Also, small whole fish, fish fillets, and shrimp can be frozen with added water in polyethylene bags.

Films made from cellulose, such as cellophane, are not good packaging material for seafood because of their very high permeability to water vapor and relatively high permeability to oxygen.

Chlorinated polyvinyl chloride films (like polyvinylidene chloride or Saran<sup>TM</sup> Wrap) provide very good protection against dehydration and oxidation, because their permeability to water vapor and oxygen is very low. These are shrink films and can be used in vacuum-packaging processes.

Packaging seafood in a metal can that will be evacuated, hermetically sealed, and frozen is an excellent way of protecting against dehydration and oxidation. This process has been used commercially to pack picked crab and shrimp. It is not widely used except for institutional packs, possibly because consumers, mistaking the product for one

that has been retorted, may believe it can be stored at room temperature.

Migration of moisture from the surface of a frozen fish product to the surrounding air through evaporation, or more precisely sublimation, causes a condition known as freezer burn or desiccation. Evaporation of moisture causes product weight loss, which can lead to legal problems if the product does not comply with the declared net weight. Evaporation also imparts a white, dry wrinkled appearance to the surface, and the affected portion of the fish will be tough and fibrous after cooking. Most freezers do not operate at a constant temperature; instead, they undergo cyclic fluctuations due to defrost cycles and opening and closing of the freezer doors. When fish is packaged in a loose fitting plastic bag or oversized container and placed in a freezer, moisture will evaporate from the fish surface until the air within the package becomes saturated or reaches equilibrium relative humidity. If the freezer temperature rises, more moisture will be evaporated until a new equilibrium relative humidity is reached for that temperature. When the freezer temperature decreases, the water vapor in

the air space of the package will precipitate as snow inside the package. This continual action of evaporation and precipitation with fluctuating temperature behaves as a water pump and results in dehydration of the fish flesh. A loss in overall product quality generally occurs as a result of cycling freezer temperature. If a fishery product is stored at some fluctuating freezer temperature, such as  $-12.2^{\circ}\text{C}$  to  $-23.3^{\circ}\text{C}$  ( $10^{\circ}\text{F}$  to  $-10^{\circ}\text{F}$ ), the effective mean temperature is not  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ) but a temperature that will be a few degrees above.

Whenever unpackaged fish are stored in a freezer for an appreciable time, the vaporized moisture will condense as frost on the evaporator plates. This will hamper the efficiency of the evaporator in addition to lowering the quality of the fish. This process can be prevented, to an extent, by increasing the surface area and temperature of the evaporator plates. A skintight, moisture-impermeable package, and minimal opening of freezer doors will reduce the incidence of freezer burn.

Hydrolytic rancidity is not considered a major cause of quality degradation in frozen fish. On the other hand, oxidative rancidity is characterized by an objectionable change in flavor, producing tastes that are sharp, bitter, or musty, reminiscent of linseed oil, cod liver oil, and paint. Rancidity is often accompanied by a change in appearance (color). The fatty strip along the lateral line or the dark red muscle may change to a yellow or rust color. In pigmented fish, such as salmon and ocean perch, the red color may either fade or become yellow to orange.

How frozen fish is stored affects its susceptibility to becoming rancid. Fish frozen whole are less prone to developing rancidity compared to gutted fish or fillets, because less surface area is exposed. Packing fish tightly in bulk also tends to reduce incidence of rancidity. In fillet blocks, rancidity has been mainly confined to the surface when the blocks were not fully protected from the air. The process of mincing fish creates a large surface area that increases contact of the flesh with air, thus enhancing rancidity. It also disintegrates the integrity of the cell, releasing enzymes and other substances that can promote either oxidative reactions causing flavor changes or textural changes. Thus, the frozen shelf life of minced fish is much less compared to that of the intact muscle.

Some practical methods for controlling rancidity are as follows:

- (1) Store the fish at as low a temperature as is economically feasible. Chemical reaction rates slow down with a decrease in temperature.
- (2) Avoid contact of the fish flesh with metals such as iron and copper, which act as catalysts in the reaction between oxygen and fat.
- (3) Treat the fish with an antioxidant, a chemical substance that prevents or retards oxidation. The water-soluble antioxidants such as sodium erythorbate and ascorbic acid (vitamin C), or the fat-soluble phenolic antioxidants such as butylated hydroxyanisole (BHA) and butylated hydroxytoluene (BHT) can delay the onset of rancidity if used properly.
- (4) Remove the fatty strip or dark muscle along the lateral line and just beneath the skin either manually or with an automatic deep-skinning machine.
- (5) Wash fish fillets prior to freezing to remove blood, which is known to accelerate rancidity formation.
- (6) Treat the fish with a chelating agent such as citric acid, or polyphosphates. These compounds bind metals such as iron and copper, which accelerate rancidity.
- (7) Package fish under vacuum in an oxygen-barrier material. Nylon and polyvinylidene dichloride films have excellent oxygen-barrier properties. Polyethylene of less than 4 ml thickness would probably not be suitable. Metal foil and metal containers would be highly satisfactory but the cost may be too high.
- (8) For large fish that are individually frozen or frozen in blocks, a water glaze can form a protective coating. The disadvantage of a water glaze is that during prolonged storage the glaze evaporates if the fish have not been packaged carefully and has to be replenished. A glaze formed from pure water can be brittle. An improvement can be made by adding a small amount of corn syrup to the glazing water. The addition of a water-soluble antioxidant such as ascorbic acid to the glaze water also enhances its protective effect.

## Thawing

Frozen fish can be defrosted several ways such as in air, in water, or by cooking directly from the frozen state. With fish and fish products packaged

in various ways, some defrost methods may be more applicable than others. Individually frozen fish or fish blocks can be thawed overnight at room temperature in still air. It has been recommended that the air temperature not exceed 18.3°C (65°F). It is also suggested that the defrost time not be too long, otherwise the product may dry out or be at a suitable temperature long enough to favor bacterial growth. Some protein damage also can occur during thawing if the product temperature remains in the critical zone for an excessive time. The frozen product is defrosted by conducting heat from the surface to the center, so product thickness will influence defrost time. A report from the Torrey Research Station indicated that a 10.2-cm (4-in.) thick cod block required about 20 hours to thaw in still air at 15.6°C (60°F). The defrost time can be shortened by thawing in moving air. It is recommended that the air be humidified to prevent surface dehydration, at a velocity of not less than 365.8 m/min (1200 ft/min), and the temperature should not exceed 21.1°C (70°F).

Thawing in water, because of its better heat transfer property, is faster than thawing in air. The water should not be too warm and should be kept moving. Whole fish or packaged fish may be satisfactorily thawed in water, but unpackaged fillets should never be defrosted in this manner because they become waterlogged and lose flavor through leaching.

Microwave heating is a rapid thaw method that employs very high-frequency microwaves at 2450 MHz to generate heat. This operation can be either batch or continuous. Microwave energy can be used to partially thaw a frozen mass of fish, shrimp, and so on, to permit separation of the individual units still in the frozen state. Tempering of fish blocks to be sawed into sticks or portions can also be achieved with microwave heating.

Double freezing describes a storage and processing operation in which the product is frozen, then thawed or partly thawed to facilitate processing, then refrozen. Seafood processors often store fish and shellfish in bulk as frozen raw material, then thaw it to create the final products, and then refreeze some of those products. An example is frozen, dressed halibut, which is sometimes partially thawed for steaking, then frozen for storage.

There is some quality loss during freezing, even with quick freezing. However, if the initial quality is very high (that is, if the first freezing is done with

very fresh fish), double freezing can still result in very good quality. Fish frozen at sea are suitable for processing methods in which a second freezing is necessary.

Studies on cod, flounder, and rockfish show that refreezing can result in a very good-quality product, especially if the first freezing is done before rigor mortis sets in (Peters et al., 1968; MacCallum et al., 1969; Tomlinson et al., 1969, 1973). Experimental work with pollock indicates that conditions for the first freezing and for thawing are more important than conditions for the second freezing to obtain a good-quality product (Choe et al., 1975).

In some processing operations, double freezing may be necessary. For example, fish may be frozen whole at sea, then defrosted at the processing plant for filleting, and the fillets then refrozen. It must be understood that freezing and frozen storage will cause some damage to the proteins. Upon thawing, some drip will be expressed. With repeated freezing and thawing, the textural damage will be cumulative. Although an acceptable product can still be attained after double freezing, the quality will be less than with a once-frozen product.

## Temperature indicators

In recent years, some regulatory authorities have considered legislation requiring mandatory open-date or pull-date labeling on frozen and perishable foods to provide quality assurance to the consumer. Opponents argue that the major function affecting quality of frozen food is temperature and not the time elapsed since freezing. If the frozen product were maintained at some known constant temperature from processing plant to consumer, then shelf life would be predictable, and open-date labeling would effectively provide quality assurance since time-temperature tolerances could be easily determined for any product. However, in commercial practice, once the frozen product leaves the processor's frozen warehouse, it is subjected to fluctuating temperatures during transport, unloading, and in the retail cabinet.

There are some warning devices that reflect the temperature experience of a frozen product. The defrost indicator is a simple device containing a eutectic salts mixture that melts at a given temperature and reacts with indicator paper to produce a color. By sealing one of these devices in each

master carton of frozen foods prior to shipping, the receiver can be assured that the product did not warm up in transit to some prescribed temperature for which the indicator was designed to be triggered. The time-temperature indicator provides more information in that it integrates the total time-temperature history the product has experienced and records it in a single reading. As an example of how these devices operate, one indicator contains sealed chemical salts, which are allowed to saturate a yellow paper strip at the time of use. A red color develops at one end of the strip, and during frozen storage, this color migrates to the other end at a rate that is dependent on the temperature. By observing the distance that the color has traveled at any given time, we can determine how much of the useful shelf life has expired and how much remains. These devices would more accurately provide quality assurance with frozen seafoods than would a pull date on the package.

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# 19

## Handling of Fresh Fish

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Thomas E. Rippen and Denise Skonberg

Fresh seafood's profit potential is substantial because of relatively large margins and increased consumer concern for the nutritional quality of meat. However, this potential can be realized only if consumers are confident about receiving consistently high-quality products. Fish lose quality more quickly and by different pathways than red meat and poultry; consequently, they must be handled with special care and with consideration for their unique properties.

Fish begin losing quality soon after they leave the water, so the most we can accomplish is to slow the rate of deterioration. This observation may seem obvious; however, its significance is easy to underestimate. For example, employees may be tempted to dress fish on unsanitary surfaces or to leave a few boxes of fish on the loading dock until after their lunch break. If the fish were prepared immediately, such practices would seldom result in a discernible loss of quality. Unfortunately, the damage shows up later by shortening the expected storage life of the product. It is not enough to buy or produce high-quality fresh fish. The product must also have a reserve of quality to carry it to the consumer's table. Nearly everything done or not done to fish will eventually impact consumer enjoyment. Commercial buyers and consumers are critical judges

who ultimately dictate a company's sales, profits, and growth potential.

### Review of fish spoilage

#### Bacteria

Bacteria are considered to be a primary cause of spoilage in fresh fish. They exist as a normal condition in the intestinal tract, slime, and gills of fish and contribute most of the sour and putrid odors characteristic of spoiled fish. Humans are able to detect very small quantities of certain obnoxious compounds and are less sensitive to others. Putrefactive bacteria produce amines, pungent acids, and other highly undesirable by-products while others, notably lactic bacteria, produce less obnoxious compounds. Conditions that favor the latter group will often extend shelf life by suppressing the growth of less desirable organisms.

Equipment used to hold and process fish is readily contaminated with the very bacteria most detrimental to shelf life. Temperature and its relationship to bacterial growth and shelf life is further detailed in Chapter 22.

## Scombroid poisoning as a special case

Scombrototoxin and the illness it causes is of special concern for handlers of susceptible fish species. The following discussion also serves to illustrate important preventive controls for the general problem of microbial growth and spoilage. However, for optimum shelf life, even higher standards of temperature control and hygiene are necessary than for prevention of this foodborne illness since spoilage bacteria grow more rapidly at lower temperatures than do those responsible for scombroid (histamine) poisoning.

Certain types of bacteria which are naturally present on fish, and are sometimes added through contact with contaminated surfaces, can produce histamine in some fish. The species most often implicated in scombroid poisoning are those containing appreciable quantities of free histidine, an amino acid that serves as an osmoregulator allowing fish to maintain water and solute balance in a marine environment.

Although the name scombroid poisoning implies an association only with tunas, bonitos and mackerels, other nonscombroid species are also commonly implicated. The species of fish most likely to cause scombroid poisoning are amberjack, jacks, shad, bluefish, mackerels, sardines, bonito, mahimahi, tunas, herring, marlin, and wahoo.

Biogenic amines, including histamine, can be formed in the fish anytime during harvest, preparation and storage if conditions allow. It appears likely that some of these compounds, in addition to histamine, serve as potentiators that heighten the pathogenic effects of scombroid poisoning.

Biogenic amines may begin to develop after the fish dies on a hook or in a net, and will increase if the fish are left in the water too long after death or if they are not adequately chilled after they are brought on board. Responsible bacteria, such as *Morganella morganii*, enzymatically convert histidine to histamine. Once formed, this enzyme can continue to rapidly produce histamine even when little or no additional bacterial growth occurs, for instance after frozen fish is thawed.

Histamine is permanent and is not removed or destroyed by further processing, such as trimming, washing, cooking, or freezing. Although high concentrations are usually associated with illness (more than 500 ppm histamine), the variable effect of potentiators, individual susceptibility, high varia-

tions in concentration from one fish to another and even within the same fish, requires a conservative approach to setting acceptable histamine tolerance levels and sampling plans. A guideline of 50 ppm maximum histamine content has been established for fish by the US Food and Drug Administration (FDA). Time/temperature controls are the only effective means of preventing this illness. Fortunately, extended exposures to abusive temperatures are usually responsible; these are conditions that are readily prevented.

## Developing a scombrototoxin (histamine) control plan

The following discussion addresses histamine control on fishing vessels but time/temperature controls are required for every step of the distribution channel, and should be incorporated into Hazard Analysis and Critical Control Point (HACCP) plans for high-risk species as appropriate. For commercial fishermen, a number of factors need to be considered when developing and implementing procedures to prevent scombrototoxin including:

- (1) how they will chill the fish they catch;
- (2) the equipment or supplies needed to properly handle and chill their catch;
- (3) the air and water temperatures encountered during the fishing trip;
- (4) the species, size, and amount of fish they expect to catch;
- (5) how they plan to monitor the catch to be certain that all fish are properly handled and chilled;
- (6) the records needed to document that the catch was properly chilled.

A complete scombrototoxin (histamine) prevention strategy will include all of these points. Decisions about chilling strategies and what equipment and supplies are needed should be part of the planning and preparation for each fishing trip. Fishermen may need to discuss plans for handling, cooling, and monitoring the catch with their packer or buyer to be sure that the chosen control strategy will meet both regulatory and company requirements. One strategy or procedure might work for all of the different types of fish they catch, or they may need

variations for specific species or sizes of fish or for different times of the year. For example, one control plan may be needed for the colder months of the year when water temperatures are low and another plan for warmer months. Control plans may also need to be tailored to the fishing methods used.

### Chilling fish properly to prevent histamine and to comply with US FDA guidelines

Fish can be chilled with ice, slurry ice (a mixture of seawater and ice), or mechanically refrigerated sea water (RSW). The rate at which the internal temperature of fish cools will depend on:

- (1) the amount of ice used, the temperature of the ice slurry or RSW;
- (2) the temperature of the fish when brought on board the vessel;
- (3) the size of the fish and/or the amount of fish added to the slurry or RSW;
- (4) whether or not the fish has been gutted;
- (5) the air temperature on the deck and in the storage hold.

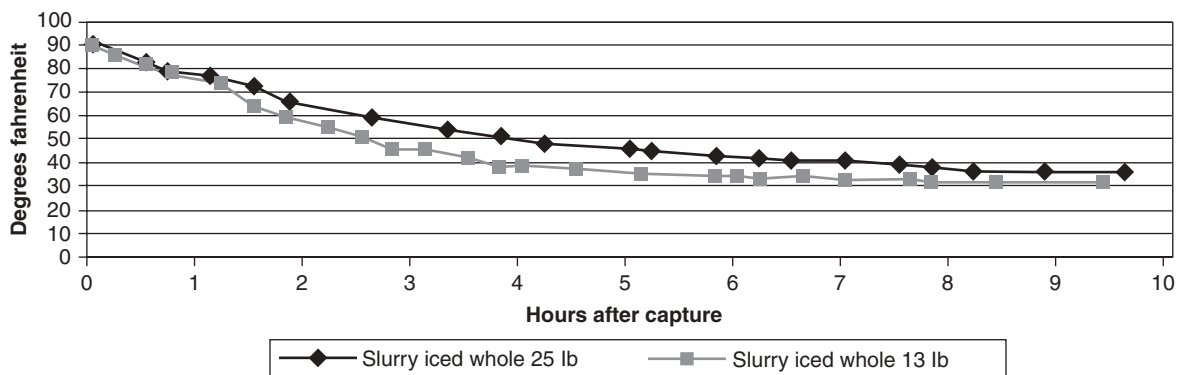
To achieve the most rapid cooling, as much surface area of each fish as possible should be in direct contact with the cooling medium (ice or seawater). Most of the heat will be removed from the fish during initial cooling phases. The ice will melt faster and the temperature of the slurry or RSW will increase faster during this initial chilling period. More ice or refrigeration is necessary to cool fish after they are landed than during storage.

Large fish will cool much more slowly than small fish. For large fish, more time is required to transfer the heat from inside the fish to the surface. For this reason, gutting large fish and then packing the gut cavity with ice, or immersing it in slush ice or RSW, will cool the fish faster. Temperature data collected by researchers at Oregon State University's Seafood Laboratory in Astoria show how cooling can be affected by the size of the fish, the type of cooling medium (ice or slurry ice), and whether the fish is whole or gutted before cooling (Figures 19.1 and 19.2).

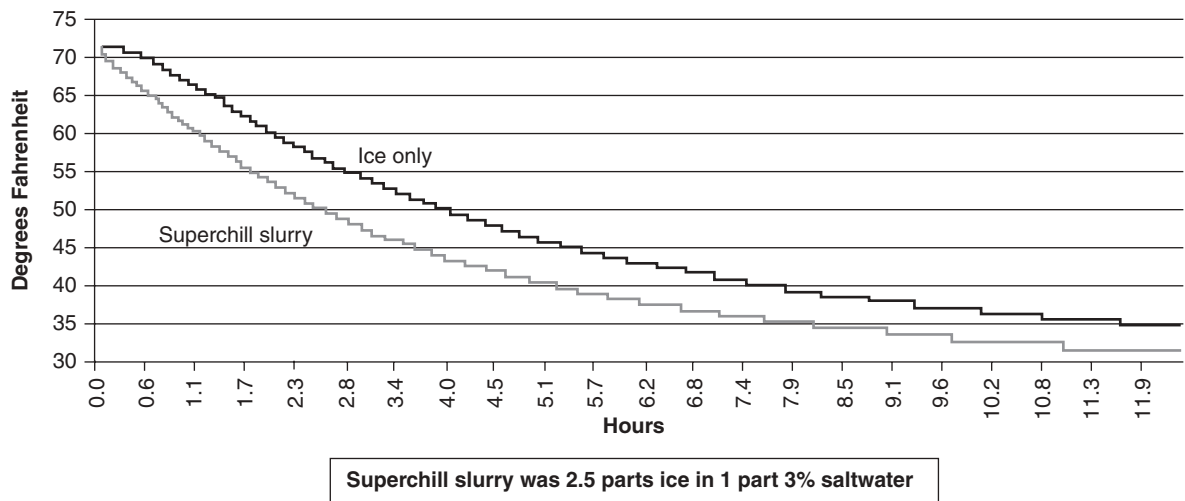
#### *Using ice to chill fish*

Flaked or crushed ice is preferred to larger pieces because it cools fish more rapidly. Ice particles should be as small as possible to ensure that the greatest surface area of each fish will be in direct contact with ice. Fish should be completely surrounded by flaked or crushed ice during cooling and storage. Large fish should be carefully gutted when possible, and the gut cavity packed with ice to speed cooling. Careless gutting may spread bacteria found in the entrails that cause histamine formation.

When using ice to cool histamine-producing fish, there are several critical conditions that are currently recommended by the USFDA. All fish, except tuna larger than 20 lb, should be packed in ice as soon as possible, never later than 12 hours after death, and then cooled quickly to 4.4°C (40°F) or less. For many fishing methods, time of death will coincide with when fish are landed on the vessel. The length of the tow or set may need to be considered for other fishing methods. When received



**Figure 19.1** Cooling curve for 25-lb and 13-lb whole albacore tuna.



**Figure 19.2** Cooling curve for 22-lb whole albacore tuna in ice and in superchill solution.

by the processor, the fish must be at 4.4°C (40°F) or less if delivered 24 hours after death (harvest), 10°C (50°F) or below if delivered between 12 and 24 hours after death (harvest), or there must be evidence that chilling began on board the vessel when necessary if delivered less than 12 hours after death (harvest). For tuna heavier than 20 lb, see the requirements described later in this chapter.

*Using slurry ice or refrigerated seawater.* Ice slurries or RSW can cool fish even faster than ice alone because each fish is completely surrounded by cold water, which maximizes heat removal rate. A general rule for rapid cooling of fish with slurry ice is to use 2 parts ice to 1 part seawater or brine. This is usually best accomplished by filling an appropriate insulated container to the desired level with ice and then adding the seawater or brine to form a dense slush.

The ice slurry mixture should be cooled to a temperature of 4.4°C (40°F), more ice added as the fish cools and the ice melts. The quality of ice needed to maintain this temperature will vary depending on the amount of fish added, their temperature, and the temperature of the dock or hold where the fish are cooled.

Refrigerated seawater should be at 4.4°C (40°F) or below before fish are added, and sufficient refrigeration capacity should be available to maintain the seawater below 4.4°C (40°F) during the cooling process and storage.

When using slurry ice or RSW to cool histamine-producing fish, several critical conditions must be

met to meet current FDA recommendations. All fish, except tuna larger than 20 lb, must be placed in an ice slurry or RSW at 4.4°C (40°F) or less within 12 hours after death (harvest). If the slurry or RSW is only at 10°C (50°F) or less, fish must be packed in a slurry or RSW within 9 hours after death (harvest). Cooling must continue until the fish reach 4.4°C (40°F) or less. The target internal fish temperatures at delivery are the same as for cooling with ice. Talk to your buyer or RSW specialist to determine if your system is adequate to meet these requirements.

*Chilling fish when water temperature is 28°C (83°F) or higher*

When the water temperature is above 28°C (83°F), the risk of histamine formation increases significantly, and cooling the catch to a safe temperature can take appreciably longer. Under these conditions, the same time and temperature limits described in the subsequent text for tuna larger than 20 lb must be met for all species that are prone to the development of scombrototoxin.

*Chilling tuna larger than 20 lb*

Tuna larger than 20 lb must be iced or put into slurry ice or RSW sooner after they die than smaller fish to ensure that the entire fish cools rapidly. According to current FDA guidelines, if the fish are gutted, they need to be iced (including the gut cavity) or put into slurry ice or RSW at 4.4°C (40°F) or less within 6 hours of death (harvest). If large tuna are not



gutted, they must be chilled to an internal temperature of 10°C (50°F) or less within 6 hours of death (harvest). Getting the temperature of large fish below 10°C (50°F) in 6 hours can be a significant challenge using ice alone. More rapid cooling can be accomplished using ice slurries or refrigerated seawater. Care should also be taken when gutting these fish. The bacteria that produce histamine can be found in high numbers in the fish's digestive tract. The digestive tract should not be cut or spilled into the gut cavity or other parts of the fish, and care should be taken to avoid cutting or puncturing the edible portions of the fish.

### **Type, size and amount of fish**

Before leaving the dock, fishermen need to consider the type and size of fish that they expect to catch, how much fish will be landed per tow or set, and how long the fishing trip will last. These factors determine what supplies (e.g., amount of ice and refrigeration capacity) and crew are needed to handle, sort, chill, and store the fish properly to prevent histamine formation. For example, longline fishermen targeting large tuna need to be prepared to kill and dress individual fish as they come on board. Getting these large fish chilled quickly and keeping them cold throughout the fishing trip is often a significant challenge.

Other fisheries such as a trawler targeting bluefish or mackerel might expect to land a large number of fish at one time. In this situation, the major challenge may be to ensure that all of the fish get sorted and packed in ice quickly enough to prevent temperature abuse on the deck or in the hold of the vessel.

### **Monitoring the catch**

Fishermen need to monitor the critical cooling and holding conditions described earlier to show that the fish were landed, handled, and chilled properly for each fishing trip. Monitoring may require making several observations that could include: water temperature, the temperature of the ice slurry or RSW, and the temperature of a representative sample of the fish as they are cooled. Fishermen may also need to estimate when the fish died to decide how much time is available before the catch must be under temperature control. For many fishing methods, time of death will coincide with when fish are

landed on the vessel. The length of the tow or set may need to be considered for other fishing methods.

The tools needed to do this monitoring are a clock and a thermometer. There are many types of thermometers or temperature monitoring devices available. Common dial type thermometers are the least expensive, but are also the least reliable. They frequently need to be recalibrated, take longer to provide a stable temperature reading, and must be inserted a considerable distance into the fish or water to work properly. Digital thermometers (thermocouple or resistor type) can cost from \$20 to \$200, but are much more durable and reliable and can provide rapid temperature readings. Other products such as temperature loggers or maximum temperature sensors are also available that automatically record temperatures over time.

It is important to check that the catch is cooled properly. This may involve manually checking variables such as whether the temperature of the ice slurry or RSW is below 4.4°C (40°F) or 10°C (50°F) for cooling, and that the fish reach an internal temperature below 4.4°C (40°F) within the required amount of time. It may also be necessary to check the ocean water temperature if it is likely to be 26.6°C (80°F) or above.

When checking the internal temperature of fish, it may only be necessary to take the temperature of one or two fish at the top of the iced container or one or two fish in a container of slurry ice or RSW to show that they have cooled to the proper temperature. This procedure may need to be repeated for the catch from each tow or set during the fishing trip. Other predetermined measurements may be monitored if a system has been validated and scientifically shown to meet the required time and temperature targets. For example, the time of landing and the time that fish are placed in a standardized slush ice mixture may be sufficient without routinely recording fish temperatures. Monitoring the catch will not only ensure safety but will also help to ensure that quality and high market value is maintained.

### **Keeping records**

Fishermen should keep records of how the fish are chilled and stored on the vessel. Receivers of histamine producing fish species are required by FDA HACCP regulations to obtain records that prove the

fish were chilled and stored properly onboard the fishing vessel. These records should show that the fish were iced or put into slurry ice or RSW in time to prevent histamine formation, and that they were chilled to the proper internal temperature. A simple logbook or form is one method to record the time and temperature observations needed to assess the relative risk of scombrototoxin formation. Electronic time/temperature records may provide a second option. Monitoring Plan Examples are provided by US Sea Grant and other organizations which include histamine control strategies and record forms for various fisheries and harvest methods.

### *Enzymes*

Fish are poikilothermic animals, their body temperature fluctuating with the surrounding water. Many species must tolerate a wide seasonal temperature range. In fish, chemically active proteins known as enzymes function even at low temperatures. These enzymes are essential to life, as they are responsible for digestion and assimilation of food, synthesis of tissues, and regulation of metabolic processes. After death, the enzymes important for body building reactions may reverse and begin to break down muscle while other enzymes "eat" through the digestive tract into surrounding tissues.

Similar processes lead to the desirable ripening (tenderizing) of chilled beef, but the cold tolerant enzymes in fish result in excessive softening of naturally tender flesh. Some native enzymes degrade fish oils while still others are responsible for degradation of nucleotides, compounds which include adenosine triphosphate (ATP). Some of the resulting breakdown products (small compounds) are responsible for off-flavors. Bitter flavor is often associated with crabmeat processed from improperly handled dead crabs and with certain species of fish if time/temperature abused.

It is interesting to note that not all compounds released through enzymatic action are detrimental to odor and flavor. The compound inosine monophosphate (IMP) results from enzymatic degradation of adenosine monophosphate (from ATP) and contributes a pleasant savory flavor to many fish as a natural flavor enhancer. The amino acid glycine adds to the sweetness of fresh fish. A class of enzymes (lipoxigenases) which attack the highly unsaturated omega-3 fatty acids of fish

produce volatile carbonyl compounds (aldehydes and ketones) and alcohols responsible for appealing fresh fruity and vegetable like or grassy odors. These enzymes and the odors and flavors they produce are often highly specific and characteristic of certain species of fish. Marine and freshwater species differ in levels and types of these enzymes and substrates, which contributes to some, but not all, of the differences observed in the two groups.

This means that fish may require a few hours to a day in ice to reach peak eating quality. This may seem contradictory to the mantra that fresher is better, but from a practical perspective, these changes occur quickly and are often fleeting. Commercial practices dictate careful time/temperature control and rapid distribution for the consumer to have any opportunity to enjoy truly fresh fish.

In most cases, fish lose quality very quickly after death. For example, the compound IMP, mentioned previously, is further converted by native or bacterial enzymes to hypoxanthine associated with off-flavor. Perhaps even more significantly, proteolytic enzymes release simple protein building blocks (amino acids and peptide chains) that are readily used as food by bacteria, so enzymatic activity often precedes and exacerbates microbial spoilage.

### *Chemical changes*

Seafoods have a large proportion of soft, polyunsaturated fats and oils that are highly vulnerable to attack from oxygen (oxidation). The condition leads to rancidity. Although more commonly associated with frozen fish than fresh, some fatty fish may develop pronounced fishy flavors due to oxidation even when held fresh. Fish possessing significant quantities of red muscle are especially vulnerable.

### *Other factors*

Like other meat animals, fish enter rigor mortis (stiffening due to muscular contraction) after death with a concomitant drop in pH. Fish have natural defenses against bacteria, which continue to function at a reduced level until after they come out of rigor mortis. Consequently, fish that enter rigor late and stay rigid 2 or 3 days tend to retain quality longer than those that stiffen quickly and remain in rigor for 2 or 3 hours. Fish species, condition, and temperature are all factors that control the time required for rigor mortis to set in and its duration.

Rapid cooling to 0°C (32°F) can greatly retard rigor mortis.

Un-iced fish may suffer severe contractions that tear the flesh and produce an unsightly product. A similar effect occurs when fish are forced into a new position while in rigor. Even when properly iced, fish filleted prior to the onset of rigor mortis may develop an undesirable rough appearance, a condition readily avoided under proper commercial conditions.

Gain or loss of moisture occasionally affects the appearance and flavor of fresh fish. When fish are inadequately iced, dehydration can occur quickly, resulting in discoloration, weight loss, and, in severe cases, a tough, dry texture. When allowed to rest directly in freshwater, fish fillets and shellfish absorb moisture which tends to shorten storage life and to dilute flavoring compounds and pigments.

Fish destined for certain markets, especially sashimi (raw fish), often require additional handling steps on fishing vessels to maintain freshest color, flavor, and texture. Live fish should be landed quickly and stunned immediately to prevent bruising. Spiking is sometimes performed after stunning. The brain is destroyed by pushing a spiking tool into the brain. Various bleeding techniques are used depending on species and the preference of the sashimi buyer. These include the gill cut, throat cut, and pectoral cut (for tunas). Gutting is then carefully performed to remove bacteria and enzymatically active viscera, and to facilitate cooling.

## Temperature effect

The importance of keeping seafood at low temperatures cannot be overstated. The growth of bacteria and the rates of enzymatic and chemical activity are directly related to temperature. Research shows that refrigerated fish must be maintained near 0°C (32°F) for maximum quality retention. Storage life can be extended several days when temperature is decreased just a few degrees, from 1.7°C to 0°C (35°F to 32°F).

Tray-packed fishery products, shucked shellfish meats, and fillets are sometimes held without ice. In this situation, refrigeration units should be adjusted to -2.2°C to 0°C (28–32°F). Commonly, un-iced retail cases are inadequately maintained at 3.3–7.2°C (38–45°F). This problem and others are alleviated when products are kept in contact with

ice. Temperatures should be checked frequently with a reliable thermometer.

## Ice advantages and uses

Ice is an ideal cooling medium for fresh fish. When used liberally, it has several advantages over standard refrigeration methods. It rapidly removes heat from fish; holds fish at or near 0°C (32°F) throughout distribution; continuously flushes away bacteria, blood, and slime, as it melts; and prevents dehydration.

A property of ice that makes it extremely valuable is its high latent heat of fusion. That is, water requires a large amount of energy (as heat drawn from its surroundings) to change from a solid to a liquid at 0°C (32°F). Because melting ice remains constant at near 0°C (32°F), warm fish in contact with it continue to cool until they also reach 0°C (32°F).

Although simplistic, the temperature decrease attainable for a given quantity of fish and ice can be calculated from the formula:

$$\begin{aligned} &\text{Temperature change (°F)} \\ &= \frac{(144 \text{ Btu})(1 \text{ lb ice})}{(1 \text{ lb of fish})(0.80^\circ\text{F})} \end{aligned} \quad (19.1)$$

International equivalent:

$$\begin{aligned} &\text{Temperature change (°C)} \\ &= \frac{(335 \text{ kJ/kg})(\text{kg ice})}{(\text{kg of fish})(3.37 \text{ kJ/kg}^\circ\text{C})} \end{aligned}$$

where 144 Btu is the amount of heat (in British thermal units) absorbed by 1 lb of ice during the transition from ice to water and 0.80°F is the specific heat of a typical fish.

For example, if we mix 10 lb of ice with 100 lb of fish we can theoretically lower the temperature of the fish by -7.8°C (18°F), from 10°C to 0°C (50°F to 32°F). The calculation required is:

$$\frac{(144 \text{ Btu})(10 \text{ lb ice})}{(100 \text{ lb fish})(0.80^\circ\text{F})} = 18^\circ\text{F} \quad (19.2)$$

International equivalent:

$$\frac{(335 \text{ kJ.kg})(4.54 \text{ kg ice})}{(45.4 \text{ kg fish})(3.37 \text{ kJ/kg}^\circ\text{C})} = 9.9^\circ\text{C}$$

Perhaps, more frequently, fish handlers need to estimate the amount of ice required to cool a known

quantity of fish at some initial temperature. By rewriting the first equation we get

$$\text{lb ice required} = \frac{(\text{fish temp} - 32^{\circ}\text{F}) (\text{lb fish}) (0.80)}{144 \text{ Btu}} \quad (19.3)$$

International equivalent:

$$\text{lb ice required} = \frac{(\text{fish temp} - 0^{\circ}\text{C}) (\text{kg fish}) (3.37)}{335 \text{ kJ}}$$

Example situation: Assume a dockside buyer for a seafood-processing firm inserts a thermometer into the mouths of several fish selected from a small boatload and finds an average temperature of  $16.7^{\circ}\text{C}$  ( $62^{\circ}\text{F}$ ). He knows that the catch was just harvested by live entrapment gear and is still in excellent condition. He decides to buy 771 kg (1700 lb) of the fish recognizing from experience that immediate icing is imperative. He determines that 128 kg (283 lb) of ice is the theoretical minimum necessary to do the job. This determination was calculated from  $16.7^{\circ}\text{C}$  ( $62^{\circ}\text{F}$ ) initial  $-0^{\circ}\text{C}$  ( $32^{\circ}\text{F}$ ) desired  $= 16.7^{\circ}\text{C}$  ( $30^{\circ}\text{F}$ ) reduction needed and,

$$\frac{(30^{\circ}\text{F}) (1700 \text{ lb}) (0.80)}{144 \text{ Btu}} = 283 \text{ lb ice} \quad (19.4)$$

International equivalent:

$$\frac{(16.7^{\circ}\text{C}) (771 \text{ kg fish}) (3.37)}{335 \text{ kJ}} = 129 \text{ kg ice}$$

(includes rounding error in conversion)

These calculations are simplistic in real world conditions. The buyer would be wise to more than double the calculated weight of ice to approximately 274 kg (600 lb), even assuming the fish are transferred to a cooler. This is because ice draws heat not only from the fish but also from the surrounding air and container walls. Also, the aforementioned formulas used to calculate heat transfer do not consider the surplus ice required to maintain  $0^{\circ}\text{C}$  ( $32^{\circ}\text{F}$ ) once the fish are cooled. Obviously, after ice melts, the heat of fusion is absorbed and the fish will again warm up to ambient temperature. The amount of ice needed to keep fish at  $0^{\circ}\text{C}$  ( $32^{\circ}\text{F}$ ) will depend on several factors, including length of time they are held, type of container used, air temperature, and air flow.

Extension specialists at Oregon State University and University of California, Davis developed detailed spreadsheets for estimating wet ice and slush ice (chilled seawater) requirements on fishing

vessels given factors such as fish weight, hold measurements, thickness of insulation, surface water temperature, fish temperature when landed, and trip length. From their calculations, a wet ice to fish ratio of roughly 1:2.5 is typical for an average vessel with an insulated hold on a 3-day trip and stowing fish at an initial  $18.3^{\circ}\text{C}$  ( $65^{\circ}\text{F}$ ).

The important point is that sufficient quantities of ice be used to completely encompass the fish at all times. To take full advantage of the cooling and flushing functions of ice, it must make direct contact with fish and it must melt. The process is facilitated by gutting fish when possible, especially large fish, and packing the body cavity with ice. Simply topping a pile of fish with ice is not sufficient. Place a 5 cm (2 in.) bed of ice in fish shipping boxes, intersperse some with the fish, and top with 5–8 cm (2–3 in.) of additional ice. Modern sealed fiberboard shipping boxes are sometimes constructed to allow for adding ice from the bottom as well as the top to replace melt losses. Bins and large containers of fresh fish will require proportionately more ice.

Meltwater must be allowed to drain away from fish because it harbors cold tolerant bacteria and provides nutrients for their growth. Retail shops with persistent odor problems are frequently a testimonial to this fact. Drip from fish collects in lower layers of ice and produces spoiled fish odors. It also provides a major source of bacterial contamination for products that subsequently come in contact with the ice.

For reasons of health, product quality, and legal compliance, ice must be made of drinkable water. A variety of shapes are available including cubes, cylinders, chunks, crushed, and flaked ice. Maximum cooling is achieved with small ice particles that make intimate contact with the fish. For this reason, some seafood handlers prefer flaked ice; however, because of its low density it tends to melt more rapidly than other forms and may be lost in handling channels. Large and irregular pieces may dent or puncture fish and are not recommended. For storage and distribution purposes, crushed ice is a reasonable compromise and performs well. Occasionally fancy ices, such as hourglass shapes, find utility in retail displays because they are attractive and appear to sparkle under display lights more than crushed ice.

Adding combl to ice that kill bacteria or retard their growth has been investigated for many years. Sorbate, citrate, ascorbate, phosphate, and ozone

treated ice may extend storage life by hours or more than 2 days for some species when well handled. Some proprietary commercial blends are available that purport to significantly extend shelf life. Perhaps the most useful additive to consider is approximately 1.5% added salt (sodium chloride). Stated benefits include reduced water gain and associated dilution effects, improved appearance (color retention) and slightly reduced temperatures. A disadvantage is the tendency of salty ice to clump in storage. Saltwater ice produced at sea is another option. Excessive salt concentrations should be avoided to prevent freezing.

Marginal benefits have also been demonstrated with antibiotic ice, especially tetracyclines. However, antibiotics are not permitted for this use in many countries and should not be used. Most additives require product labeling and other legal considerations. Even when the end of storage life is delayed with treated ice, loss of freshness during the first 5–10 days may be just as rapid as with untreated ice.

### Ice in retail display cases

Ice used in retail cases should be removed frequently: twice weekly for refrigerated units, daily for open counters. The cases should be cleaned and sanitized, then refilled. If ice is used liberally, little or no additional refrigeration is required in air conditioned retail shops. The benefits of melting ice are maximized including a continuous rinsing of the cases. The cases must drain completely and provide discreet disposal of drip so that stagnant pools and odor causing floor drains are avoided.

Whole or dressed fish should be nestled in ice with some ice on top. Although this arrangement partially obscures fish from view, it connotes quality to most customers. Orient dressed fish so that the belly cavity faces down to avoid collecting water from melted ice. Recess containers of shellfish in a bed of ice so that only the top of the containers protrude. Fish fillets may become soft if buried directly in ice but are effectively displayed in a single layer on trays or plastic film that possesses drainage holes. Fillets may overlap, but never pile them in multiple layers above the ice because there may be as much as 16.7°C (30°F) difference between the bottom and top fillets in such a stack. To prevent dehydration and discoloration, occasionally mist with water from a chilled spray bottle, sprinkle a

small quantity of additional ice on top, or overlay with plastic wrap. Some display units humidify the air.

### Other cooling systems

As previously discussed, conventional forced air refrigeration systems are generally less desirable than ice for cooling fresh fish. However, they can be used successfully in conjunction with ice when coolers and display cases are maintained at 1.7°C–4.4°C (35°F–40°F). This method is especially important during summer months and when handling boxed fish, which are time consuming to re-ice.

A special use for low temperature cooling systems exists for some overwrapped tray packaged products. In this instance, ice does not contact the fish. Either before or after packaging they are cooled rapidly by exposure to subfreezing temperatures, usually by a blast freezer or by short term contact with CO<sub>2</sub> snow or other cryogenic media. The superchilled exterior of these products then equilibrates with the interior at an ambient –2.2–0°C (28–32°F). Such “chill pack” items offer convenience, economic advantages, minimal contamination, and avoidance of excess fillet leaching.

Weak brine (approximately 4% salt) may be chilled with ice or refrigeration coils to cool and hold fish. This method is usually employed on off-shore fishing vessels but may prove valuable for bulk storage prior to processing or boxing. Fish are immersed directly in the cooling media, so they are cooled very rapidly and are protected from physical damage. Salt added at proper usage levels keeps the temperature of a well iced solution at or below 0°C (32°F) without freezing and reduces water absorption by the fish. However, changes in fish appearance, bacterial growth, and salt uptake by the flesh will occur with time. Consequently, the technique is probably best reserved for short-term holding of whole fish, for example, in concert with fish washing equipment.

### Bruises and cuts

Fish are very delicate and easily damaged. Bruises caused by careless handling produce a nutritious environment for bacteria and frequently form soft, discolored areas. Cuts similarly promote spoilage by introducing bacteria into otherwise sterile



tissue. Bruises may not be visible in fish muscle until several days after the damage is inflicted. The problem is not limited to handling on fishing vessels but can affect quality when it occurs during any step in the marketing system.

The following list may prove helpful for reducing physical damage:

- (1) Avoid overfilling fish boxes because crushing can result if they are stacked. Similarly, never stack fish boxes so that upper boxes or other objects rest directly on the contents of lower boxes.
- (2) Hold iced fish in shallow containers. Small, tender fish are especially vulnerable to crushing if piled more than 46 cm (1.5 ft) deep.
- (3) All surfaces that contact fish should be free of sharp edges, including off-loading equipment, fish washers, conveyor systems, filleting tables, and so on.
- (4) Use crushed or flaked ice and keep ice storage bins cold (41–50°C/5–10°F) to reduce clumping. Large ice chunks promote crushing.
- (5) Never use hooks (picks) or pitchforks to handle fish.
- (6) Use shovels only with extreme care. File the leading edge blunt and smooth.
- (7) Keep knives sharp. Dull blades result in ragged, irregular cuts that promote degradation and damage appearance.
- (8) Avoid dropping fish onto hard surfaces. Design product flow patterns so that fish are handled as little as possible and with a minimum of bumps.
- (9) Do not lift fish by their tails, especially salmon.

## Bacterial contamination

Low initial numbers of bacteria on fish extend storage life compared to high bacteria counts. Fish handlers risk heavy contamination and a corresponding loss of quality each time seafood touches an unsanitary surface. These surfaces need not appear dirty to harbor large numbers of bacteria. Some research suggests that wood may not serve as a major reservoir for bacteria as once thought; however, its porous nature makes it virtually impossible to adequately clean or sanitize, and its use is discouraged by most regulatory agencies. Wood also holds moisture which is essential for survival of microbes. Therefore, objects that routinely con-

tact fish should be made of appropriate food-grade plastic or corrosion-resistant metal. These include fish storage bins, reusable shipping boxes, cutting boards, and knife handles. The problem is less critical for single use applications of wood and paper products. Modern plastics are economical, durable, and easily cleaned, and make a sensible alternative to wood and corrodible metals.

A partial list of other contamination sources follows:

- (1) *Fish washing equipment*: Wash water should be changed frequently. In large tanks, use a water intake and overflow system that exchanges the water several times per hour. Stagnant wash water may seed fish with more bacteria than they carry into the washer. Washing works best when fish are agitated with fast-flowing water or, better still, a pressure spray of chlorinated water. Even without chlorine, a high-pressure spray may reduce surface bacteria populations by 90–99%. Use cold water and transfer fish to ice rapidly to prevent warming. Dipping or spraying fish in solutions of acidified sodium chlorite or chlorine dioxide have been demonstrated to lower initial bacterial counts and extend shelf life when fish are properly handled. Be sure to follow regulatory guidelines when using any additive or processing aid.
- (2) *Ice*: Used ice should be discarded and replaced with clean ice for subsequent batches of fish. Buildup of blood, slime, and feces in ice will significantly contaminate fish with spoilage microorganisms. For similar reasons, ice bins should be constructed with an elevated floor and should be cleaned well at least twice per year.
- (3) *Fish cutting operations*: Most fish maintain quality longer when promptly eviscerated, especially if they were actively feeding prior to capture. However, improperly gutted fish may actually spoil faster than whole fish because digestive enzymes and bacteria are exposed to the flesh as internal organs are cut. Remove viscera intact when possible and thoroughly wash the body cavity. Kidney material next to the backbone is enzymatically active and contributes to off-flavors if not removed.
- (4) *Personal hygiene*: Controlling the spread of disease begins with a clean food supply. People are major carriers of disease microorganisms. Also, handling fish with dirty hands or gloves can greatly shorten shelf life. All individuals

should wash their hands before handling a seafood product and observe sensible hygienic and health practices. This is a simple, inexpensive solution to a common shelf life problem. Sanitation dictates the use of clean high-quality clothing such as rubber aprons and boots. Rubber or vinyl gloves in good condition are much easier to keep clean and sanitized than cloth gloves. Large numbers of bacteria survive in cloth gloves, even when soaked in chlorine sanitizer.

- (5) *Equipment design*: Crevices, pockets, and overlapping joints tend to trap food particles, which permit growth of bacteria. When buying or fabricating processing equipment, carefully consider ease of access for cleaning, construction methods that simplify cleaning and seal out water and soils, and elimination of recesses that might hinder drainage and overnight drying. Handling systems and display cases should ensure segregation of fresh products from cooked or other ready-to-eat items. Drip from raw fish can contaminate ready-to-eat products with disease causing bacteria.
- (6) *Construction of seafood handling areas*: Walls, floors, and ceilings should be of hard materials that are impervious and readily cleaned. Slope floors toward drains equipped with traps. Keep window screens, doors, and building foundations in good repair as part of a thorough pest control program. Consult state and local regulatory agencies regarding specific requirements.
- (7) *Chemical contamination*: Avoid placing fish where lubricants, fuels, paints, or other chemicals are found. This is nearly universally required by regulatory agencies under good manufacturing practices. However, not only is safety potentially compromised but unpleasant odors or stains on products or packaging can seriously damage a company's reputation.
- (8) *Cleaning practices*: A daily schedule of washing and sanitizing is extremely important to the distribution and sale of high-quality seafoods.

## Washing and sanitizing

Cleaning jobs are generally scheduled after processing runs or after busy business periods during the day and before breaks and lunch. As a result, employees are seldom motivated to conduct vigor-

ous washing campaigns. They should understand that thoughtful sanitation can greatly extend the storage life of fish. Modern detergents and cleaning equipment facilitate cleaning of processing plants and retail outlets. However, no system can totally substitute for brooms, brushes, and a little muscle.

Remember, once quality is lost, it cannot be regained. All surfaces that come in contact with fish should be thoroughly washed with detergent and then sanitized. Proper cleaning involves separate applications of detergent, and then sanitizer, since combining the two will largely neutralize the sanitizer's bactericidal effect. Detergent alone does little to kill bacteria but is needed to reduce gross contamination and expose bacteria to the sanitizer. In fact, between the two, the proper selection and use of detergents is more likely to improve the microbiological quality of equipment surfaces and fish than does the application of sanitizers. A presoak with an alkaline detergent in a tank or as a foam may significantly reduce the amount of scrubbing required.

Follow these steps:

- (1) Clear and rinse surfaces to remove the majority of blood, scales, and other matter, and prepare surfaces for detergent.
- (2) Apply a warm detergent solution and gently scrub with brushes or pads intended for the task.
- (3) Rinse.
- (4) Apply an appropriate sanitizer.
- (5) Rinse off corrosive sanitizers when used on corrodible metals.

See Chapter 22 for a detailed discussion of detergents and sanitizers.

Cleaning and sanitizing is not difficult once a routine is established. Benefits realized from consistently high-quality products and satisfied customers make the time taken for these activities a very small sacrifice. Thoughtful and careful sanitation is the responsibility of every seafood business from the largest processor to the smallest retailer or restaurant kitchen.

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# 20 Shellfish—Biological Safety

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Fresh and processed shellfish present potential food-borne illnesses to both healthy and immunocompromised individuals from bacteria, viruses, and parasites. The contamination of the shellfish is due to naturally occurring organisms or those introduced into the environment through animal and human pollution, agricultural runoff, and other chemical components. The threat of illness from handling and consumption of shellfish can be increased through environmental conditions in the growing waters, harvesting methods, processing operations, and marketing. Some shellfish present a much greater risk than others. Since most shrimp are consumed fully cooked, most bacteria, viruses, and parasites are either destroyed or reduced to a level where infection may not occur. For many individuals, the greatest risk from shrimp consumption is an allergenic reaction. However, many molluscan shellfish are consumed raw or with minimal heating. The consumption of raw molluscan shellfish (primarily oysters and mussels) has been a major concern of national and international health agencies since naturally occurring bacteria have caused food-borne outbreaks and mortality. Some post-processing operations have been effective in either

eliminating or reducing the health hazard to an acceptable level.

## Shrimp

Shrimp are the most important exportable aquatic product in the global fishery commerce. About 75% of the shrimp production worldwide, whether from culture or capture, originate from developing countries and 70–75% of the global shrimp consumption occurs in developed countries (Bhaskar et al., 1998). Shrimp is a product that is marketed cooked or raw, peeled or unpeeled, and with or without breading or another coating (Silverman et al., 1961). Examination of fresh and frozen shrimp revealed that spoilage of this product is largely due to biochemical changes induced by microbial populations and to a lesser degree by endogenous enzymes and chemical compounds in the shrimp (Fieger, 1950). In an effort to control the quality and safety of foods, the National Advisory Committee on Microbiological Criteria for Foods (NACMCF, 1990) and the International Commission on Microbiological Specification for Foods (ICMSF, 1988) have

recommended a microbiological criteria as a means of assessing the effectiveness of Quality Assurance and Hazard Analysis Critical Control Point (HACCP) programs.

## Shrimp production

Studies have shown that shrimp analyzed at harvest possess a higher total coliform count (TCC) than the sediment (Putro et al., 1990; Bhaskar et al., 1995). However, Bhaskar et al. (1998) reported that cultured shrimp contained a higher TCC than that of the surroundings but less than that of the sediment. The low level of coliforms encountered in the water samples at times may be attributed, in part, to the fact that sampling coincided with the water exchange in the farm, that sampling occurred in cold weather, or the density of stocking. It is presumed that the feed and manure are major sources of *Escherichia coli* in a pond.

*Salmonella* were found to be associated with pond water, sediment, and shrimp throughout the culture cycle, including the prestocking period, farming phase, and at harvest (Bhaskar et al., 1998). This study supports prior research that showed that *Salmonella* is inherently present in shrimp pond sediment (Lyer and Varma, 1990; Bhaskar et al., 1995) and brackish water ponds (Reilly and Twiddy, 1992; Bhaskar et al., 1995). The survival rate of *Salmonella* is enhanced by the nutrients, manure, and feed present in the pond system (Venkateshwaran et al., 1985) and the favorable interaction of various biological and physical factors (Rhodes and Kator, 1988). Numerous studies conducted in Thailand, India, and the Philippines have shown that *Salmonella* was isolated from shrimp throughout the production cycle and at harvest.

Bacteria of the genus *Vibrio* are ubiquitous in marine and estuarine aquatic ecosystems in which shrimp are farmed. *Vibrio* species form part of the natural biota of fish and shellfish (Vanderzant et al., 1971; Colwell, 1984; Otta et al., 1999). *Vibrio harveyi* and *Vibrio parahaemolyticus* are associated with bacterial infections in shrimp and are generally considered to be opportunistic pathogens causing disease when shrimp are stressed (Lightner, 1993; Lavilla-Pitogo, 1995). Among more than 20 *Vibrio* species known to be associated with human disease, *Vibrio cholerae*, *V. parahaemolyticus*, and *Vibrio vulnificus* are most important. Depending on

the species involved, the clinical manifestations are different, ranging from gastroenteritis to septicemia and wound infection (Oliver and Kaper, 1997; Ulusarac and Carter, 2004).

A variety of *Vibrio* spp. were reported to be present in cultured shrimp and in the growing water by Bhaskar et al. (1998) and Singleton et al. (1982), with *Vibrio alginolyticus* being the most prevalent in the shrimp and sediment. *V. cholerae* was detected in all the samples but at relatively low levels compared to other species, except in formulated feed. *V. cholerae* has been isolated from pond mud, water, and shrimp samples in Thailand (Leangphibul et al., 1986) and in India (Bhaskar and Setty, 1994). The major sources of this *Vibrio* species in shrimp samples may be sediment, water, and feed. However, the possibility of natural food items such as algae, plankton, invertebrate animals such as copepods, and zooplankton could also be contributors (Kaneko and Colwell, 1978; Tison et al., 1986; Rodrick, 1991). Dalsgaard et al. (1995) studied the presence of *V. cholerae* in a total of 107 samples that included water, sediment, shrimp, feed, shrimp gut, and chicken manure. The results indicate that *V. cholerae* non-01 is ubiquitous in aquatic environments where shrimp culture is practiced under a variety of conditions.

*V. parahaemolyticus* occurred in all samples during farming with the exception of the Kanagawa-positive strain in the formulated feed. The microorganism has been found to occur more commonly in shrimp and other crustaceans rather than in fish (Pradeep and Lakshmanperumalswamy, 1984) because it has chitinoclastic activity (Sugita et al., 1987). The microorganism, *V. parahaemolyticus*, has been found in shrimp in the Philippines (Cruz et al., 1990) and in shrimp-pond sediment and water in Thailand (Leangphibul et al., 1986). A study by Bhaskar et al. (1998) clearly implicated the role of sediment, water, and feed used as sources of the bacterium. However, the natural association of the pathogen with shrimp and its natural food items for which *V. parahaemolyticus* is an indigenous pathogen cannot be minimized (Hobbs, 1987; Puente et al., 1992). *V. vulnificus* and *Vibrio mimicus* were two other pathogens reported in shrimp by Bhaskar et al. (1998). All *Vibrio* species have been found to be indigenous to tropical aquaculture systems.

Bhaskar et al. (1998) reported that *Listeria monocytogenes* was absent from both shrimp and sediment



**Table 20.1** Prevalence of various *Listeria* species in different samples during the study of cultured shrimps.

Species of <i>Listeria</i>	At harvest <sup>a</sup>	
	Sediment	Shrimp
<i>L. monocytogenes</i>	ND <sup>b</sup>	ND
<i>L. innocua</i>	01 (33.3)	ND
<i>L. grayi</i>	ND	ND
<i>L. seeligeri</i>	01 (33.3)	02 (100)
<i>L. welshimeri</i>	01 (33.3)	ND
<i>L. murrayi</i>	ND	ND
Total no of <i>Listeria</i> spp.	03	02

Values in parentheses indicate percentage prevalence of that species in that sample.

<sup>a</sup>All samples of sediment, water, shrimp during farming and water samples at harvest were negative for *Listeria* spp.

<sup>b</sup>Not detected.

(Table 20.1). However, at harvest, *Listeria seeligeri* was isolated from shrimp and sediment and *Listeria innocua* and *Listeria welshimeri* was isolated from sediment samples. The presence of *L. innocua* could indicate that *L. monocytogenes* also occurred in the system. The incidence of *L. seeligeri* is highly significant because like *L. monocytogenes*, it is pathogenic (Huss, 1994).

## Raw and processed shrimp

A total of 1264 samples of individually quick-frozen, peeled, and deveined raw shrimp (pond-raised *Penaeus monodon*) and 914 samples of cooked ready-to-eat shrimp were analyzed for their microbiological content (Mohamed Hatha et al., 1998). A

summary of the bacteriological results of the samples is presented in Table 20.2. For the raw shrimp samples, 96% showed an aerobic plate count (APC) less than  $10^5$  cfu/g, out of which 74% were less than  $10^4$  cfu/g. APC values of cooked ready-to-eat shrimp were less than  $10^4$  cfu/g in 99% of the samples. The total APCs were much lower than those reported by Varma et al. (1985) who reported that 6.7% raw and 4.5% of cooked shrimp collected from a processing facility exceed the limit of  $10^6$  and  $10^5$  cfu/g, respectively. The presence of coliforms in frozen raw shrimp was 15% but 3% in frozen cooked shrimp samples. This agrees with the findings of Buchanan (1991) who reported that the total APC increased even in adequately refrigerated shrimp whereas the level of coliforms and thermal tolerant coliforms increased only in the product that was temperature abused. While 1% of the raw shrimp contained coagulase positive staphylococci, none of the cooked shrimp tested positive for this microorganism. Since the presence of staphylococci is mainly from workers (Garret, 1988), the absence of *Staphylococcus* in cooked product indicates no postprocessing contamination.

*Aeromonas* spp. represents a group of ubiquitous microorganisms of aquatic environments (Monfort and Baleux, 1990). These bacteria have a broad host range and have often been isolated from humans with diarrhea (Ashdown and Koehler, 1993; Janda and Abbott, 1998), though they are recognized as primary pathogens to a wide range of cold-blooded animals. Strains isolated from the environment do not seem to differ from strains isolated from cases of infection with respect to the prevalence of virulence factors (Krovacek et al., 1994). *Clostridium botulinum* is a worldwide contaminant

**Table 20.2** Summary of the bacteriological results of the individually quick-frozen raw and cooked ready-to-eat shrimp analyzed during the period January 1994–December 1995.

Sample	No. of samples analyzed	Percentage of samples with indicated count levels per gram								
		APC				Coliforms		<i>Staphylococcus</i> <sup>a</sup>	<i>E. coli</i>	<i>Salmonella</i>
		$10^2$	$10^3$	$10^4$	$10^5$	$10^1$	$10^2$			
Raw shrimp	1264	35	39	22	4	12	3	1	2	0.1 <sup>b</sup>
Cooked shrimp	914	79	20	1	0.0	3	0.1	0.0	0.0	0.0

<sup>a</sup>Coagulase positive staphylococci.

<sup>b</sup>serotype *Salmonella typhimurium*.

of seafood. Its incidence in fish and incrimination in outbreaks of food poisoning have been extensively studied (Huss, 1981; Dodds, 1993; Hauschild, 1993). Botulism in seafood has been a major food safety concern because *C. botulinum* requires anaerobic conditions for growth. In recent years, there has been renewed interest in the use of modified atmosphere and high barrier film packaging (MAP/VP) of seafood, combined with refrigeration as a supplement to icing to extend shelf life of fresh product at reasonable cost (Cann et al., 1965; Finne, 1982; Gopal et al., 1990, 1996; Reddy et al., 1992). There is concern because all type E and nonproteolytic type B and F strains (metabolic Group II) can grow at 3.3°C. All type A and proteolytic type B and F strains (Group I) have a minimum growth temperature of 10°C, and type C and D strains (Group III) do not grow below 15°C. Groups I and II have been associated with human botulism. Toxin production by *C. botulinum* types A, B, C, D, and E in shrimp tissue homogenate stored between 4°C and 30°C under vacuum for 6 weeks was evaluated by Lalitha and Gopakumar (2001). At 30°C and 15°C storage, growth and toxin production by all types were found in shrimp tissue homogenate. Only type E toxin was observed in the homogenate held at 4°C and 10°C.

### Ice storage of shrimp

The microbiological changes in 156 bacterial cultures from farm-reared freshwater shrimp (*Mac-*

*robriachium rosenbergii*) during ice storage were studied by Lalitha and Surendran (2006). The total aerobic, mesophilic, and psychrotrophic counts and hydrogen sulfide producing bacterial counts were determined. The APC counts at 20°C and 37°C on fresh prawns was in the range of  $10^{4-5}$  cfu/g. This is in agreement with Lalitha and Surendran (2004) who earlier reported the mean microbiological count of *M. rosenbergii* as  $10^5$  cfu/g at 30°C. Aerobic counts at 20 and 7°C exceeded  $10^7$  cfu/g after 26 days of storage, of which 40–52% were H<sub>2</sub>S producers. Enterobacteriaceae and Aeromonadaceae were the dominant Gram-negative organisms that constituted 73% of the total flora of the fresh prawn (Table 20.3). These results confirmed the previous study by Lalitha and Surendran (2004) on water and sediment. After 19 days of iced storage, more than 80% of the bacterial flora of prawn were Gram negative. *Pseudomonas*, *Aeromonas hydrophila*, *Aeromonas veronii* biovar sobria, and *Shewanella putrefaciens* were identified as spoilage bacteria (Table 20.4). The study confirmed that freshwater prawns possess significant numbers of motile aeromonas capable of growth at low temperatures.

### Oysters

The consumption of raw oysters has been linked to outbreaks of acute gastroenteritis in several communities in both the Eastern and Western hemispheres (Dowell et al., 1995; Hlady and Klontz, 1996; Centers for Disease Control and Prevention, 1997;

**Table 20.3** Samplewise prevalence of different pathogens during the study of cultured shrimps.

Pathogens	Particulars	During farming <sup>a</sup>				At harvest <sup>b</sup>		
		Sediment	Water	Shrimp	Formulated feed	Sediment	Water	Shrimp
<i>Salmonella</i>	Total typical colonies	105	110	80	60	40	20	40
	No. positive	30	40	30	15	6	12	05
	Prevalence (%) <sup>c</sup>	28.8	37.4	37.5	25.6	16.7	54.5	12.5
<i>Vibrio</i> spp.	Total typical colonies	130	146	125	83	76	54	39
	No. positive	62	57	51	10	26	15	17
	Prevalence (%) <sup>c</sup>	48.0	39.0	41.0	12.0	43.0	28.0	43.5
<i>Listeria</i> spp.	Total typical colonies	116	120	75	20	43	47	69
	No. positive	0	0	0	0	3	0	2
	Prevalence (%) <sup>c</sup>	0	0	0	0	6.9	0	2.9

<sup>a</sup>Includes samples collected before stocking also.

<sup>b</sup>Formulated feed samples were not analyzed at harvest.

<sup>c</sup>As positive isolates.

**Table 20.4** Percentage distribution of the main bacterial groups and genera associated with giant freshwater prawn and farm environment.

Bacterial group	Genera	Water		Sediment		<i>Macrobrachium rosenbergii</i>	
		F	Fc	F	Fc	Shell with muscle	Interstine
Enterobacteriaceae	<i>Enterobacter cloacae</i>	9.0				7.1	10.0
	<i>Enterobacter aerogenes</i>					5.3	1.7
	<i>Enterobacter sakazakii</i>					3.6	1.6
	<i>Citrobacter freundii</i>	9.0				5.3	8.4
	<i>Klebsiella pneumoniae</i>					12.5	5.1
	<i>Kluyvera</i> spp.		3.6			1.8	
Aeromonadaceae	<i>Aeromonas hydrophila</i>	16.2	15.0	11.8	11.3	10.7	8.4
	<i>Aeromonas schubertii</i>					1.8	5.0
	<i>Aeromonas sobria</i>					3.6	1.6
Niesseriaceae	<i>Chromobacterium violaceum</i>	5.4	7.4	6.1	5.6	1.8	3.4
Gram-negative nonmotile aerobic rods	<i>Moraxella</i> spp.	1.8	3.5	2.1	7.6	1.8	1.7
	<i>Acinetobacter calcoaceticus</i>	5.4	5.6	2.1	7.6	7.1	6.7
Gram-negative motile aerobic rods	<i>Shewanella putrefaciens</i>	3.5		2.0		1.8	3.3
	<i>Pseudomonas fluorescens</i>	3.5	9.3	6.1	5.7	5.4	5.0
	<i>Cytophaga</i> spp.	8.8	9.3	7.9	11.4		5.0
	<i>Flavobacterium</i> spp.	3.5	2.0		3.7	1.8	1.6
Gram-positive cocci	<i>Kocuria varians</i>	5.3	9.4	9.9	7.5	5.3	3.4
	<i>Enterococcus</i> spp.	3.6	5.5	6.1	7.6	5.4	8.3
Gram-positive rods	<i>Bacillus</i> spp.	10.6	9.3	18.0	9.3	7.1	6.7
	<i>Corynebacterium</i> spp.	7.2	5.5	9.9	9.5	5.4	8.3
	<i>Arthrobacter simplex</i>	3.6	9.1	5.9	5.7	3.6	3.3
	<i>Nocardia</i> spp.	1.8		4.1	3.8		
	<i>Kurthia gibsonii</i>	1.8	5.5	4.2	5.6	1.8	1.5

F, farm; Fc, feeder canal.

Laloo et al., 2000; Orban et al., 2004). Oysters are filter feeders that efficiently concentrate microorganisms and because they are consumed raw, they pose a health risk to consumers (Kaysner et al., 1987; Centers for Disease Control, 1993; Bouchriti et al., 1995).

Oysters (*Crassostrea commercialis*), water, and sediment were examined for *V. cholerae* and the bacterium was detected in 20%, 30%, and 11%, respectively (Eyles and Davey, 1988). Toxigenic *V. cholerae* 01 Inaba, resembling the epidemic Latin American strains (C6706, C6707), was recovered from oysters taken from Mobile Bay, Alabama, on five separate occasions. The levels of toxigenic *V. cholerae* in the oysters, estimated by the MNP procedure, ranged from  $10^1$  to  $10^7$ /100 g. The isolates resembled those previously recovered from five cargo ships docked at Gulf of Mexico ports. As with the Gulf Coast strain, the occurrence of the epidemic strain appeared to be sporadic and essentially limited to the warmer months (Motes et al., 1994). *Vibrio*

species most often identified in patients living in the state of Florida with gastroenteritis included *V. parahaemolyticus* (29%), *V. cholerae* non-01 (28%), *Vibrio holllisae* (15%), and *V. mimicus* (12%). The remaining 31% of patients with raw oyster associated *Vibrio* infections developed primary septicemia resulting from infection with *V. vulnificus* (80%), *V. parahaemolyticus* (9%), *V. cholerae* non-01 (8%), and *V. holllisae* (3%). Non-*V. vulnificus* species accounted for 72% of all oyster associated *Vibrio* infections, and differed from infections with *V. vulnificus* in their lack of a seasonal distribution and the absence of underlying medical conditions in infected patients. The results clearly demonstrate that *Vibrio* species other than *V. vulnificus* are more commonly associated with raw oyster consumption (Hlady, 1997).

A study in Texas showed that *V. vulnificus* was not detected in seawater, oysters, or suspended particulate matter (SPM) samples during the cold winter months. Increased levels of the organism were

first observed in early spring in the sediment, and then in SPM, and oysters. The increase in *V. vulnificus* occurred only after the seawater temperature had increased to above 20°C and the winter-spring rainfall had lowered the salinity below 16 ppt. The highest *V. vulnificus* levels at each site were associated with SPM. These results suggest that *V. vulnificus* (1) overwinters in a floc zone present at the sediment–water interface, (2) is resuspended into the water column in early spring following changes in climatic conditions, (3) colonizes the surfaces of zooplankton that are also blooming during early spring, and (4) are ingested by oysters during their normal feeding process (Vanoy et al., 1992).

Cook et al. (2002) sampled 370 lots of oysters (*Crassostrea virginica* and *Crassostrea gigas*) in the shell at 275 different establishments (71% restaurants or oyster bars, 27% retail seafood markets, and 2% wholesale seafood markets) in coastal and inland markets throughout the United States over a 1-year interval for their *V. vulnificus* and *V. parahaemolyticus* contents. The oysters were harvested from the Gulf of Mexico (49%), Pacific (14%), Mid-Atlantic (18%) and North Atlantic (11%) coasts, and Canada (8%). Densities of both bacteria in market oysters from all harvest regions followed a seasonal distribution, with highest densities found in the summer. The highest densities of both organisms were observed in oysters harvested from the Gulf coast, where densities often exceeded 10,000 MPN/g. The majority (78%) of lots harvested in the North Atlantic, Pacific, and Canadian coasts had *V. vulnificus* densities below the detectable level of 0.2 MPN/g; none exceeded 100 MPN/g. *V. parahaemolyticus* densities were greater than those of *V. vulnificus* in lots from the same areas, with some lots exceeding 1000 MPN/g for *V. parahaemolyticus*. Overall, there was a significant correlation with salinity. Storage time significantly affected the *V. vulnificus* (10% decrease per day) and *V. parahaemolyticus* (7% decrease per day) densities in the market oysters.

A study on the contamination of *V. parahaemolyticus* in oysters (*Crassostrea madrasensis*) showed that the bacterium was present in 93.9% of the samples and the densities ranged from <10 to 10<sup>4</sup> organisms per gram (Deepanjali et al., 2005). Pathogenic *V. parahaemolyticus* could be detected in 10.2% of the samples. Isolates from one of the samples belonged to the pandemic serotype 03:K6. The *trh* (thermolabile-related hemolysin) gene, which

is considered to be a major virulence factor in the bacterium, was observed in 59.3% of the samples. An analysis of oysters in Washington, Texas, and New York showed that only two oyster samples exceeded the level of concern of 10,000 cfu/g. Pathogenic strains were detected in a few samples, mostly Puget Sound oysters, but at low densities (usually, <10 cfu/g). On the basis of the data, findings of more than 10,000 cfu/g total *V. parahaemolyticus* or >10 cfu/g of pathogenic organisms in the environmental oysters should be considered extraordinary. Studies with *C. virginica* in Mobile Bay, Alabama resulted in the detection of pathogenic strains of *V. parahaemolyticus* in 21.8% of samples collected (De Paola et al., 2003). A New Zealand study revealed that 57% of the oyster samples contained *V. parahaemolyticus* but 95% of the samples contained less than 10 organisms per gram. Only one sample exceeded 1000 organisms per gram (Fletcher, 1985).

Intertidal harvest is practiced extensively in some Pacific Northwest estuaries. After the tide recedes from the harvest area, the shellfish are hand picked and placed in large baskets that are left in the harvest area until the tide rises to a depth sufficient for a vessel to retrieve the baskets and transport them to the processing plant. Intertidal harvest potentially exposes oysters to favorable conditions for growth, especially on sunny days. Nordstrom et al. (2004) determined that the mean *V. parahaemolyticus* densities in oysters were generally four to eight times greater at maximum exposure (when high tide occurred) than at the corresponding first exposure (when low tide occurred). While pathogenic counts were generally low ( $\leq 10$  cfu/g) at first exposure, counts as high as 160 cfu/g were found at maximum exposure. Pathogenic *V. parahaemolyticus* was detected in 21% of the oyster samples at maximum exposure and in 26% of sediment samples. These results demonstrate that summer conditions permit the multiplication of the bacterium in oysters exposed by a receding tide.

*Campylobacter* is a common bacterial pathogen that causes enteritis in humans worldwide. The genus *Campylobacter* comprises multiple species of which the thermophilic *Campylobacter jejuni*, *Campylobacter coli*, *C. lari*, and *Campylobacter upsaliensis* are the most important (Allos and Blaser, 1995). *C. jejuni* and *C. coli* account for the majority of enteric infections in humans, outbreaks of *C. upsaliensis* have also been reported (Goossens

et al., 1995). *C. lari* appears to be widely present in the environment but is rarely reported as a human pathogen. Epidemiological surveys revealed a low incidence of *C. lari*, often accounting for less than 1% of all *Campylobacter* infections (Mishu et al., 1992). Bacteraemia in immunocompromised and immunocompetent patients has been described and one, water-borne, common-source outbreak involving 162 patients has been reported (Broczyk et al., 1987; Soderstrom et al., 1991). Arumugaswamy and Proudford (1987) isolated both *C. coli* and *C. jejuni* from Sydney Rock oysters (*Crassostrea commercialis*). The bacteria were present in approximately 14% of 79 samples tested. Oysters in the Netherlands were screened for the presence of *Campylobacter* spp. during a 6-month period; 11 out of 41 batches of oysters were colonized with the bacterium (Endtz et al., 1997). An analysis of 39 *Campylobacter* spp. cultured from the samples revealed that all isolates, except two, were *C. lari*. The remaining two isolates were identified as *C. coli* and *Campylobacter hyointestinalis*.

The incidences of *Salmonella* infections have risen in recent years and many cases are linked to seafood (Centers for Disease Control and Prevention, 2000), particularly to the consumption of shellfish (Heinitz et al., 2000). Heinitz et al. (2000) tested seafood and shellfish around the world for the presence of *Salmonella* spp. and found that United States shellfish, particularly oysters, had a 1.2% prevalence of *Salmonella* in domestic shellfish. Wilson and Moore (1996) conducted a study that showed 8% of 433 shellfish contained *Salmonella*. Harvesting areas have become more populated in recent years, with more human sewage discharged into coastal waters resulting in an increase in pathogens in these waters, thus a higher incidence of food-borne disease from shellfish. A study was performed by Brands et al. (2005) to determine the prevalence of *Salmonella* spp. in oysters harvested from 36 United States bays (12 each from the West, East, and Gulf coasts in the summer and 12 bays, four per coast in the winter). *Salmonella* was isolated from each coast and 7.4% of all oysters tested positive for the bacterium. Isolates tended to be bay specific, with some bays having a high prevalence of *Salmonella* while other bays had none. A difference in the percentage of oysters from which *Salmonella* was isolated were observed between the summer and winter months, with winter numbers much lower probably due to a variety of weather-related events. The vast major-

ity (78/101) of *Salmonella* isolates from oysters were *Salmonella enterica* serovar Newport, a major human pathogen, confirming the potential hazard of raw oyster consumption.

Aeromonads are ubiquitous throughout the environment and are found in both freshwater and saltwater (Abeyta and Wekell, 1988; Kirov, 1997). One member of the genus, in particular, *A. hydrophila*, is of concern. Although evidence is circumstantial, this organism is believed to be the cause of food-associated gastroenteritis (Agger et al., 1985; Deodhar et al., 1991). Because this organism is known to occur naturally in oysters, it is of special concern since oysters are consumed either raw or undercooked (Abeyta et al., 1986). Abeyta et al. (1986) reported that *A. hydrophila* was recovered from frozen oysters that had been stored at  $-72^{\circ}\text{C}$  for 1.5 years. Birkenhauer and Oliver (2002) reported that oysters, immediately after shucking, contained a presumptive *A. hydrophila* count of  $7.6 \times 10^4$  cfu/g. After 7 days of refrigeration, the average number increased to  $3.2 \times 10^5$  cfu/g.

Numerous viral illnesses have been associated with the consumption of contaminated shellfish. Viruses likely to be transmitted by this route are enteric viruses that are capable of persisting in the environment and can be concentrated by shellfish. In the 1960s, hepatitis A was the predominant disease reported, but in recent times, acute gastroenteritis has emerged as the most prevalent (Melnick, 1995). However, hepatitis A continues as a pathogen when raw oysters are consumed. In 2005, hepatitis A virus (HAV) was confirmed as causing illness in four states among restaurant patrons who ate Gulf Coast oysters (Shieh et al., 2007). Many cases of gastroenteritis are caused by small round-structured viruses (SRSVs). An SRSV was implicated in an outbreak in oysters (*C. virginica*) harvested in Louisiana (Le Guyader et al., 1996). Molecular characterization has shown that these viruses are human caliciviruses and that they are genetically related to the Norwalk virus (Estes and Hardy, 1995). Oysters (*C. gigas* and *Ostrea edulis*) imported into Switzerland were monitored for the presence of viruses. Eight oyster samples from six suppliers were positive for Norwalk-like viruses, and four samples from four suppliers were positive for enteroviruses; two of the later samples were positive for both viral agents. No HAVs were detected (Beuret et al., 2003).

Oysters (*C. virginica* and *C. gigas*) were collected from 45 bays on the East, West, and Gulf



coasts during the summer and winter by Costantini et al. (2006). Nine samples (20%) were positive for HuNoV genogroup II. Animal enteric caliciviruses were detected in ten (22%) samples. Seven of the samples were positive for porcine norovirus genogroup II, and one sample was positive for porcine sapovirus. Bovine noroviruses were detected in two samples. Five HuNoV samples were similar to the norovirus genogroup II US 95/96 subset (genogroup II-4) previously implicated in diarrhea outbreaks. Different seasonal and state distributions were detected. The presence of animal caliciviruses was associated with states having high livestock production.

### Postprocessing treatments of oysters

It is known that high pressure reduces the microorganism count while retaining acceptable sensory properties of muscle foods (Lopez-Caballero et al., 2000). Pascual (1992) reported that predominate microorganisms during alteration of oysters are Gram-negative proteolytic (*Pseudomonas* and *Vibrio*) and Gram-positive saccharolytic (*Lactobacillus*) bacteria. He also reported that at a pressure as high as 400 MPa, the appearance of the meat was good. The appearance of the meat was better when pressurization was performed under chilling (7°C) rather than higher temperatures (20°C and 37°C). The flavor was virtually unchanged, although Hoover et al. (1989) described an intensification of the flavor.

Both clinical and environmental *V. parahaemolyticus* isolates in pure culture and in oysters were treated with high pressure processing (HPP). The initial *V. parahaemolyticus* population ranged between  $10^6$  and  $10^8$  cfu/mL. No survivors were detected in samples pressurized for 180 seconds at 310 MPa and 30 seconds at 345 MPa that resulted in a  $10^7$  log cycle reduction. Optimum conditions for reducing *V. parahaemolyticus* in pure culture and oysters to nondetectable levels were achieved at 345 MPa for 30 and 90 seconds, respectively. A pressure of 241 MPa for 600 seconds did not eliminate the organism and a pressure of 276 MPa required 300 seconds for complete destruction.

He et al. (2002) subjected whole Pacific oysters (*C. gigas*) to HPP treatments ranging from 207 to 310 MPa at 0, 1, and 2 minutes and stored at <4°C and evaluated over 27 days. The initial microbial count was reduced by  $10^3$  log cycles and the counts

remained at a reduced level throughout the storage study. The optimum shucking pressures that caused minimum changes in appearance were in the range of 240–275 MPa.

Research by Kingsley et al. (2002) using 5-minute treatments showed limited activation of HAV at 300 MPa in cell culture media. Treatments of 460 MPa resulted in a  $10^7$  log reduction of HAV to nondetectable levels. In a subsequent study, Calci et al. (2005) reported that HAV within contaminated oysters (*C. virginica*) was inactivated by HPP.

Comparisons of different models in inactivation kinetics were conducted on data obtained from high pressure and gamma-irradiation processing (Hu et al., 2005). *V. vulnificus* (MO-624) and *V. parahaemolyticus* (TX-2103, 03:K6) were suspended in PBS (phosphate buffered solution) and exposed to pressures from 207 to 379 MPa for 1–20 minutes. Inoculated whole oysters (*C. virginica*) ( $10^6$  cfu/g) were exposed to pressures from 276 to 379 MPa for 1–15 minutes.

Pure cultures and inoculated oysters ( $10^6$  cfu/g) also were irradiated (gamma irradiation) at doses of less than 3 kGy. The effect of gamma irradiation processes on high levels of *Salmonella enteritidis*, *Salmonella infantis*, and *V. parahaemolyticus* incorporated by oysters (*Crassostrea brasiliana*), as well as the effects on the sensory attributes was studied by Jakabi et al. (2003). The oysters were exposed to gamma irradiation ( $^{60}\text{Co}$ ) in doses ranging from 0.5 to 3.0 kGy. A dose of 3.0 kGy was generally sufficient to reduce the level of *Salmonella* serotypes by 5–6 log<sub>10</sub> units. A dose of 1.0 kGy was sufficient to produce a 6 log<sub>10</sub> reduction in the level of *V. parahaemolyticus*. A dose of 3.0 kGy did not change the odor, flavor, or appearance of the oysters.

The effect of electrolyzed oxidizing (EO) water treatment on reducing *V. parahaemolyticus* and *V. vulnificus* was investigated by Ren and Su (2006). Populations of *Vibrio parahaemolyticus* ( $8.74 \times 10^7$  cfu/mL) and *V. vulnificus* ( $8.69 \times 10^7$  cfu/mL) in pure culture decreased quickly in EO water containing 0.5% NaCl to nondetectable levels ( $>10^6$  log reductions) within 15 seconds. Freshly harvested Pacific oysters (*C. gigas*) were inoculated with a 5-strain cocktail of *V. parahaemolyticus* or *V. vulnificus* at levels of  $10^4$  and  $10^6$  MPN/g and treated with EO water (30 ppm chlorine; pH 2.82; oxidizing potential 1131 mV) containing 1% NaCl at room temperature. Reductions in the two bacterial species were determined after 0 (before treatment), 2, 4, 6, and

8 hours resulting in a significant ( $p < 0.05$ ) reduction of *V. parahaemolyticus* and *V. vulnificus* by 1.13 and 1.05 log<sub>10</sub> MPN/g, respectively. An extended exposure greater than 12 hours was found to be detrimental to the oysters. EO water can be used as an effective postharvest treatment to reduce *Vibrio* contamination in oysters; however, it should be limited to 4–6 hours to avoid death of the oysters.

## Mussels

Water and mussel samples were collected from two brackish lakes in Sicily in the district of Messina, used as mussel farms, at different times of the year, for the quantitative analysis of *Vibrio* spp. and for the isolation of potential pathogenic species (Maugeri et al., 2000). During the spring and summer, *Vibrios* were detected in water and mussels (*Mytilus galloprovincialis*) collected in 30 sampling sites located in Taranto (Ionian Sea, Italy) by Cavallo and Stabili (2002). Fecal coliforms and *E. coli* densities were also determined to evaluate the degree of microbial pollution of the investigated area. The highest coliform densities in the water samples were between 94/100 and 2/100 mL. In the mussel samples, the maximum coliform density was 4900/100 g and the minimum was 200/100 g. The *E. coli* density ranged between 46 and 0/100 mL in the water and between 4600 and 200/100 g in the mussels. During the sampling period, a total of 1186 *Vibrio* strains were isolated. Approximately 40% were isolated from the seawater samples and 60% from the mussel samples. Some *Vibrio* species such as *V. alginolyticus*, *Vibrio mediterranei*, *V. parahaemolyticus*, *Vibrio diazotrophicus*, *Vibrio nereis*, and *Vibrio splendidus* were present in the water as well as in the mussel samples. Other *Vibrios* such as *V. vulnificus*, *V. cincinnatiensis*, *V. orientalis*, *V. anguillarum*, *V. marinus*, and *V. hollisae* were isolated from mussels when none were detected in the growing water. Normanno et al. (2006) analyzed 600 samples of *M. galloprovincialis* from the Puglia region of Italy. Forty-seven (7.83%) were contaminated with *V. parahaemolyticus* and 17 (2.83%) with *V. vulnificus*. None of the samples displayed isolates of both vibrios. *Salmonella* spp. was isolated in one (0.16%) sample. Twenty-eight samples (4.66%) contained levels of fecal coliforms higher than the allowed limit ( $>300$  MPN/g) and 21 (3.5%) were noncompliant for the number of *E. coli* ( $>230$  MPN/g). Their

study did not show a statistical significant variation ( $p > 0.05$ ) in isolates of *V. parahaemolyticus* and *V. vulnificus* during the summer months. The investigators also concluded that depuration and production of mussels in “Type A” waters were clearly inadequate for eliminating the potential health hazards due to the presence of the vibrios analyzed.

The genus *Aeromonas* has emerged as an important human pathogen because of suspected disease outbreaks and the increased incidence of its association from patients with traveler’s diarrhea. Among the 14 species of *Aeromonas* known to date, *A. hydrophila*, *A. caviae*, and *A. veronii* biotype *sobria* have most commonly been involved in human infections. Ottaviani et al. (2005) collected mussel (*M. galloprovincialis*) samples from natural beds on the Adriatic Sea in Ancona Province, Italy. Out of 144 samples, 32 *Aeromonas* strains were isolated and 12 showed virulence and enteropathogenicity in mice. The most prevalent species was *A. hydrophila* (68.7%), while the other strains belonged to the species HG2 (25%), and to *A. caviae* (6.2%).

Endtz et al. (1997) screened mussels for the presence of *Campylobacter* spp. Forty-one out of fifty-nine batches of the mussels contained *Campylobacter* spp. with all but two being the *C. lari* species. In a prior report from Ireland, *Campylobacter* spp. was detected in 42% of the shellfish (Wilson and Moore, 1996). Van Doorn et al. (1998) obtained 44 *Campylobacter* spp. isolated from mussels in the Netherlands. Three of the isolates were identified as *C. jejuni*, one *C. upsaliensis*, one double infection with *C. jejuni* and *C. coli*, and 38 *C. lari* strains.

## Hepatitis A

The contamination of shellfish with enteric viruses is a significant public health concern. The consumption of raw or undercooked bivalve shellfish is often associated with the transmission of viral diseases such as infectious hepatitis and gastroenteritis. Enteric viruses are very resistant to physical and chemical inactivation and may persist in shellfish tissues after depuration (Casas and Sunen, 2001). The frequency of hepatitis A virus (HAV) contamination in mussels sold in southern Italy, where a high incidence of HAV infection both in residents and travelers is reported each year, was investigated during a 3-year period (Crocì et al., 2003). On a total of 180 mussel (*M. galloprovincialis*)

samples collected from markets in five large cities, 15.6% contained infectious HAV. A previous study by Croci et al. (2000) in which 36 mussel samples were collected from three different areas of the Adriatic Sea showed the presence of enteric viruses. The analysis showed five samples positive for the presence of enteroviruses and 13 for the presence of HAV (in three samples both viruses were present). Most of the mussels complied with the bacteriological standards established by European law. In fact, the *E. coli* values exceeded the European limit (230 MPN/100g) in only seven samples. The discovery of HAV in several samples in which no enteroviruses were reported, confirms that the presence of either of these two parameters is not indicative of the presence of the other.

Hernroth et al. (2002) investigated human enteric contaminants in blue mussels (*Mytilus edulis*) from three sites on the west coast of Sweden, representing a gradient of anthropogenic influence. Mussels were sampled monthly from February through July and analyzed for adeno-, entero-, Norwalk-like, and HAVs as well as the potential viral indicator organisms somatic coliphages, F-specific RNA bacteriophages, bacteriophages infecting *Bacteroides fragilis*, and *E. coli*. Enteric viruses were found in 50–60% of the mussel samples, and there were no pronounced differences between the samples from the three sites. *E. coli* counts exceeded the limit for category A for shellfish safety in 40% of the samples from the sites situated in fjords. However, at the site in the outer region, the limit was exceeded only once, when extremely high levels of atypical indole-negative strains of *E. coli* were registered at all three sites. The environmental factors influenced the occurrence of viruses and phages differently, and it was not possible to provide a correlation. The investigators concluded that for risk assessment, a separate model would be required for every specific area, with special emphasis on environmental factors, such as temperature and land runoff. The *E. coli* standard was not a reliable indicator of viral contaminants. The report concluded that to ensure safe shellfish, a viral analysis would be required.

Surveys were performed over 16 months to assess the distribution of enteroviruses of human origin in sediments and mussels (*Perna canaliculus*) near two sewage outfalls in New Zealand (Lewis et al., 1986). Enteroviruses were present in high numbers in both sediment and shellfish with maximum virus levels

of 32,000 pfu/g of wet mussel tissue and 59 pfu/g of wet sediment material. Coxsackievirus B4 was the predominant virus type isolated but CB5 and Poliovirus 1, 2, and 3 were also recovered. Attempts to deplete the viruses for 8 days with daily water replacement did not achieve a significant reduction in virus numbers. Since food-borne viruses are infectious at very low doses, there is a need for a viral indicator. Studies on the individual variability of accumulation of viruses in bivalves and how environmental factors can influence the persistence seems necessary for improving risk assessment.

## Toxins

Many species of marine microalgae produce substances that are highly toxic: because the algae are widespread and periodically form large concentrations in the form of population blooms, the amounts of toxins are considerable. Mussels have been reported to accumulate substantial amounts of some phycotoxins faster than other bivalves (Shumway, 1990). Although the mussels may acquire phycotoxins by the ingestion of bacteria or as dissolved forms, the most important accumulation processes are due to ingestion of toxic phytoplankton (Morono et al., 2001). Substantial variability has been observed in the uptake rate among individuals of the same species (White et al., 1993). Mussels are highly resistant to saxitoxin and similar compounds, and in most cases, do not exhibit adverse reactions when feeding on paralytic shellfish poisoning (PSP) producing dinoflagellates. This resistance, along with the generally elevated filtration rate of mussels, is probably one of the factors that determine their faster rate of phycotoxin accumulation, as compared to other bivalves. Aalvik and Framstad (1981) observed that the concentration of toxins per unit weight is greater in the smallest mussels. Diarrhetic shellfish poisoning has been reported in blue mussels (*M. edulis*) in Europe from Denmark (Jorgensen et al., 2005) to Spain (Losada et al., 1999). In the western hemisphere, domoic acid (DOM), the toxin involved in amnesic shellfish poisoning has been reported in cultivated mussels (*M. edulis*) by Novaczek et al. (1991). PSP toxins were found in green mussels (*Perna viridis*) from the Gulf of Paria between Trinidad and Venezuela, as well as the northern coast of Venezuela (Yen et al., 2006). The calculated

saxitoxin equivalents in each sample were below 80 µg/100 g of tissue.

## Parasites

Over the last decade, among the protozoan parasites of animal and human interest, *Cryptosporidium* has attracted great attention from the scientific community for its public health implications. *Cryptosporidium* is present worldwide and is responsible for diarrheal disease in humans and can be life threatening in immunocompromised patients and can severely debilitate immunocompromised subjects (Fayer et al., 1997). The smallness of the oocysts and their viability in the environment (up to 1 year in artificial seawater), infectivity for newborn mice after 30 days in shellfish, high concentrations reported in the feces ( $10^8$  oocysts per gram) of young calves, low sedimentation rate, and resistance to commonly used disinfectants, as well as the low doses required for human infection ( $\leq 30$  oocysts), and lack of specific treatments, are factors that facilitate transmission to humans and their accumulation in bivalves (Casemore et al., 1997).

Manila clams (*Ruditapes philippinarum*) were analyzed for the presence of *Cryptosporidium* spp. along the northern Adriatic coast by Molini et al. (2007). A total of 2160 clams were collected from six clam sites. Both *C. hominis* and *Cryptosporidium parvum* were detected with infection rates ranging from 0.36% to 1.15%.

Mussels (*M. edulis*) was first reported as harboring oocysts in 1997 (Chalmers et al., 1997), and thereafter other mussel species have been reported to harbor them. The presence of *Cryptosporidium* oocysts in mussels has been reported in samples from Spain (Gomez-Bautista et al., 2000), United Kingdom, France (Li et al., 2006), and other European countries (Gomez-Couso et al., 2004), United States (Graczyk et al., 1999), and Canada (Graczyk et al., 2001). Oocysts were incubated in artificial seawater at 6–8°C under moderate oxygenation and the infectivity of oocysts was tested five times, over a 12-month period (Tamburrini and Pozio 1999). The oocysts remained infectious for 1 year. Forty mussels (*M. galloprovincialis*) held in an aquarium filtered out more than  $4 \times 10^8$  oocysts in a 24-hour period. Oocysts collected from the gut of mussels after 7 and 14 days were observed to have infected mice. These results suggest that *C. parvum* can sur-

vive in seawater for at least 1 year and can be filtered out by benthic mussels, retaining their infectivity up to 14 days, so seawater and mussels are a potential source of *C. parvum* infections for humans.

Researchers detected *C. parvum* in Eastern oysters (*C. virginica*) at all commercial harvesting sites tested in Maryland tributaries to Chesapeake Bay (Fayer et al., 1998; Graczyk et al., 2000). Additional research found *Cryptosporidium* species in oysters from 64.9% of sites sampled in 13 Atlantic coast states from Maine to Florida and New Brunswick, Canada (Fayer et al., 2003). Commercial and non-commercial oysters (*C. gigas*) and oyster culture water from the Netherlands contained *Cryptosporidium* oocysts and *Giardia* cysts (Schets et al., 2007). Nine of 133 (6.7%) oysters from two noncommercial harvesting sites contained *Cryptosporidium*, *Giardia*, or both. Six of forty-six (13.0%) commercial oysters harbored *Cryptosporidium* or *Giardia* in their intestines.

Customary processing operations may not completely eliminate *C. parvum* oocysts from shellfish. The parasite is able to survive in the tissue of fresh shellfish from harvest through consumption and is resistant to treatment with many toxic chemicals (liquids and gasses) and can survive several months at refrigeration temperatures.

Contaminated mussels with *C. parvum* were heated by atmospheric steaming until all the mollusks opened their valves by Gomez-Couso et al. (2004). A neonatal mouse assay revealed the preparation method was not sufficient to completely destroy the infectivity of the parasite. Collins et al. (2005a) subjected infected oysters (*C. virginica*) with *C. parvum* to e-beam irradiation (1.0, 1.5, and 2.0 kGy) and microwave energy (2100 watts delivering 915 MHz) for 1, 2, and 3 seconds. An irradiation exposure of 1 kGy reduced *C. parvum* by 57% and 47% in shell and shucked oyster, respectively. The 1.5 kGy treatment resulted in a 63% and a 73% reduction in shell and shucked oyster, respectively. A dose of 2 kGy completely terminated *C. parvum* mouse infectivity and did not adversely affect the visual appearance of the oysters. Oysters showed a reduction in *C. parvum* mouse infectivity of 26.7%, 33.3%, and 46.7%, respectively, when subjected to the microwave processes for 1, 2, and 3 seconds.

HPP (Collins et al., 2005b) of shucked Eastern oysters (*C. virginica*) at high hydrostatic pressures of 305, 370, 400, and 550 MPa was significantly effective ( $P < 0.05$ ) in reducing mouse infectivity of *C.*



*parvum* oocysts. A dose of 550 MPa for 180 seconds holding time produced the maximum decrease of mouse infectivity (93.3%).

## Conclusions

The consumption of oysters and mussels presents an unacceptable food-borne hazard to normal and immunocompromised individuals. International research has shown that various indicator microorganisms are not capable of accurately identifying the risk of consuming raw or minimally heat-treated products. The optimum method of pathogen control is the application of a postharvest treatment to eliminate a pathogen or reduce its presence to an acceptable level. Some treatments such as pasteurization, irradiation, high hydrostatic pressure processing, and long-term freezing are processes that have been shown to reduce the potential for food-borne illness by reducing pathogenic microorganisms, viruses, parasites, and the allergenicity of specific proteins in shellfish species. Depuration is effective in removing some pathogenic organisms but many remain after the traditional depuration process (approximately 15 days in growing waters exceeding 10°C) has been terminated. Effective depuration can only be achieved when the shellfish are placed in clean waters for extended time periods. The time will vary depending on: the shellfish species; amount of pathogen accumulation; type of pathogen; and environmental factors.

Some shellfish, such as shrimp, are customarily consumed fully cooked so that the major health hazard would result from cross-contamination or an allergic reaction. The greatest hazards from shrimp are from wounds obtained through handling either the live or fresh (sometimes referred to as green) animal.

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# 21

## Allergens, Decomposition, and Toxins

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Sherwood Hall

Seafood is inherently wholesome and nutritious, valued for sustenance and enjoyed as a luxury. But under some circumstances seafood can cause illness, often severe and sometimes fatal. Prosperity in the seafood industry requires the implementation of reliable strategies for assuring that customers get the good and avoid the bad.

For a food safety regulatory agency, it may suffice to implement programs that ensure that products are safe and consumers are protected from harm. For industry, this is not enough. To prosper, industry has to sell products. This requires not only that there be seafood to harvest and that it be safe, but that there are customers who want to buy it. Industry has to go the extra distance of ensuring that customers are convinced that the product is safe and worth what it costs.

Unfortunately, consumer perceptions and purchasing decisions may not make clear distinctions between different types and sources of seafood. Therefore, a problem with one product may have an impact on the profitability of others. Furthermore, seafood is often less a subsistence product than a luxury product, something for which people may be willing to pay a bit more. It tends to be an elective purchase, so it is easy for the customer

to choose something else. The industry's ability to assure safety and quality play a significant role in these decisions.

Three very different seafood hazards will be discussed in this chapter. They are similar in that all involve natural compounds in seafood that can harm consumers. They differ in the nature of the compounds, their origins, and their effects. The first compounds are allergens, proteins intrinsic to seafood to which some consumers develop an immune response. The second are products of seafood decomposition that can cause illness in consumers. This illness is often referred to as scombroid poisoning because it is most commonly associated with scombroid fish. Seafood toxins make up the third group of compounds mostly accumulated from dietary sources, often from unicellular algae or protozoa.

Some useful references are as follows:

- (1) *FAO seafood safety overview*:  
<http://www.fao.org/docrep/006/y4743e/y4743e00.htm#Contents>
- (2) *UC Davis seafood information listserv*:  
<http://seafood.ucdavis.edu/>

- (3) *FDA Seafood HACCP*:  
<http://www.fda.gov/Food/FoodSafety/HazardAnalysisCriticalControlPointsHACCP/SeafoodHACCP/default.htm>
- (4) *Code of Federal Regulations Title 21, Part 123, Fish and Fishery Products*:  
[www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?CFRPart=123](http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?CFRPart=123)

## Allergens

Some people develop allergies to seafood; the symptoms of the allergic response can range from annoying to lethal. The problem lies not with the seafood but with the response of the person's immune system to proteins that are natural, intrinsic constituents of seafood. In fish, the principal allergenic proteins are parvalbumins (Lim et al., 2008). In invertebrates, the principal allergenic proteins are tropomyosins (Taylor, 2008). Tropomyosin structures are relatively similar in different kinds of organisms, so an allergic person is more likely to experience an allergic response to a broad range of invertebrate species. Parvalbumins are more variable, so a person is more likely to experience an allergic response to only a few fish species. Proteins from anisakid parasites in seafood can also cause allergic responses (Audicana and Kennedy, 2008). The severity of allergic response bears little relationship to the amount of allergen; it is determined primarily by the sensitivity of the consumer. Seafood allergies have been reviewed by Lopata and Lehrer (2009), Wild and Lehrer (2005), Chu et al. (2005), Flick (2004), Ree-Kim and Lehrer (2004), and Lehrer et al. (2002, 2003).

Exposure to seafood allergens can occur through consumption, or among people processing seafood. Managing the risk of allergens for consumers requires that the contents of a product be accurately and completely described, including any breeding and other nonseafood components, so that consumers can avoid things to which they know themselves to be sensitive. This in turn implies that the supplier must accurately know the contents, known product coming from reliable sources, and processing lines managed to rigorously ensure against cross-contamination.

Managing the risk in the workplace involves minimizing exposure through control of mists and airborne particulates, adequate ventilation, and personal protective equipment. Surveys of workers for

sensitization, either through questionnaires regarding symptoms or testing, may allow management to reduce exposure for sensitized individuals to avoid more serious symptoms. Seafood allergy among process workers has been reviewed by Jeebhay et al. (2001, 2010). Gautrin et al. (2010) discussed allergies among workers processing crabs in eastern Canada. Metcalf et al. (2008) is a comprehensive text on food allergy.

## Decomposition

There are two aspects to seafood decomposition: loss of sensory quality and thus market value, and the production of substances that cause illness in consumers. Both result from time/temperature abuse and can be avoided by proper handling, but they are otherwise not necessarily linked. Time/temperature abuse of the sort that causes detectable odors will not necessarily result in the formation of substances that cause illness. On the other hand, decomposition that forms substances that can cause illness will not necessarily result in a loss of sensory quality to warn producers or consumers that the seafood may be harmful.

The distribution of decomposition within a fish and among fish in a lot is not uniform. In principle (at least), it is straightforward to decide whether or not a small piece of fish flesh is decomposed; however, it is very difficult and expensive to meaningfully characterize an entire batch of fish. It is far more practical and cost-effective to avoid decomposition than to find it. In short, do not spoil the fish.

In the past, when fisheries resources seemed unlimited, there could be an economic tradeoff: one could bring in a higher quality catch by spending more to get it out of the water quickly and care for it, or skimp on handling costs and accept a lower return for lower quality product. Now, it is painfully clear that fisheries resources are not unlimited, and that those fish that are left to be harvested need to be captured and handled with sufficient care to ensure that they reach consumers in the best possible condition, so that they have the highest possible market value.

Some useful references are as follows:

- (1) A recent review by Hungerford (2010) is particularly helpful for understanding scombroid poisoning.

- (2) Sea Grant guidance:  
<http://www.iceyourfish.seagrant.org/index.html>.
- (3) FAO overview:  
<http://www.fao.org/docrep/006/y4743e/y4743e0a.htm#bm10>.
- (4) FDA detection methods for histamine and indole:  
[www.fda.gov/downloads/ScienceResearch/.../UCM092251.pdf](http://www.fda.gov/downloads/ScienceResearch/.../UCM092251.pdf).

Seafood decomposition can follow many different paths. The type of fish, its history, the way it is handled after capture, and the microbial flora that happen to be present all contribute to the type of spoilage.

Fish decomposition is largely due to bacterial growth inside the fish after the fish dies. The intrinsic variability of this sort of microbial growth, coupled with variations in microenvironments within and among individual fish, helps explain why decomposition varies so much within a fish and among fish.

## Biogenic amines

Histidine, lysine, and ornithine are amino acids found in animals. Histidine and lysine are constituents of protein. Ornithine is a key intermediate in metabolism. Each of these amino acids has a carboxylate group that can be removed by the appropriate enzyme, forming the corresponding amine:

histidine → histamine

lysine → cadaverine

ornithine → putrescine

Lysine and ornithine have terminal primary amino groups. Decarboxylation of the amino acid head in each leaves another primary amine. The decarboxylation products of lysine and ornithine, cadaverine and putrescine, are therefore referred to as diamines: carbon chains of five and four members, respectively, with primary amines on each end. Histamine is similar, though not a diamine because the amino acid histidine terminates in a five-membered ring containing two nitrogens, rather than a primary amine. Cadaverine and putrescine, as the names imply, contribute to the characteristic odor of rotting flesh.

Bacterial growth during seafood decomposition produces enzymes that can decarboxylate histidine, lysine, and ornithine to their corresponding amines. The decarboxylating enzymes can persist, even though bacterial growth has been stopped when the catch is chilled. Thus, fish flesh that may not yet have significant levels of amines can be primed with decarboxylating enzymes for the rapid production of amines or other harmful decomposition products when the product is allowed to warm again.

Histamine plays several important roles in human metabolism, among them serving as the signaling compound for the allergic response. As a signaling compound, it is normally present in the human body, but its location and concentration are carefully regulated.

Consumers of decomposed fish may suffer symptoms that seem like an allergic response. The syndrome is referred to as scombroid poisoning because it is most often caused by decomposed tuna, mackerel, or other scombroid fish. Scombroid fish are notable for having relatively high concentrations of free histidine. The traditional explanation for scombroid toxicity is that the high levels of free histidine in scombroid fish, coupled with histidine decarboxylase formed by bacteria during decomposition, allow rapid formation of high concentrations of histamine. When such fish is consumed, the histamine does just what normal histamine does in the human body: it elicits the response we experience as allergy. This explanation is likely correct as far as it goes, but there appears to be more going on in scombroid toxicity because experimental oral dosing of histamine in human volunteers is reported to not reproduce the symptoms seen in scombroid poisoning. However, histamine concentrations are often found to be elevated in remnants of fish that have caused scombroid symptoms.

Whether or not histamine is the entire cause of scombroid toxicity, or even one of the causes, histamine, cadaverine, and putrescine are useful chemical indicators of decomposition (CIDs) in fish. Similarly, indole is a CID in shrimp, crabs, and other crustaceans.

## Management

Again, the most cost-effective strategy for dealing with seafood decomposition is to avoid it, through

rigorous adherence to time/temperature parameters: do not spoil the fish. Time/temperature monitors that can be included within containers of fish now make it more practical to ensure that the product remains within the required parameters.

If decomposition is allowed to occur, finding and quantifying it is very challenging because of its nonuniform distribution within and among individual fish. Adequate characterization of a lot requires a large number of samples. Sensory analysis is the most practical way to analyze the large number of samples required. Effective sensory analysis requires training and review. Sensory training courses are offered by the University of Florida, NOAA (National Oceanic and Atmospheric Administration), and others.

There is a dilemma, however, since the conditions that lead to scombroid toxicity do not necessarily result in odors detectable by sensory analysts. Therefore, analysis for CIDs is also necessary. Many instrumental methods have been developed for detecting decomposition in seafood. Relatively few have been validated and accepted for regulatory purposes. For a discussion of detection methods for histamine, see the review by Hungerford (2010). A regulatory method for the determination of cadaverine and putrescine by GC has been developed and an AOAC collaborative study completed (Rogers and Staruszkiewicz, 1997). Indole, a chemical indicator of decomposition in shellfish, can be determined by HPLC using fluorescence detection, AOAC method 981.07.

## Seafood toxins

In contrast to bacterial contamination and the protein toxins produced by bacteria, the seafood toxins are nonprotein compounds that cannot readily be destroyed or deactivated by processing. They can cause illness or death in consumers. The best defense is to identify seafood that is or may be toxic and ensure that it is not harvested or consumed (Figure 21.1). Easier said than done, however, because toxicity comes and goes and there tend to be no outward signs of contamination. There are a few exceptions, cases in which toxicity can be managed by removing toxic parts or avoiding toxic species. In most cases, however, management requires monitoring to decide what seafood is toxic, when, and where. There are various options for



**Figure 21.1** A mussel farmer in Chile, holding a string of his product. Note the smile. He has reason to be proud. These are good food, and good business. Note the floats, all supporting strings of mussels. The mussels could become dangerously toxic in a few days, accumulating potent toxins from the plankton they consume. Fortunately, Chile has an excellent biotoxin monitoring program, protecting both his customers and his business. In the absence of such a program, the first indications of toxicity could be sick customers. Bad for the customers, bad for business. Cost-effective biotoxin management is one of the keys to profitability in bivalve fisheries.

monitoring. They differ in reliability and cost, but no program, no matter how expensive, can provide absolute assurance of safety. The situation is somewhat like buying insurance: you want to get the most protection for what you spend. The most cost-effective protection will likely be provided by an integrated program that uses observations of environmental and other indicators to guide and focus toxicity monitoring on the toxins, times, locations, and seafood species of greatest concern.

There are many different families of seafood toxins and different patterns of occurrence; most generalizations have exceptions. However, it's useful to discuss seafood toxins relevant to the seafood industry in three general classes according to their patterns of occurrence, since these categories largely determine the options available for protecting consumers:

- (1) Shellfish toxins and primary accumulation
- (2) Ciguatera and secondary accumulation
- (3) Pufferfish, intrinsic toxicity, and toxicity of uncertain origin

The discussion here will focus on the seafood toxins and patterns of occurrence that are currently understood to be most relevant to the seafood industry. There are many other toxins known and organisms known to be toxic (Halstead, 1988; Yasumoto, 1998).

It should be noted that these toxins are all perfectly natural.

### Some useful resources

Two useful references, both from 2004, are available from the FAO via the Web. The first is a review of marine biotoxins prepared by experts in the Netherlands:

- (1) <http://www.fao.org/docrep/007/y5486e/y5486e01.htm>  
The second is from a consultation sponsored by WHO and FAO, in part to provide guidance to the Codex Alimentarius.
- (2) [http://www.fao.org/ag/agn/agns/chemicals\\_biotoxins\\_en.asp](http://www.fao.org/ag/agn/agns/chemicals_biotoxins_en.asp)  
Two recent books (Botana 2007, 2008) are comprehensive references on marine biotoxins.

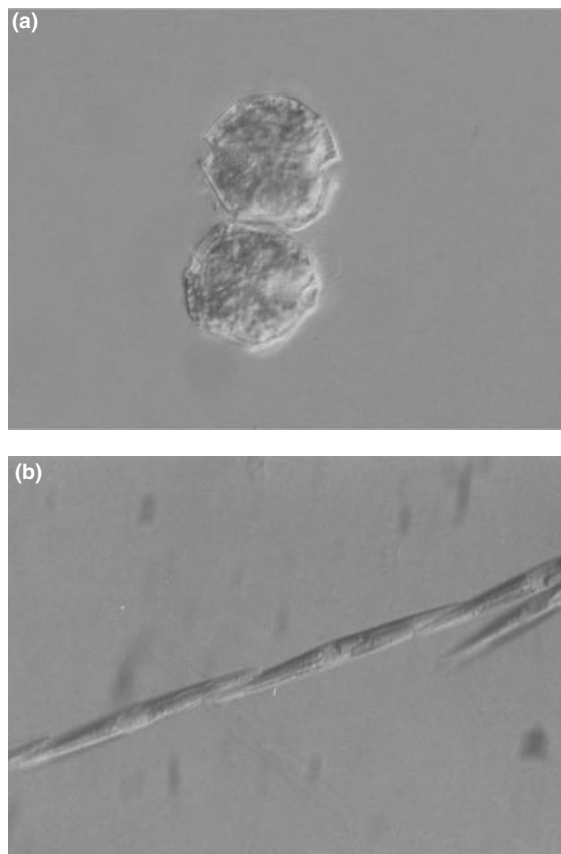
### Shellfish toxins and primary accumulation

Shellfish toxins are produced by plankton, most commonly dinoflagellates, that are consumed by bivalve mollusks, which then retain the toxins but are relatively unaffected by them. The toxins may be retained for periods ranging from a few days to more than a year, depending on the organism, toxin, and conditions. Since plankton populations can grow rapidly and are part of water masses that can move even more rapidly, toxicity can appear suddenly in a given area. Toxicity levels can rise from undetectable to lethal within a few days.

The shellfish toxins tend to occur as families of related compounds. The following is a brief introduction to the known toxin families.

#### Paralytic shellfish poisoning ; the saxitoxins

Paralytic shellfish poisoning (PSP) was one of the first seafood toxin syndromes identified. It has caused large mortalities: more than 100 deaths in an outbreak north of Sitka, Alaska, in 1799 and 26



**Figure 21.2** (a, b) *Alexandrium* spp. and *Pseudo-nitzschia* spp. are two genera of plankton that produce toxins that can be accumulated by shellfish and other kinds of seafood. The pumpkin-shaped cells of the motile dinoflagellate *Alexandrium* spp. contain saxitoxins, the compounds that cause paralytic shellfish poisoning (PSP). Victims of PSP tend to recover promptly, but may die of suffocation if they consume a dose large enough to cause respiratory paralysis and do not receive respiratory support. The long, tapered cells of the diatom *Pseudo-nitzschia* spp. may contain domoic acid, the cause of amnesic shellfish poisoning (ASP). Most victims of ASP experience only gastrointestinal distress. A few suffer permanent brain damage.

deaths in Guatemala in 1987 (Rodrigue et al., 1990). PSP is the first syndrome to be linked to a planktonic source, the dinoflagellate *Alexandrium catenella* (originally *Gonyaulax catenella*). Known sources of the saxitoxins now include several species of dinoflagellates from the genus *Alexandrium* (Figures 21.2a and 21.2b), and the two dinoflagellate species *Pyrodinium bahamense* and *Gymnodinium*



*catenatum*, as well as some species of freshwater blue-green algae. More than 20 saxitoxins are now known, all variations on the single parent structure, saxitoxin. The saxitoxins block transmission of impulses along nerves and muscles, causing numbness, other sensory symptoms, and paralysis. Death from suffocation can result if the respiratory muscles are paralyzed and the victim is not provided artificial respiration. Onset of symptoms is rapid, less than 2 hours. The saxitoxins wash out of the system quickly, so recovery tends to be rapid and complete, with no lasting effects (Gessner et al., 1997).

Toxin composition, which of the many saxitoxins is present, tends to be relatively constant within a given dinoflagellate population in a given location, but varies significantly from one location to another. Toxin composition that starts with that of the source organism undergoes significant change in accumulators due to spontaneous and metabolic transformations. Toxin composition in seafood therefore tends to vary and cannot be assumed. As an example, the populations of *Alexandrium* found in Southeast Alaska contain several of the saxitoxins, but no toxin (Hall et al., 1990). Butterclams in Southeast Alaska accumulate the saxitoxins from these dinoflagellates and therefore initially have a toxin composition resembling that of the source dinoflagellates. However, processes within the clam lead to changes in toxin composition such that the butterclams end up containing primarily saxitoxin. The saxitoxins are very water soluble, with only limited solubility in nonaqueous solvents, except for the recently found *p*-hydroxybenzoate derivatives. These are sufficiently lipophilic (fat soluble) that they may be lost in cleanup procedures that are adequate for the other saxitoxins. The saxitoxins differ in potency, the range of toxicity being more than 100-fold. The least toxic are saxitoxins bearing a sulfo substituent on the end of the carbamate side chain, which may be called sulfamate saxitoxins. The sulfamates often predominate in natural mixtures and are easily hydrolyzed to the corresponding carbamates, with increases in toxicity ranging from 5 to 70 times, or to the corresponding decarbamoyl saxitoxins. Shellfish containing the sulfamates can therefore undergo large increases in toxicity as a result of these transformations. In quantifying the toxicity of shellfish, one must therefore consider not only the observed toxicity at a given time, but also the potential toxicity that may result from such transformations.

### Neurotoxic shellfish poisoning; the brevetoxins

Brevetoxins (Baden, 1989), the primary toxins along the Gulf of Mexico coast, from Florida to Mexico (McFarren et al., 1965), are accumulated from blooms of unarmored planktonic dinoflagellate *Karenia brevis* (previously called *Gymnodinium breve* and *Ptychodiscus brevis*). The cells of *K. brevis* are easily ruptured because they lack the protective covering found on *Alexandrium*, *Pyrodinium*, and many other dinoflagellates. *K. brevis* blooms often cause massive fish kills and airborne particulates that cause respiratory irritation, both of which serve to announce the presence of a bloom. In contrast to the saxitoxins, the brevetoxins are very lipophilic; much more soluble in organic solvents than in water. The brevetoxins can be metabolized after accumulation by shellfish. The brevetoxins cause peripheral neurological symptoms and can in extreme cases cause a blockage of impulses but, more commonly, cause annoying sensory disruption. No consumer deaths have been attributed to the brevetoxins but, in one outbreak in Florida, two children were severely affected and might have died without emergency care (Poli et al., 2000). The largest known outbreak of neurotoxic shellfish poisoning (NSP) occurred in New Zealand in 1992–1993, with more than 100 cases reported, none severe.

### Diarrhetic shellfish poisoning; okadaic acid and derivatives

Okadaic acid and its derivatives, produced by various species of *Dinophysis* and *Prorocentrum*, cause acute diarrhea in consumers (Yasumoto et al., 1978; Yasumoto and Michishita, 1985). The diarrhetic shellfish poisoning (DSP) toxins have been detected at low levels in some locations along coasts of the United States, but significant levels of DSP in shellfish and recognized outbreaks of DSP have so far occurred primarily in Europe, Asia, and South America. The DSP toxins are mostly lipophilic, although some derivatives are sufficiently polar to be lost in analytical cleanup procedures. Some derivatives of okadaic acid are acyl esters that have very low intrinsic toxicity, but can be hydrolyzed to more active forms in a manner analogous to some of the saxitoxins. Thus, the toxicity of natural DSP mixtures may require hydrolysis of the acyl esters before it can be fully assessed (Rodrigues and Vale, 2009).

### Azaspiracid poisoning

Azaspiracid and its derivatives were first recognized as the toxins responsible for an outbreak of diarrhea and other gastrointestinal symptoms among consumers in the Netherlands after dining on mussels from Ireland. Like the DSP toxins, the azaspiracids are primarily lipophilic, but they differ in both structure and mechanism (Satake et al., 1998). The proximate source may be heterotrophic dinoflagellates of the genus *Protoperidinium* (James et al., 2003), although *Protoperidinium* may only be a vector for toxins produced by its microbial prey. Azaspiracids have primarily been reported from the coasts of Western Europe and northwest Africa.

### Amnesic shellfish poisoning; domoic acid

Domoic acid is produced by diatoms of the genus *Pseudonitzschia*, particularly when the diatoms are under nutrient stress (Figure 21.2). Domoic acid is anomalous among seafood toxins in several respects. It is produced by diatoms rather than dinoflagellates. It has a strong UV chromophore, so detection in HPLC is very simple; most other seafood toxins lack any chromophore useful for detection. While structural modifications of domoic acid occur, only domoic acid itself appears to have significant toxicity, so toxin detection methods can focus on a single compound (Wright et al., 1990). In consumers, domoic acid may cause only gastrointestinal symptoms but, if it enters the bloodstream, it can cross the blood-brain barrier and cause permanent damage to the brain, particularly in the regions responsible for short-term memory. This is particularly likely in victims with impaired excretory function. In contrast, survivors of exposure to other seafood toxins tend not to suffer permanent damage.

Filter feeders other than bivalve mollusks can also be vectors of toxins from plankton. Planktivorous fish such as anchovies can accumulate large body loads of domoic acid (more than 200 mg/kg gross weight) by filtering diatoms from blooms of *Pseudonitzschia* spp. It is not clear whether or not the fish actually accumulated domoic acid into their tissues. The toxin may initially be entirely within the diatoms in the stomach contents, but diffuse into the product if the fish are not cleaned promptly after capture, before freezing.

Toxins that can be accumulated from plankton but are of uncertain risk to consumers

In the past years, the primary tool for investigation and regulation of marine toxins, in the absence of a better option, has been the mouse bioassay in which an extract is injected intraperitoneally (IP) into mice. This has proven marginally effective for detecting NSP and DSP toxins, and has also detected several toxins that, while they are toxic to mice when injected IP, do not appear to cause illness in consumers. These include the yessotoxins, pectenotoxins, and several families of cyclic imine toxins. Regulatory policy in Europe has recently been revised to recognize that such toxins can cause positive mouse assay results but not constitute a threat to consumers. The best solution to the problem will be the replacement of the mouse bioassay by Liquid Chromatography/Mass Spec (LC/MS) analyses for regulatory purposes.

### Ciguatera and secondary accumulation

Ciguatera toxins (or their precursors) are accumulated from dinoflagellates that are benthic, tending to spend their time on surfaces, like seaweed and coral, rather than swimming free in the water. These are consumed by grazers that eat seaweed or scour surfaces, which are in turn consumed by carnivorous fish. The toxins are lipophilic and tend to be concentrated and modified as they move up the food chain. The greatest risk of ciguatera is in larger, older individuals of tropical fish species that are higher carnivores, like barracuda. The ciguatoxins are very similar to the brevetoxins in structure (Murata et al., 1989, 1990; Vernoux and Lewis, 1997) and effect, but have much greater potency. While the effects of the brevetoxins tend to resolve after a couple of days, the effects of ciguatoxins in consumers may last for weeks and reoccur over months (Withers, 1982). In contrast to NSP, there have been deaths from severe cases of ciguatera (Friedman et al., 2008). The ciguatoxins appear to account for most of what is referred to as ciguatera poisoning. This does not exclude the possibility that other lipophilic toxins are involved, to some extent, in some cases.

Just as ciguatera is accumulated in higher carnivores from their prey, other toxins can be

accumulated by carnivores from their diet. Significant levels of PSP toxins have been found in the viscera (though not the meat) of lobsters in New England and crabs in Alaska. The livers of mackerel along the Atlantic Coast of the United States have low but detectable levels of PSP toxins. Whelks and other carnivorous snails that prey on bivalves can accumulate significant levels of PSP toxins if the bivalves are toxic. Domoic acid has been detected at significant levels in the viscera of lobsters in New England and of crabs along the Pacific coast of the United States.

### Palytoxins and *Ostreopsis* toxins

Notorious as one of the most toxic substances known when administered IV or IP, palytoxin is far less toxic orally (Munday, 2011). Nevertheless, palytoxin and related compounds have sufficient oral toxicity to have caused deaths from consumption of crabs (Yasumoto et al., 1986; Alcalá et al., 1988), fish (Melton et al., 1984; Kodama et al., 1989), and other seafood contaminated with the toxins. "Clupeotoxin," associated with small, planktivorous fish in some tropical regions, appears to be palytoxin and related compounds. Known sources of palytoxin and related compounds include soft corals (zoanthids, including various *Palythoa* spp.) and dinoflagellates of the genus *Ostreopsis*.

### Pufferfish, intrinsic toxicity, and toxicity of uncertain origin

#### Tetrodotoxins

The tetrodotoxins are the toxins of the notorious pufferfish or fugu. They are very similar in their action to the saxitoxins (Catterall, 1985), causing temporary sensory disfunction and, in extreme cases, paralysis. Like the saxitoxins, they are polar, not lipophilic. Although, originally known from pufferfish, they are found in a broad range of animals (Yasumoto and Yotsu-Yamashita, 1996). The tetrodotoxins in pufferfish differ from shellfish toxins in that pufferfish of species that tend to be toxic tend to be and remain toxic. While there are variations, there are strong correlations between taxonomy and toxicity. The toxicity of a population of pufferfish will therefore be relatively con-

stant, compared to the rapid changes in toxicity generally seen with shellfish toxins that are accumulated from plankton. Species of pufferfish that tend not to be toxic can, however, accumulate toxins. Southern puffers from bays along the Atlantic coast of Florida have been traditionally fished and consumed without incident until they caused a series of illnesses (19 reported) in 2002. Instead of tetrodotoxins, the traditional pufferfish toxins, the toxins proved to be saxitoxins, apparently accumulated from small bivalves which, in turn, accumulated saxitoxins from blooms of the dinoflagellate *Pyrodinium bahamense*. One of the reasons for the illnesses was the distribution of the saxitoxins in the puffers. While tetrodotoxins are found primarily in the skin and viscera, so that the fish can be rendered safe for consumption by careful cleaning, the saxitoxins were found at significant levels in the flesh, so that cleaning did not eliminate toxicity (Landsberg et al., 2006).

#### Tetramine

"Tetramine" is the common name for tetramethylamine, naturally produced in the salivary glands of some marine snails and responsible for occasional mild illness in consumers. Kim et al. (2009) reported on a recent outbreak involving unpleasant but not life-threatening symptoms in which the estimated dose was around 10 mg per person. Tetramine, referring to the natural toxin from snails, should not be confused with the potent synthetic rodenticide tetramethylene disulfotetramine, also called tetramine, which has been responsible for many human deaths, through accident or malice. Tetramine snail poisoning can be avoided by removing the salivary glands of snails before cooking.

#### Toxicity of uncertain origin

Abalone from Spain and South Africa have been reported to contain saxitoxins at levels high enough to preclude harvest. The origin of these toxins is not yet known. Abalone are neither filter feeders nor carnivores, so it is unclear where they can be getting the toxins. Xanthid crabs, found in the tropics and sometimes consumed, can contain high levels of saxitoxins and tetrodotoxins and have caused mortalities.

## Distribution

Since most practical options for the management of seafood toxins are based on avoiding the harvest of toxic seafood, it is helpful to consider the typical patterns in which toxicity may occur:

- (1) *Variation with time:* Toxins accumulated directly from plankton are more likely to increase in concentration during the periods when plankton bloom. However, while the frequency of toxicity increase is far higher in the seasons with more sunlight, this is no guarantee that toxic plankton or toxicity will not occur at other times. Plankton populations tend to be ephemeral—here today, gone tomorrow. Plankton move with the water masses, so they can sweep into or out of an area. Toxicity can therefore increase rapidly.
- (2) *Variation with location:* Phytoplankton blooms tend to be patchy and are often vertically stratified, often with maxima below the surface. Patchy blooms imply that shellfish in one area may have significantly more or less toxin than those in another area close by. Vertical stratification implies that shellfish at one depth may have significantly more or less toxin than those at another depth, up or down a bed, or along a rope in suspended culture. In Funka Bay, Japan, it was found that shellfish in suspended culture had very little PSP near the surface or at the bottom of a line, but were highly toxic at a depth of about 10 m due to a stratum of *Alexandrium* at that depth.
- (3) *Variation among individuals:* Individual shellfish or fish will vary in the amount of toxin they contain. In the case of small animals, like mussels, for which a serving will consist of a large number of individuals, the mean toxicity of the population provides a useful estimate of consumer exposure. As the animal gets larger, the number per serving decreases, the individual variation becomes more significant, and the range of toxicity more useful than the population mean for estimating consumer risk. In the extreme case of geoducks, a serving may only be part of a clam, resulting in very weak statistics and a challenge to estimate consumer exposure. In the case of large clams prepared in industrial batches, minced and mixed, individual variations are much less of a concern as long as the population mean is determined using an appropriately large sample.
- (4) *Variation within individuals:* Generally, the viscera of shellfish or fish are the most likely to contain the highest concentrations of toxins and, in some cases, the only significant levels of toxins. In most crabs, lobsters, and geoducks, toxin levels in the body meat are negligible. In most scallops, toxicity in the adductor muscles is low or undetectable. Butterclams retain saxitoxin in their siphons for longer than they retain saxitoxins in the rest of their tissue. Freshly caught anchovies, before freezing, can contain domoic acid in their digestive tracts but little or none elsewhere.

Since plankton move with the water mass they are in, currents may determine the distribution of toxicity in shellfish resulting from a toxic bloom. This may help management, allowing the detection of toxicity in one location to predict its likely occurrence in another. In New England, close cooperation among the states often allows one state to anticipate toxicity detected first in a neighboring state.

Ciguatera, coming from benthic dinoflagellates rather than from those that move with a water mass, can be associated with particular locations to the extent that the fish that accumulate the toxins stay put. Unfortunately, fish do swim. However, it is still possible to identify locations and associated fish populations that have a relatively high or low incidence of ciguatera over time.

## Concepts and strategies for managing seafood toxins

The core goal is to protect consumers and industry from the risk of seafood toxins. Ideally, it would be possible to do something to simply eliminate the toxins. In general, this is not practical. The few exceptions will be discussed later. Lacking the option of eliminating toxicity, and because most seafood is safe most of the time, the remaining option is to identify the toxic product and prevent its harvest or consumption. Since there are no outward signs of toxicity, this requires monitoring, taking samples, and checking them for toxicity. This can be done either at the origin, where the seafood is grown or downstream at dockside or further along in market channels. In general, it is more efficient to monitor the growing area and not harvest product



if it is toxic, since the toxicity will usually dissipate in a short time. If a product is harvested and then found to be toxic, it generally cannot be returned to the growing area and has to be disposed of.

The ability to trace seafood back to its source, or to the point at which it was tested, is essential for biotoxin management. This is a foundation of the National Shellfish Sanitation Program in the United States and in countries with memoranda of understanding with the United States. The establishment of effective traceability for fish that can accumulate ciguatera toxins will greatly aid in the management of ciguatera.

Any biotoxin management program costs money or other resources. Both industry and government need to balance the costs of biotoxin management with the demands of other priorities. No practical management program can offer absolute assurance of safety. The need is to find biotoxin management strategies that offer the most assurance of safety for the money and other resources they consume.

The decisions are easier regarding risks that are frequent or continual. PSP occurs regularly in Maine; there is an obvious need in Maine for a strong, sustained PSP monitoring program to ensure prosperity by protecting consumers and industry. The decisions are more difficult for risks that are less persistent, and most difficult for risks known to be possible but not yet encountered.

A biotoxin program can rely on toxicity monitoring alone, and many do, but such programs are relatively expensive for the protection provided. There is no warning until toxicity is detected, so the response time available is limited by the margin between the detection limit and the regulatory limit, coupled with the rate of increase of toxicity. This often leaves a producer very little time to respond or, worse and very expensive, needing to recall product. It is impractical to monitor for all known toxins all the time, so toxicity monitoring is generally based on historical trends, which toxins are "reasonably likely to occur," where and in what season. But historical trends have proven to be treacherous, with toxicity showing up at times and in places for which there is no precedent. It is furthermore very challenging to monitor for toxins that have not been discovered yet.

Keeping in mind that no program can be perfect, cost-effectiveness of a program and the odds of avoiding the consumer bioassay are greatly improved by integrating monitoring of other

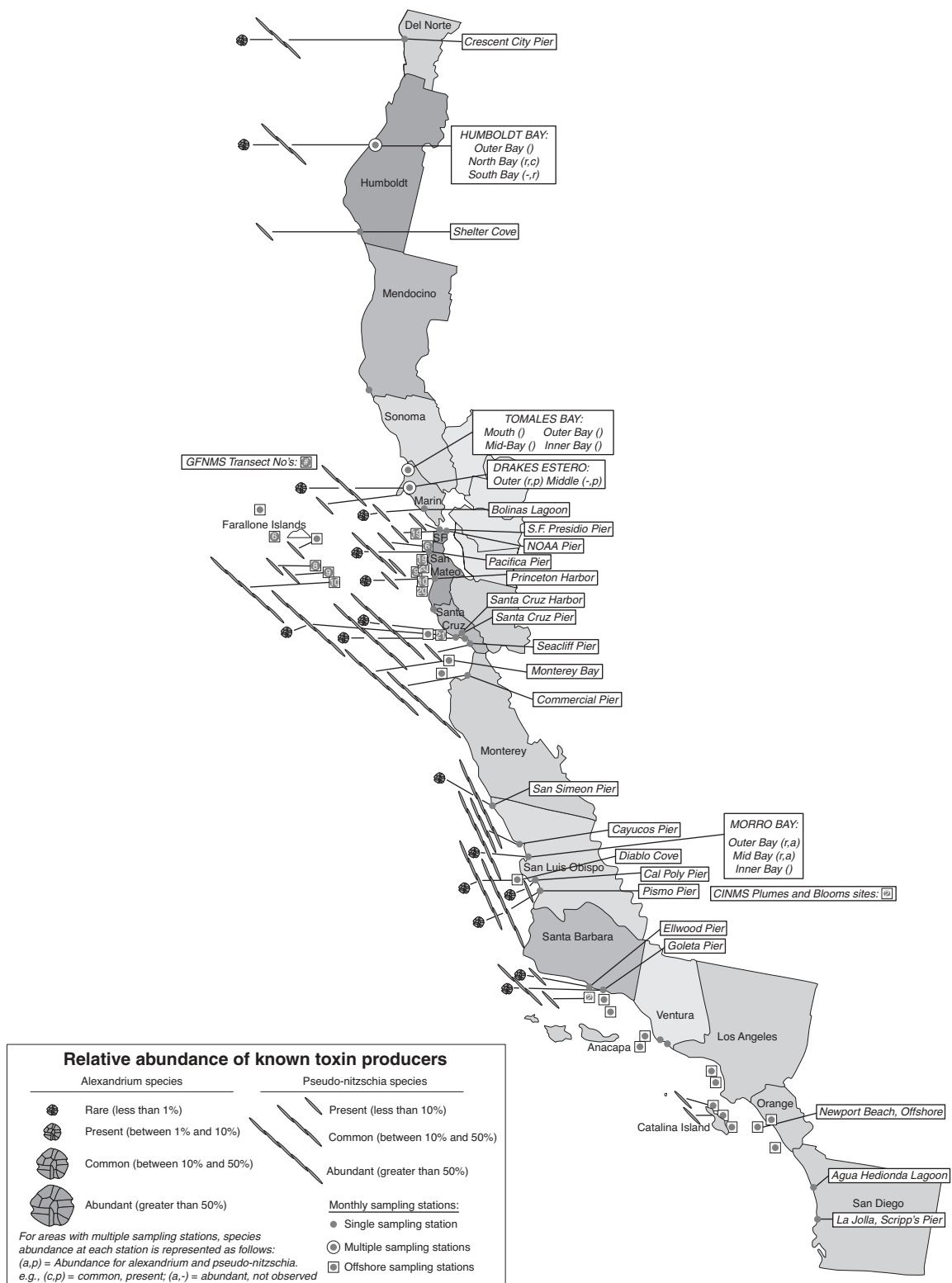


**Figure 21.3** Shellfish growers in the Gulf of California use a field microscope to check the plankton in the waters around their shellfish beds. This allows them to both check for toxic species and to assess the general quality of the food available for their crop. Frequent observations on site like this can provide an early warning of shellfish toxicity which in turn can guide and focus testing for the toxins themselves on the times and locations of greatest concern. This improves the reliability of the monitoring program while reducing its overall cost, since toxicity testing is relatively expensive and field plankton observations can be conducted at a much greater temporal and spatial frequency.

parameters to guide and focus toxicity monitoring. Plankton monitoring, particularly when conducted by volunteer observers at high temporal and spatial frequency (Figures 21.3 and 21.4), can be very useful. Observations of animal behavior can provide useful signals. Along the California coast in 1991, deaths and odd behaviors among pelicans were the first indication that seafood was contaminated with domoic acid. In New Zealand, in 1992, a report of paralysis in two domestic cats that had been fed clams alerted the government to an unprecedented outbreak of seafood toxicity. This concept can be referred to as Signal Environmental and Plankton Observations in Real Time (SEAPORT). The final "RT" is very important. The information is useful only if it is communicated to managers rapidly enough that they can make decisions, check for toxicity, and issue warnings. As evident from the two cases cited, one benefit of SEAPORT is that it can provide warning of toxicity that does not have historical precedent.

Regarding plankton monitoring, it is important to recognize that increases in toxicity follow the arrival





**Figure 21.4** Along the California coast, volunteers conduct plankton observations to assist the state biotoxin monitoring program, improving both density and coverage over that which could otherwise be afforded. Results are communicated promptly to the central program, where they help focus toxicity testing. Monthly reports like this summarize the results to keep the observer network and others informed. The icons correspond to the photomicrographs in Figures 21.2a and 21.2b. (Graphics by Gregg Langlois, California Department of Public Health.)

of toxic plankton, so plankton observations can provide lead time to initiate a response. On the other hand, shellfish remain toxic after the toxic plankton have departed, often for a long time, so the absence of toxic plankton does not mean that the shellfish are not toxic. Biotoxin management works best when the monitoring is conducted at high resolution, narrowly defining the areas where shellfish are toxic, when they are toxic, and permitting the continued harvest of safe shellfish when and where possible. Monitoring for PSP in New England, most notably in Maine, manages to keep bivalve resource available that would have to be closed to harvest if the programs did not so efficiently define the areas and shellfish that are safe or toxic.

### Sampling, sample preparation, and the significance of a sample

The seafood toxins may be challenging to detect, but the time, effort, and expense of sample preparation are significant relative to the actual detection of toxin in the prepared extract. Also, the detection of toxins in a sample is relatively easy compared to the challenge of sampling in a way that allows reliable prediction of the amount to which a consumer might be exposed. It is useful to emphasize this point: the determination of toxicity in a sample has little meaning in itself. It is meaningful only to the extent that it allows prediction of the toxicity to which consumers might be exposed. While the toxicity of a sample lies within the range of toxicity for the population from which it is drawn and at the time the sample is taken, that range can be very large. Given the rapidity with which toxicity can increase and the variability with location and among individuals, it is very challenging to sample in enough locations and at enough times to provide a reliable estimate of consumer risk. The variation with time is a particular challenge. Toxicity may increase rapidly, and the rate of increase can be large compared to the time from sampling to analysis, or from harvesting to consumption. If shellfish are harvested after a management decision is made, then the critical comparison is between the time from sampling to decision and the possible increase in toxicity from sampling to harvest. If harvest and sampling are done at the same time, then the critical comparison is between the time from sampling to decision and the time from harvest to table.

While it is essential to ensure conformity to regulatory standards, consumers are more at risk from extremely high values that may occur suddenly but at low frequency, than from small increases over regulatory limits. Again, protection from the more serious risk comes from a high frequency of samples more than from high accuracy in a small number of samples.

In considering the safety of imported products, it should be remembered that the kinds of toxins present may be quite different from those normally encountered, and monitored for, in domestic products.

### Detection methods for toxicity monitoring

It is useful to distinguish between two fundamentally different kinds of detection methods for marine toxins (Hall and Reichardt, 1984). For the purpose of this discussion, these can be called assays and analyses. In an analysis, the toxins are separated and individually quantified. The toxicity of the sample is the sum of the toxicities of the individual toxins. There's some question whether or not this is strictly true, but it's a useful estimate. Contemporary analyses are generally done using HPLC, which in turn requires that the samples be carefully filtered. The time, effort, and material required for the filtration is one of the major costs of conducting analyses. Analyses generally require a reference standard for each of the toxins analyzed, and tend to require relatively complex and expensive equipment, not well adapted to field use and requiring a suitably trained operator. However, a system can usually be set up to run unattended with an autosampler, so analyses can be conducted with a relatively high throughput per day. Detection of seafood toxins using such systems is problematic, except for domoic acid. Basic HPLC systems use an absorbance detector (usually, UV) and, among the various toxins, only domoic acid has a useful absorbance. For the other toxins, it is necessary to either modify the toxin (before or after analysis) or use a mass spectrometer (MS) for detection. Modifying the toxins adds time, effort, and room for error. LC/MS is now the approach of choice for many of the toxins, with the power and versatility of the technique making up for cost and complexity.

In contrast to an analysis, an assay gives a single value for the overall toxicity of the sample. Assays

require little if any filtration and only a single standard. They tend to be much simpler and require little or no equipment, often being adaptable to field use. However, to provide a reliable estimate of net toxicity, an assay must have the same ratio of assay response to toxicity for each of the toxins to which it responds. To the extent that it does, an assay can be said to have a level response spectrum. To the extent that an assay does not have a level response spectrum, the ratio between the overall response of the assay to the net toxicity of the sample will vary with toxin composition. Since toxin composition (the relative amount of the various members of a toxin family, like the saxitoxins) tends to vary significantly, this is an important constraint on assay performance. In the worst case, if an assay fails to respond to some of the toxins and those toxins predominate in the sample, the assay can dangerously underestimate the toxicity of a sample.

## Assays

### *Assays using natural receptors*

(1) *Mouse bioassay*: The mouse bioassay for PSP was the first assay employed for regulatory monitoring and is still in use (AOAC Official Method 959.08, AOAC 2010). It involves IP injection of an aqueous extract of shellfish or other product. A median death time of 4 minutes and 50 seconds for 20 g mice with a standard extract (2 mL suspension per gram of tissue) indicates toxicity at the regulatory limit, 80 mg saxitoxin dihydrochloride equivalent toxicity per 100 g tissue. For most accurate results, extracts are diluted to give a median 6-minute death time. Longer death times with characteristic signs show that PSP-like toxins are present, but at levels below the regulatory limit and not a threat to consumer health. The same assay can be used effectively for tetrodotoxin. In both cases, there is a large safety margin between the detection limit of the assay and levels safe for consumption. While it will be very desirable to replace the mouse bioassay and there are alternatives available that are far more sensitive, far more precise, and that offer much higher throughput, there is no assay known or contemplated that can more rapidly and reliably identify dangerous levels of PSP in a sample.

Mouse bioassay is used to detect other biotoxins including NSP, ciguatera, and DSP. In all three cases, the detection limit is marginal for protection of consumers and the response time longer, hours instead of minutes. Domoic acid can be detected by mouse assay, but only at levels well above the safe limit for consumers.

(2) *Receptor binding assay*: The saxitoxins and tetrodotoxins bind to a specific receptor site on the voltage-activated sodium channel, which is found on most nerve and muscle membranes in mammals. Homogenizing mammalian brain, from anything from mouse to cow, provides a suspension rich in such channels. If a portion of such a suspension is mixed with radiolabeled saxitoxin and filtered, some of the toxin (and therefore radioactivity) will remain bound to the membrane, on the filter. If, instead of just radiolabeled saxitoxin, the brain membrane suspension is combined with a mixture of radiolabeled saxitoxin and a shellfish extract that may contain saxitoxins, the radiolabeled saxitoxin will be diluted by the natural, unlabeled saxitoxins and the amount of radioactivity bound will be reduced by an amount that corresponds to the concentration of saxitoxins in the shellfish extract (Davio and Fontelo, 1984). The *receptor binding assay* (RBA) for the saxitoxins has been shown to have a level response spectrum compared to the mouse bioassay (Hall et al., 1990), and to be at least 100 times more sensitive than the mouse bioassay. The RBA can use either radiolabeled saxitoxin or radiolabeled tetrodotoxin and can detect either saxitoxins or tetrodotoxins, but cannot in itself distinguish between saxitoxins and tetrodotoxins. This is not a significant limitation.

Similarly, brevetoxins and ciguatoxins bind to a different site on the same channel. Radiolabeled brevetoxin and the same homogenized brain suspension can be used to assay for either NSP (brevetoxins) or ciguatera toxins.

The sole drawback of the RBA is the need to use radiolabeled materials, but the levels are very low and the isotope used is tritium, which has very low energy.

Van Dolah et al. (1994) have adapted the RBA to a high throughput format (Figure 21.5) which makes the RBA very efficient, well suited for handling



**Figure 21.5** The receptor binding assay, developed initially for paralytic shellfish poisoning, is very sensitive and can be run in a high throughput format that makes it very efficient. With appropriate reagents, the same equipment can be used to assay for some of the other seafood toxins. Samples and reagents are distributed into 96-well plates, incubated, filtered, and rinsed. Scintillant is added. The plates are then put into a multiwell plate counter. (Photos courtesy of Dr. Fran Van Dolah, NOAA, Charleston, SC.)

a large number of samples in a toxin monitoring laboratory. The same equipment and materials can be used to assay for PSP, NSP, ciguatera, and tetrodotoxins just by changing the radiolabeled toxin.

- (3) *Cytotoxicity assay*: Cultured nerve cells treated with the appropriate reagents can be used to assay for saxitoxins, tetrodotoxins, brevetoxins, and ciguatoxins in various different formats (Jellett et al., 1992; Manger et al., 1993, 1995; Dickey et al., 1999; Louzao et al., 2001, 2004). Conducting the assays requires the ability to culture cells, but the assay is otherwise relatively simple and applicable to monitoring assays in a lab setting. Since the assays are based

on the response of the voltage activated sodium channel, they likely also have level response spectra.

- (4) *DSP protein phosphatase inhibition assay*: Okadaic acid and related DSP toxins act by interfering with protein phosphatase enzymes, which normally hydrolyze phosphate groups from proteins. Assays for okadaic acid and related DSP toxins can be set up using a preparation of protein phosphatase and a synthetic substrate that changes either color (Simon and Vernoux, 1994; Tubaro et al., 1996a, 1996b) or fluorescence (Vieytes et al., 1997) when acted on by the enzyme. Attenuation of the change by a sample extract provides a measure of the phosphatase inhibition and thus the DSP content.
- (5) *Assays using synthetic receptors (immunoassays)*: The seafood toxins tend not to be antigenic but, by linking them to carrier proteins, it is possible to produce antibodies that, to some useful extent, recognize the various seafood toxins. These can be used in assays that, in some cases, can be used on site with minimal equipment by people with minimal training. Immunoassays currently available commercially include those for PSP (Jellett Rapid Testing, Ltd. and the r-biopharm Ridascreen); for okadaic acid, a principal DSP toxin (Erfa Bio-Tech, Montreal, and Biosense, Bergen); and for domoic acid (from Mercury Science, Biosense Laboratories, and Jellett Rapid Testing, Ltd.). Jellett Rapid Testing emphasizes fully portable field test kits. The principal limitation of the available immunoassays, particularly for PSP, is that their response spectrum may not be level: The available PSP immunoassays have very low response to some of the significant saxitoxins. This is relatively inconsequential in the case of domoic acid immunoassays, which need to detect only a single compound.

## Analyses

Most contemporary analyses are based on HPLC. Unfortunately, detection tends to be challenging since, with the exception of domoic acid, most seafood toxins do not absorb visible or UV light, except at very short wavelengths. HPLC for domoic acid is relatively simple, thanks to a UV chromophore due to a conjugated pair of double bonds on its side chain. HPLC of okadaic acid and related

DSP toxins is practical after derivitization to make the toxins fluorescent (Lee et al., 1987).

The saxitoxins can be oxidized to yield fluorescent derivatives. The first effective HPLC analysis for the saxitoxins was developed by Sullivan, employing gradient ion-pair chromatography, postcolumn oxidation of the saxitoxins, and fluorescent detection (Sullivan and Iwaoka, 1983). Several later methods, including those developed by Oshima (1995) and Van de Riet et al. (2009) used a similar approach to postcolumn oxidation with variations in chromatographic conditions. Alternatively, the saxitoxins can be oxidized to fluorescent products prior to HPLC (Lawrence et al., 2005). HPLC of the tetrodotoxins is also possible using postcolumn degradation to fluorescent products (Yasumoto and Michishita, 1985).

A MS can be used as the detector for an HPLC system. Quilliam et al. (1989) were the first to employ such LC/MS systems for the analysis of marine biotoxins, McNabb et al. (2005) at the Cawthron Institute in New Zealand, were the first to work toward their application for routine regulatory use. LC/MS systems have now become less expensive, more reliable, and simpler to operate to the point that LC/MS is the best approach for routine analyses for many of the seafood toxins, particularly the lipophilic toxins (DSP, azaspiracid, NSP, etc.) for which there are no good alternatives. While such systems remain expensive (more than US\$100,000), several factors make them cost effective. They offer nearly universal detection, and are thus applicable to a broad range of analyses, including marine toxins and other kinds of food and environmental contaminants. With an autosampler, they can be set up for continuous operation, providing high throughput so that the cost per sample is relatively low.

## Elimination

Ideally, it would be possible to take positive steps to eliminate toxicity. Unfortunately, in most cases, it's not. But there are a few exceptions.

In a few cases the distribution of toxicity within an animal makes it possible to manage toxicity risk by eliminating the potentially toxic body parts. In sea scallops, the adductor muscle contains little or no toxin even when other parts are very toxic. Shucking of the scallops at sea and bring-

ing only the adductor muscles ashore controls the risk. PSP in geoducks, when it is found, tends to be concentrated in the visceral ball. When monitoring reveals toxicity, some product can still be harvested if butchered to remove the visceral ball. Dungeness and other crabs in the Pacific Northwest have at times been found to contain PSP or domoic acid in their viscera, but no significant levels of toxicity in their meat. Butchering and removal of the viscera controls the toxicity risk. Unfortunately, live geoducks and crabs can be sold at a premium, so managing toxicity in this way implies a significant loss of value.

As noted earlier, many species and populations of pufferfish are intrinsically toxic. Some are highly valued, particularly in Asian cuisine. The meat generally has little or no toxicity and so, if the fillets are properly cleaned, can be safely consumed. However, as also noted earlier, one population of Southern Puffers, from inlets along the Atlantic coast of Florida, normally nontoxic and fished for years without incident, accumulated dangerous levels of saxitoxins and caused several illnesses. Unlike the tetrodotoxin in puffers that are intrinsically toxic, the saxitoxins in these puffers were present at high concentrations in well-cleaned fillets (Landsberg et al., 2006).

While seafood toxins cannot be eliminated from seafood by heat processing in the same way that pathogens can be eliminated, heat processing can in some cases reduce toxicity to a limited extent. Studies at the former Bureau of Commercial Fisheries laboratory in Ketchikan, Alaska, demonstrated that PSP in butterclams could be reduced by trimming off the siphons (which often contain a substantial portion of PSP), draining after an initial cook, and then retorting the canned product (Waskiewicz et al., 1951). Similarly, Burdaspal et al. (1998) were able to significantly reduce PSP levels in thermally processed bivalves. However, in contrast to thermal processing to eliminate microbial hazards, such processes cannot be relied upon to make toxic shellfish safe. Instead, the levels of toxicity in the feedstock and the product have to be carefully monitored.

## History

It is instructive to review some history. Entirely new seafood toxins continue to appear. Late in



1987, mussels from Prince Edward Island in eastern Canada caused 3 deaths and more than 100 illnesses. The toxin was found to be domoic acid, a compound known from seaweed and thought safe enough that it was once tested as a drug in human subjects. It had not previously been known to be a potent neurotoxin, or that it could be produced by plankton and accumulated by shellfish. In 1995, despite monitoring programs for PSP and DSP, shellfish from Ireland were contaminated with azaspiracid, a previously unknown toxin, causing illness among consumers in Europe.

Known toxins continue to appear in places where they were not previously recognized. In Guatemala, in 1987, 26 people died from PSP; there was no prior history of PSP in Guatemala. In New Zealand, in 1992, more than 100 people fell ill from seafood toxins. The symptoms were mostly those of NSP. New Zealand at the time had no known history of illness from seafood toxins and had for years resisted suggestions that, having a large and profitable shellfish industry, it should implement a biotoxin monitoring program. Even with all the illnesses the outbreak went unrecognized until the owner of two cats took his pets to the vet because of hind limb paralysis. The owner had fed the cats clams from a local beach and the vet recognized the signs of shellfish toxicity. Following the domoic acid outbreak in Canada, the United States had conducted extensive surveys for domoic acid in US seafood, finding nothing of consequence. In 1991, mortalities and erratic behavior among seabirds near Santa Cruz were found to be due to very high levels of domoic acid in anchovies. Subsequent investigation revealed widespread domoic acid contamination in seafood along the coasts of California, Oregon, and Washington.

Despite such events, effective biotoxin management has time and again restored market confidence and industry profitability. After the 1987, Prince Edward Island domoic acid outbreak, despite the toll of illness, death, and permanent brain damage, Canada restored consumer confidence in shellfish from the region with a very efficient biotoxin management program. New Zealand, after the 1992–1993 outbreak, sustained the confidence of its trading partners by candid explanation of the situation and went on to implement an exemplary biotoxin management program.

## Summary

Effective management of seafood risks can sustain customer confidence and therefore ensure a profitable market for seafood products.

The risk of allergens in the workplace is best dealt with by minimizing exposure, through ventilation and other environmental controls, and by personal protective equipment. The sole control for the risk of allergens to consumers is to be sure that consumers are accurately informed of what is in a product.

The risk of scombroid toxicity is best managed by temperature control, chilling fish immediately after death, and then either freezing the product or keeping it cold and getting it to the consumer quickly.

Strategies for managing the risk of seafood toxins vary depending on the circumstances but most involve identifying and avoiding the consumption of toxic product. The challenge is doing this in a way that is reliable and affordable. In most cases, the best option is to employ widespread monitoring of environmental indicators to guide and focus toxicity monitoring on the toxins, times, and locations of greatest concern.

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# 22

## Cleaning and Sanitation

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Clean and sanitary conditions in a seafood operation are required under the US Hazard Analysis Critical Control Point (HACCP) Regulation for Fish and Fishery Products (Title 21 Code of Federal Regulations Part 123 (21CFR123)) under Section 123.11 Sanitation control procedures, commonly referred to as Sanitation Standard Operating Procedures (SSOPs). Among the factors that must be monitored under the regulation is the cleanliness of all food-contact surfaces, all packaging materials, employee hygiene, and overall environment of a seafood-processing operation. It is critical that these requirements be understood thoroughly in order to support an effective HACCP plan. This chapter will provide an in-depth understanding of what factors are involved in cleaning and sanitizing a seafood operation.

Before we can discuss how to clean and sanitize a seafood operation adequately, we must understand why this is so important. Simply stated, “cleaning” is the process of removing soil and the accumulation of food residues; and “sanitation” (or more accurately “sanitization”) refers to a final disinfection step where any microorganisms remaining on a surface are destroyed. In some instances, the word “sanitation” also refers to maintaining a

food-processing operation under hygienic conditions that will prevent contamination of the food, equipment and packaging materials.

In addition to meeting regulatory requirements and minimizing the presence of microorganisms, nutrients for any remaining microorganisms are removed, thus improving quality and shelf life of products. Elimination of chemical films or scale and especially biofilms on equipment is also vital to assure complete removal of soils and microorganisms. In addition, an adequate cleaning and sanitation program will help prevent contamination of future food preparations, which is essential in controlling allergens; it will maintain the proper functioning of equipment, minimize pest attractants, improve employee outlook on their operation, and will serve to improve food-safety conditions overall. So, an adequate cleaning and sanitation program will do more than just keeping equipment clean.

An understanding in basic microbiology and knowing the types of target microorganisms in any given operation is critical in deciding how to clean, what cleaning and sanitizing agents to use, and the frequency of cleaning. The Seafood Network Information Center Web site and the Food



and Drug Administration (FDA) Hazards Guide provide helpful information on the characteristics of the different types of microorganisms that are “of concern” for different types of seafood operations. Becoming familiar with their growth needs and how they are destroyed is one of the keys in designing an effective sanitation program.

Typically, there are up to six steps involved in cleaning and sanitizing: (1) removal of excess soil with a prerinse step; (2) application of cleaning solution; (3) rinse to remove cleaning solution; (4) acid rinse, if necessary; (5) application of sanitizer to disinfect the surface; (6) potable water rinse may be required, depending on sanitizer and concentration used. The steps must be done in this order, because each has its purpose. If any of the essential steps are skipped to attempt to sanitize a surface before it is properly cleaned, it is a waste of time and chemicals.

## Cleaning

There are many different cleaning compounds or detergents available for food-processing operations. The appropriate compound must be selected carefully and is dependent on several variables. First, assure that the cleaning agent has been approved by the regulatory agencies for the intended application. There are regulatory guidelines from FDA and United States Department of Agriculture (USDA) that provide this information. In addition, consider the local and state restrictions for discharging these compounds.

### Surfaces to be cleaned

Food-contact surfaces should be smooth and free of pitting, cracks, and crevices. These types of surfaces are nearly impossible to clean thoroughly because foodstuffs can accumulate and microorganisms can breed. They must be maintained in good shape to allow thorough cleaning. Biofilms are of particular concern in these surfaces.

Equipment location and design, together with surrounding structures should be evaluated carefully to identify any potential growth niches that may have developed over time. Growth niches are locations within the food-processing environment that can harbor and sustain growth of spoilage or pathogenic microorganisms so that they can

hide, spread, and contaminate subsequent products. These must be identified and eliminated, wherever possible.

### Metal surfaces

For food-contact surfaces, stainless steel is the metal of choice, since it is more resistant to corrosion than most other metals. Soft metals, like aluminum, brass, copper, or mild steel, may also be used, but since they are more susceptible to corrosion, cleaners and sanitizers have to be selected carefully. Aluminum, for example, is readily attacked by acids as well as high alkaline cleaners, which can result in noncleanable surfaces.

### Nonmetal surfaces

Plastic and rubber are also commonly used for food-contact surfaces, but if the nature of the food and cleaners and sanitizers used are corrosive, they can get stress cracks and develop cloudy surfaces.

### Nonfood-contact surfaces

All other surfaces, even though not in direct food contact, will need to be cleaned on a regular schedule using the appropriate procedures and cleaning compounds so that they do not become indirect contaminants of the product or equipment.

### Type of soil

Soils vary, depending on the nature of the raw materials being used. Seafood contains protein, fat, and minerals. In addition, sugar, salts or starches may be used in the formulation of further processed foods. Water used in the operation may contribute mineral deposits as well. Proteins and fat emulsions are not soluble in water but are soluble in alkali, and proteins are slightly soluble in acid. Monovalent salts such as sodium chloride are water soluble and are easy to remove. However, polyvalent ions such as calcium phosphate are not soluble in water but are soluble in acid. Sugars are water soluble and are relatively easy to remove. Some starches are soluble in water, whereas others are not. Freshly deposited soils are usually easier to remove, ones that have accumulated for longer periods of time, or that have been “cooked onto” a surface are obviously more difficult to remove. In most cases, soils

are composed of more than one type of material, so a cleaner that can work with all of them needs to be selected.

## Water properties

Water will be used to remove soils, dilute cleaners and sanitizers, and rinse surfaces, so water quality and composition is a major consideration. Water source and quality varies greatly depending on geographic location. Impurities in water can drastically alter the effectiveness of a detergent or sanitizer and its reaction with the particular soils.

Water used in a food-processing operation must be free from pathogens, toxic metal ions, and objectionable odors and tastes. The cleaning compounds must be tailored to the individual water supply, the treatments it may receive, and the processing operation. Water, no matter what the source is, should be tested on a routine basis, at the site of use, for bacterial levels and for chemical contaminants. Standards for water quality are established by the US Public Health Service.

In addition, depending on the source, water used in a food-processing facility may contain allowable levels of dissolved substances like calcium, magnesium, iron, chlorides, sulfates, manganese, sulfur, and carbon dioxide, which can affect its ability to clean. The presence of these substances defines the characteristic of the water and gives rise to terms such as hard, soft, red, black, acid, and so on.

## Hardness and softness

The hardness or softness of water is related to the amount of calcium and magnesium present. The degree of hardness is measured in parts per million (ppm) or grains per gallon (gpg). There are two types of hardness: temporary and permanent. Hardness is temporary when it can be removed by boiling the water or by adding lime (calcium hydroxide). Permanent hardness refers to mineral content that cannot be removed by boiling; it can only be removed by using a water softener, ion exchange column or other means. Using hard water in the cleaning process may result in the formation of a tough adherent scale, which is influenced by the heat of the cleaning solution and the components of the cleaner. If an improper cleaner is selected or if the concentration used is incorrect, a residue

of soil remains and the scale is called a foodstone (mineral stone, milk stone, etc.). Although most of these scales can be removed, usually with addition of acids, the process can be time consuming and expensive.

## Iron

Red water is caused by a relatively high concentration of iron. Initially, the iron is present in a soluble, colorless form; however, on exposure to air, the colorless form changes to an insoluble form, red in color (rust). Approximately 0.3 ppm iron is required for red color to be evident. The iron will react with chlorine, which is present in many cleaner or sanitizer formulations, to produce ferric chloride, a brown precipitate.

## Salt

Salt waters, those with a high chloride or sulfate content, are often encountered in coastal areas. Generally, salt waters do not affect cleaner efficiency; however, they can corrode equipment and cause scale buildup.

## pH

Typically, water pH ranges between 5.0 and 8.5. Some waters can be acidic (pH below 5.0), which may affect cleaner performance and could be corrosive to metals and cause deposits. Other waters can be alkaline (pH above 8.5), which can also affect cleaner performance and cause corrosion and deposits.

Most water supplies have a number of these characteristics in combination. It may be both hard and contain iron or have both temporary and permanent hardness. The character of water may change because of changes in the raw water supply, in municipal treatment, or in-plant treatment. Thus, having a clear understanding of what causes water quality to change and making the appropriate adjustments to chemical cleaners and sanitizers that are being used is essential to good cleaning and sanitation practices.

## Temperature

Heating may improve solubility of fats, but causes some compounds to interact with other constituents

forming a complex soil, which makes removal more difficult. Heating can cause caramelization of sugars, denaturation of proteins, and polymerization of fats, which makes them more difficult to remove. Starches are likely to interact with other soils when heat is applied, forming a difficult to remove complex soil. Freshly precipitated soils are usually easier to remove than old, dried, or baked-on deposits.

## Equipment and resources

Every operation will have different types of equipment and resources available for their sanitation programs. The type of cleaning to be done and the resources available may influence the type of cleaning agent that is most appropriate.

### Clean-in-place

Clean-in-place (CIP) systems are systems that can be attached to in-line cleaners and they automatically deliver the right amount of cleaner, with pressure or force (usually, 1.5 m/s or 5 ft/s) to remove soils from equipment interiors.

### Clean-out-of-place

Clean-out-of-place (COP) refers to pieces of equipment that must be disassembled and cleaned in a separate container, where the force to remove the soil is usually applied by hand.

### High pressure

Probably the most common method for removing soils is high-pressure hoses. These can be very effective in removing soil, but they also create aerosols, and should be used cautiously to minimize cross-contamination.

### Foams

Foams have gained popularity, because these can be sprayed onto large surfaces that may be difficult to reach but must be cleaned, including elevated conveyor belts, walls, ceilings, and floors. The foam allows a longer contact time for these surfaces. Foams are usually removed with a high-pressure hose, which provides the mechanical force in removing any remaining soils.

## Mechanical force

Brooms, brushes, scrub pads, steel wool pads, and other tools can be very effective in removing soils from different surfaces. Care should be taken to use materials that will not leave residues behind on the cleaned surfaces, like bristles or nylon or steel wool "threads."

## Factors to consider when selecting the cleaning compound

Several actions occur during the cleaning step. It is important to understand what is happening and what ingredients in the cleaning compounds perform which function to be able to select the proper cleaning compound:

- (1) The cleaning compound must be easily soluble in water.
- (2) The cleaning compound must remove soils by means of good wetting and penetrating properties.
- (3) Solid and liquid soils are displaced from the surface by saponifying or emulsifying fat, peptizing proteins, and dissolving minerals.
- (4) Dispersion of the soil in the cleaning solution is obtained by deflocculation or emulsification.
- (5) Soil is prevented from being redeposited on the surface by the good suspending and rinsing properties of the cleaning compounds. The rinse ability of detergents cannot be overemphasized. The last step of the cleaning process, it is the result of all the properties previously discussed. An acceptable rinsed surface is one free of all particulate matter and detergent film.

Finally, consider the cost of the cleaner, including the concentration of the chemical to be used, the contact time necessary for it to be effective, and any personnel safety issues.

In practice, these characteristics are not observed independently but all occur together. No simple chemical-alkali, acid, or wetting agent can supply all the necessary properties. By combining selected chemicals, cleaners can be prepared having the desired characteristics. No one combination will include all the various functions in the right amounts to be effective on a given application; different cleaning compounds are required for

different cleaning tasks. One group of detergents that works satisfactorily in one plant may not be effective in a similar plant because of difference in water supply.

The ideal cleaning compound contains a balance of all these properties, which is only obtained by knowing the type of water that is available, the types of soils to be removed and the types of cleaning options available. Knowledgeable suppliers of cleaning compounds can provide guidance on what to use, but plant personnel are ultimately responsible for knowing how to choose the proper compounds and understanding the factors that affect their effectiveness. No matter what cleaners or sanitizers are selected, proper procedures are mandatory to ensure a clean surface in any method of cleaning from CIP to hand cleaning. It is critical that SSOPs be written and followed for all cleaning and sanitizing procedures in a food plant. Writing these effectively is discussed later in the chapter.

Familiarity with the terms used in cleaning compounds will help understand the proper application of different detergents. These are summarized in Table 22.1.

## Sanitizing

There are basically two ways to sanitize surfaces. One is thermal sanitation, the other is with chemicals. The most common type of thermal sanitation is hot water. Time and temperature recommendations for processing operations are 85°C (185°F) for 15 minutes or 80°C (176°F) for 20 minutes.

Depending on the type of processing operation, the primary advantages of hot-water sanitization are: relatively easy to apply and readily available, generally effective over a broad range of microorganisms, relatively noncorrosive and penetrates into cracks and crevices and growth niches. Some disadvantages to hot-water sanitization are that it is a slow process that requires come-up and cool-down time; it can have high-energy costs; and has certain safety concerns for employees. The process also has the disadvantage of forming or contributing to film formations and shortening the life of certain equipment or parts thereof (gaskets, etc.).

By far, the most common way to sanitize surfaces in food-processing operations is with chemical compounds. But selecting the right sanitizer will depend on the application. The selection of a

sanitizer depends on the type of equipment to be sanitized, the properties of the water, and the application equipment available.

As with cleaning compounds, the first factor is whether the sanitizer is approved for the particular application, particularly if it is to be used on a food-contact surface. A list of approved sanitizers, concentrations, and applications is available in 21CFR178.1010. Technical advice may also be obtained from a reputable sanitizer manufacturer.

Also consider if the sanitizer has a wide range or scope of activity and if it destroys target microorganisms rapidly and effectively. The sanitizer should be stable under different conditions and should tolerate a broad range of environmental conditions. The sanitizer should also be readily soluble and possess some detergency, be low in toxicity, and be noncorrosive to metal surfaces. Finally, consider the price of use of the sanitizer and any issues with personnel safety.

No sanitizer meets all these criteria. Therefore, it is important to evaluate the properties, advantages, and disadvantages of each sanitizer for the specific applications.

Remember that the purpose of the sanitization step is to destroy any microorganisms remaining after the cleaning step. If a surface is not cleaned thoroughly, even the best sanitizer at its optimum concentration will not be able to destroy microorganisms trapped under soil. In fact, some sanitizers will be deactivated if organic material remains on a surface.

As with cleaning compounds, some factors that must be considered are as follows:

- (1) Exposure time—generally, the longer time a sanitizer chemical is in contact with the equipment surface, the more effective the sanitization effect; intimate contact is as important as prolonged contact.
- (2) Temperature is also positively related to microbial kill by a chemical sanitizer. Avoid high temperatures (above 55°C (131°F)) because of the corrosive nature of most chemical sanitizers.
- (3) Concentration—generally, the activity of a sanitizer increases with increased concentration. However, a leveling off occurs at high concentrations. A common misconception regarding chemicals is that “if a little is good, more is better.” Using sanitizer concentrations above recommendations does not sanitize better and,

**Table 22.1** Basic compounds and cleaning terminology.

Class of compounds	Major functions
Acids	Mineral deposit control and water softening. The importance of acidity is in relation to the amount of mineral salt that can be dissolved in the solution. Above a pH of 3.9 for phosphoric acid products, the mineral dissolving capability of the solution decreases rapidly. A standard of acidity to compare various acid solutions has not been established.
Basic alkalis	Soil displacement/emulsifying, saponifying, and peptizing. Alkalinity of a solution is the actual amount of the alkali present. Because many different alkalis are used in formulating detergents, certain standards of expression have been developed. Alkalinity consists of two parts, the active and the inactive, which together comprise the total alkalinity. Active alkalinity is the portion that exists above a pH of 8.4. The term <i>active</i> is used because this is the alkalinity responsible for cleaning. Inactive alkalinity is the portion that exists between a pH of 8.4 and 3.4. The term <i>inactive</i> is used because in this pH range little or no cleaning is obtained.
Chelates	Water softening, mineral deposit control, soil displacement by peptizing and prevents these soils from redepositing.
Complex phosphates and water	Soil displacement by emulsifying, peptizing, dispersion of soil, softening, and prevention of soil deposits.
Dispersion or deflocculation	Breaking up solid aggregates of soil into small particles. Dispersion is the action of breaking up solid aggregates of soil into smaller particles down to colloidal size. It is accomplished through the action of the chemical agent and mechanical agitation.
Emulsification	The action of breaking up fats and soils and dispersing them throughout the cleaning solution. The emulsion formed must be stable enough to prevent these soils from redepositing.
Peptizing	Occurs only by chemical action without agitation and can be considered as spontaneous dispersion of the solid soil throughout the cleaning solution. Peptization is usually associated with the removal of protein soils.
Saponification	The chemical conversion of water insoluble fatty acid soils into more soluble substances (soaps, which can be easily removed).
Sequestering/chelating	Ability to prevent deposition of undesirable mineral salts on surfaces being cleaned.
Surfactant	Wetting agent or a compound reducing surface tensions.
Synergism	When a chemical is used as a builder with a soap or detergent, the detergency resulting from the combination is greater than the total detergency of the chemical and the soap when used independently.
Water softening	The function of rendering the hardness of water unavailable for reaction with certain components of the cleaning solution. Softening can be accomplished by precipitating the hard water elements as insoluble salts. A second method is by sequestration.
Wetting	Ability to lower the surface tension of the water medium so as to increase its ability to penetrate soil. Wetting and penetration are complex phenomena and depend on diffusion rates, surface tension, concentration, and roughness of the surface.

in fact, can be corrosive to equipment, and may be hazardous to workers. Follow manufacturer's label instructions.

- (4) Soil—the presence of organic matter dramatically reduces the activity of sanitizers and may, in fact, totally inactivate the sanitization properties.

### Chemical factors

Some sanitizers will be affected by certain chemical interactions with other compounds, including impurities in the water. Some are dramatically affected by the pH of the solution. Many chlorine sanitizers, for example, are almost ineffective at pH



values above 7.5. Organic and/or inorganic inactivators may react chemically with sanitizers giving rise to nongermicidal products. Some of these inactivators are present in cleaning compound residues. Thus, it is important that surfaces be rinsed thoroughly prior to sanitization.

## Biological factors

Since not all sanitizers are equally effective against all microorganisms, it is important to know which microorganisms are being targeted in the operation and in the specific application. The microbiological load can affect sanitizer activity. Spores are more resistant than vegetative cells. Certain sanitizers are more active against Gram-positive than Gram-negative bacteria, and vice versa. Sanitizers also vary in their effectiveness against yeasts, molds, fungi, and viruses.

## Sanitizers

The most commonly used chemical sanitizers in the seafood industry are discussed in detail.

### Chlorine-based sanitizers

Chlorine, in its various forms, is the most commonly used sanitizer in food-processing and handling applications. Commonly used chlorine compounds include: liquid chlorine, hypochlorites, inorganic chloramines, and organic chloramines. Chlorine-based sanitizers form hypochlorous acid (HOCl, the most active form) in solution. Available chlorine (the amount of HOCl present) is a function of pH. At pH 5.0, nearly all is in the form of HOCl. At pH 7.0, approximately 75% is HOCl. The maximum allowable level for no-rinse applications is 200 ppm available chlorine, but recommended usage levels vary. For hypochlorites, an exposure time of 1 minute at a minimum concentration of 50 ppm and a temperature of 24°C (75°F) is recommended. For each 10°C (18°F) drop in temperature, a doubling of exposure time is recommended. For chloramines, 200 ppm for 1 minute is recommended.

Chlorine-based sanitizers are effective against all bacteria. In diluted form, chlorine-based sanitizers are colorless, relatively nontoxic, and nonstaining. They are the easiest sanitizers to prepare and apply, and they are generally the most economical. Usu-

ally, no water rinse is required if chlorine solutions do not exceed 200 ppm. Chlorine concentrations can be easily measured by a test kit.

Chlorine has activity at low temperature, is relatively cheap, and leaves minimal residue or film on surfaces. The activity of chlorine is dramatically affected by such factors as pH, temperature, and organic load. However, chlorine is less affected by water hardness when compared to other sanitizers (especially the quaternary ammonium compounds (QACs)).

The major disadvantage of chlorine compounds is corrosiveness to many metal surfaces (especially at higher temperatures). Health and safety concerns can occur due to skin irritation and mucous membrane damage in confined areas. At low pH (below 4.0), deadly Cl<sub>2</sub> (mustard gas) can form. Chlorine solutions prepared from chlorine gas, hypochlorites, and chloramines are not compatible with QAC sanitizers.

### Chlorine gas

Chlorine gas is a highly volatile compressed gas that forms hypochlorous acid (HOCl) when injected into water. It may make the pH (acidity/alkalinity) of water slightly lower (more acidic).

### Hypochlorites

Sodium hypochlorite and calcium hypochlorite are formed by treating alkalis with chlorine gas. In water, they form hypochlorous acid and sodium or calcium salts. These salts can raise the pH of the water (more alkaline) and reduce the killing action of the chlorine. Hypochlorites are unstable; they lose chlorine during storage. Under controlled conditions, the germicidal action of hypochlorites equals that of chlorine gas.

### Chloramines

Chloramines are formed by a reaction of chlorine with ammoniacal nitrogen in water. In solution, they slowly form hypochlorous acid and organic salts. Chloramines are more stable and less corrosive than hypochlorites, and they have a longer lasting germicidal action. Chloramines require a long contact time to be effective sanitizing agents.

The rate at which gaseous chlorine, hypochlorites, and chloramines kill bacteria is directly related to the amount of free chlorine (hypochlorous acid)

in the water. In general, killing rates decrease as the pH becomes higher (more alkaline). Very acidic chlorinated water is corrosive to equipment. Very alkaline chlorinated water is also corrosive and has a reduced killing ability. A pH range of 6.0–7.5 is recommended for chlorine sanitizing solutions.

Organic matter will react with hypochlorous acid, leaving less free chlorine. Since it is the free chlorine that kills bacteria, large amounts of organic matter will reduce the germicidal activity of a chlorine solution. The killing rate of chlorinated water increases with temperature, but the increased killing rate is counteracted by increased corrosiveness and vaporization (loss of chlorine). Apply chlorine-based sanitizers in cold water.

### Chlorine dioxide

Chlorine dioxide ( $\text{ClO}_2$ ) is formed by reacting chlorine gas ( $\text{Cl}_2$ ) or hydrochloric acid ( $\text{HCl}$ ) with sodium chlorite ( $\text{NaClO}_2$ ). In water, chlorine dioxide is the active sanitizing compound. It differs from hypochlorous acid in several significant ways.

Chlorine dioxide is uniformly active across a wide pH range, while the germicidal activity of hypochlorous acid varies with the pH of the solution. Hypochlorous acid becomes ineffective above pH 8.5, but chlorine dioxide retains some sanitizing power up to pH 10.0. Chlorine dioxide is a stronger oxidizer than other chlorine sanitizers and it is less likely to form chlorinated organic compounds. Chlorine dioxide is desirable whenever the organic load of the water is high. In addition, chlorine dioxide removes iron, manganese, odors, flavors, and colors from the water. Concentrations of chlorine dioxide can be easily measured by a test kit.

Chlorine dioxide is more expensive than chlorine gas or hypochlorites. It is highly reactive and cannot be manufactured and shipped in bulk; an on-site generating system is required. Chlorine dioxide decahydrate may be commercially prepared, but must be refrigerated because it decomposes at room temperature and can explode under certain conditions.

### Iodine compounds

This sanitizer exists in many forms and usually exists with a surfactant as a carrier. These mixtures are termed iodophors. The most active agent is the

dissociated free iodine (also less stable). Iodine solubility is very limited in water.

It is generally thought that the bactericidal activity of iodine is through direct halogenation of proteins. More recent theories have centered upon cell wall damage and destruction of microbial enzyme activity.

Iodophors, like chlorine compounds, have a very broad spectrum: being active against bacteria, viruses, yeasts, molds, fungi, and protozoans. Iodine is highly temperature dependent and vaporizes at 120°F. Thus, it is limited to lower temperature applications. The degree to which iodophors are affected by environmental factors is highly dependent upon properties of the surfactant used in the formulation. Iodophors are generally less affected by organic matter and water hardness than chlorine. They are most effective in acidic conditions, and have minimal activity at pH 7.0. Generally recommended usage for iodophors is 12.5–25 ppm for 1 minute. No water rinse is required if iodophor solutions do not exceed 25 ppm. Iodophor concentrations can be easily measured by a test kit. The color of an iodophor hand-dip solution gives a visual check on concentration. The primary disadvantage is that iodine solutions may stain porous surfaces and some plastics.

### Quaternary ammonium compounds

QACs are active and stable over a broad temperature range. Because they are surfactants, they possess some detergency. Thus, they are less affected by light soil than are other sanitizers. However, heavy soil dramatically decreases activity, QACs generally have higher activity at alkaline pH. While lack of tolerance to hard water is often listed as a major disadvantage of QACs when compared to chlorine, some QACs are fairly tolerant of hard water. QACs are effective against bacteria, yeasts, mold, and viruses. QACs are generally more active against Gram-positive than Gram-negative bacteria. They are not highly effective against some common spoilage bacteria and bacteriophages. Their incompatibility with certain detergents makes thorough rinsing after cleaning operations imperative. Further, many QAC formulations can cause foaming problems in CIP applications.

No water rinse is required if QAC solutions do not exceed 200 ppm. However, QAC solutions may leave objectionable films on equipment and

should be rinsed off with fresh cold water. QACs may be combined with nonionic wetting agents in detergent-sanitizer formulations. QACs are not compatible with other common detergent compounds or chlorine sanitizers.

Under recommended usage and precautions, QACs pose little toxicity or safety risks. Thus, they are in common use as environmental fogs and as room deodorizers. However, care should be exercised in handling concentrated solutions or use as environmental fogging agents.

### Acid-anionic surfactants

Acid-anionic surfactants are combinations of acid, usually phosphoric acid, with surface-active agents. They are effective only below pH 2.5. These sanitizers are effective against most bacteria, and are odorless, relatively nontoxic, stable, and noncorrosive to stainless steel. They are effective in removing and controlling milkstone and hard water films.

### Fatty acid sanitizers

Fatty acid or carboxylic acid sanitizers were developed in the 1980s. Typical formulations include fatty acids plus other acids (phosphoric acids, organic acids). These agents also have the dual function of acid rinse and sanitization. The major advantage over acid anionics is lower foaming potential. These sanitizers have a broad range of activity, are highly stable in dilute form, are stable to organic matter, and are stable to high temperature applications.

These sanitizers have low activity above pH 3.5–4.0, are not very effective against yeasts and molds, and some formulations lose activity at temperatures below 10°C (50°F). They also can be corrosive to soft metals and can degrade certain plastics or rubber.

### Ozone

Ozone is usually dissolved in water and applied as an aqueous solution and can be used as a cleaning and a sanitizing agent. It can be sprayed directly on product-contact surfaces during production to keep microbial loads to a minimum. Ozone systems are also used to augment current cleaning practices, providing the additional sanitation ben-

efits of continuous cleaning. Ozone-based systems have been marketed to the food industry for some years, but had not gained wide acceptance until recently. The reasons for this lag include inadequate science, ineffective validations, lack of service after purchase and general skepticism about new technology. Ozone destroys bacteria, mold, mildew, spores, yeast, and fungus, and it inactivates viruses and parasite cysts.

Ancillary benefits include reduced energy costs resulting from a large reduction in hot water consumption and chemical cost reductions resulting from lessened chemical usage. Disadvantages include instability, so it cannot be pressurized or heated. Since it is applied at much more dilute concentrations than conventional sanitizers, it is less likely to work with heavy soil loads.

### Peroxyacetic acid or peracetic acid solutions

Peroxyacetic acid or peracetic acid (PAA) solutions have been known for their germicidal properties for a long time. However, it has only found food-industry application in recent years and is being promoted as a potential chlorine replacement. PAA solutions contain a mixture of peracetic acid, acetic acid and hydrogen peroxide. These sanitizers are effective against all microorganisms, including bacterial spores. The precise mode of action mechanism has not been determined, but PAA is highly active against both Gram-positive and Gram-negative bacteria. The germicidal activity of PAA is most effective between pH of 3.0 and 7.5. They are effective in cool or warm water.

PAA is relatively stable at use strengths of 100–200 ppm and can be used in nonrinse applications. Other desirable properties include absence of foam and phosphates, low corrosiveness, tolerance to hard water and favorable biodegradability. PAA solutions have been shown to be useful in removing biofilms.

PAA solutions have a pungent odor and should be used in a well-ventilated area. Concentrated solutions (40%) are strong oxidizers and can be corrosive to the skin.

### Writing sanitation standard operating procedures

As mentioned previously, whatever procedures are used, they must be followed carefully and

consistently. For this purpose, SSOPs are essential (and required by the HACCP regulation). SSOPs should be written for each procedure that needs to be followed and should include the mentioned information:

- (1) Objective—a general statement of what is to be accomplished by doing this procedure.
- (2) List of materials necessary to accomplish the task.
- (3) Procedures—easy to follow steps that can be followed by the appropriate personnel so that the objective is accomplished.
- (4) Frequency with which the procedure must be done. Establishing a sanitation schedule can be helpful to keep track of which procedures must be done and when.
- (5) Responsible party for completing the task.
- (6) Performance standards or criteria to determine if the objective was accomplished.
- (7) Actions to be taken if the objective was not accomplished.
- (8) Name of record that will be filled out to confirm that the task was completed according to the SSOP.
- (9) Names of persons responsible for writing the SSOP and person who approved the SSOP, along with the corresponding dates.
- (5) Dehumidifiers or air conditioning units, coils and pans
- (6) Pallets (clean before placing them in the process areas)
- (7) Areas under floor conveyors and equipment
- (8) Air hoses and air
- (9) Hoses (water and sanitizer)
- (10) Pipes (overhead sewer or drain pipes, insulated pipes)
- (11) Lunchrooms, locker rooms, rest rooms
- (12) Cleaning aids (mops, brooms, squeegees), floor mats, condensate wipers
- (13) Forklifts, trash dumpsters
- (14) Air lock door pull cords and electrical on/off buttons

It may also be prudent to write SSOPs for mechanics, for example:

- (1) Before working on ready-to-eat lines, mechanics must wash and sanitize their hands and tools.
- (2) After working on the line, the area or areas touched by mechanics, their clothes, or their tools must be sprayed with sanitizer and wiped down with clean paper towels.
- (3) If allergens are a concern, different tools may be used in allergen-containing and allergen-free zones to minimize the possibility of cross-contamination.

A system should be established to number all SSOPs and keep track of when they are revised. It may be beneficial to add a list of changes made to the SSOP for easy reference. An organized numbering system and version number will help assure that everyone is always following the current procedures and the appropriate records are being filled out.

In addition to the obvious SSOPs, which must be written for processing equipment and food-contact surfaces, a list of other areas is mentioned that may be considered in a food-processing facility for which SSOPs should be written and followed:

- (1) Walls, ceilings, floors, and drains
- (2) Cooling units, drip pans, overhead pipes, doors, plastic curtains, air curtains
- (3) Vacuum equipment (hose, nozzle, and air filter coming out of tank)
- (4) Air handling systems (air makeup units ductwork, filters, traps, etc.)

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## Webliography



# 23

## Implementing the Seafood HACCP Regulation

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Pamela D. Tom

The processed seafood industry was the first US commodity to comply with a federally mandated Hazard Analysis Critical Control Point (HACCP) regulation that was passed on December 18, 1995, and implemented after a 2-year grace period as of December 18, 1997. This chapter gives an overview on how to address the requirements of the US Food and Drug Administration (USFDA) seafood HACCP regulation, "Procedures for the Safe and Sanitary Processing and Importing of Fish and Fishery Products," (21CFR123; USFDA, 1995) that is introduced in Chapter 27. This chapter introduces information and resources to explain and implement the seafood HACCP regulation that is based on a system of preventive controls for food safety. The seafood HACCP regulation applies equally to US processors and foreign processors that ship their products to the US large and small firms are required to follow the seafood HACCP regulation. The seafood HACCP regulations supplement other regulations enforced by the USFDA, including the low-acid canned food regulations (USFDA, 1999).

### Overview of the seafood HACCP regulation and principles

HACCP (pronounced as "hassip") is a food safety management and inspection program based on

risk assessment and record keeping. HACCP is a science-based regulation that aims to prevent hazards that are reasonably likely to occur. Using a preventive approach to food safety, the seafood HACCP regulation requires seafood processors, repackers, and warehouses, both domestic and foreign exporters to the United States, to focus on identifying and preventing hazards that could cause food-borne illnesses. Prior to the seafood HACCP regulation, industry and regulators relied on spot-checks of manufacturing processes and random sampling of finished products to catch any problems. USFDA inspections of seafood processors concentrated on the sanitation conditions and practices of the processor plus the quality of the product. Considerable emphasis was placed on end-product testing for microbiological and other defects. The focus of the inspection shifted under HACCP to determining the adequacy of the processor's controls to prevent the occurrence of food safety hazards. The seafood inspector assesses the adequacy of the processor's HACCP plan, observes the degree to which the plan is implemented in the plant, and reviews records of critical control point monitoring and corrective action. Also, the inspector reviews the processor's sanitation monitoring program (USFDA, 1999). Following these review procedures, the seafood inspector can determine how

**Table 23.1** Biological hazards.

Bacteria	
Sporeformers	Nonsporeformers
<i>Clostridium botulinum</i>	<i>Brucella abortus</i> , <i>Brucella suis</i>
<i>Clostridium perfringens</i>	<i>Campylobacter</i> spp.
<i>Bacillus cereus</i>	Pathogenic <i>Escherichia coli</i> ( <i>E. coli</i> O157:H7)
	<i>Listeria monocytogenes</i>
	<i>Salmonella</i> spp. ( <i>S. typhimurium</i> , <i>S. enteritidis</i> )
	<i>Shigella</i> spp. ( <i>S. dysenteriae</i> )
	<i>Staphylococcus aureus</i>
	<i>Streptococcus pyogenes</i>
	<i>Vibrio</i> spp. ( <i>V. cholerae</i> , <i>V. parahaemolyticus</i> , <i>V. vulnificus</i> )
	<i>Yersinia enterocolitica</i>
<b>Viruses</b>	
Hepatitis A and E	
Norwalk virus group	
Rotavirus	
<b>Parasitic Protozoa and Worms</b>	
<i>Anisakis simplex</i>	
<i>Ascaris lumbricoides</i>	
<i>Cryptosporidium parvum</i>	
<i>Diphylobothrium latum</i>	
<i>Entamoeba histolytica</i>	
<i>Giardia lamblia</i>	
<i>Pseudoterranova decipiens</i>	
<i>Taenia solium</i> , <i>Taenia saginata</i>	
<i>Trichinella spiralis</i>	

well a company is complying over time, rather than just during the immediate duration from an on-site inspection.

The seafood HACCP regulation defines processing as handling, storing, preparing, heading, eviscerating, shucking, freezing, changing into different market forms, manufacturing, preserving, packing, labeling, dockside unloading, or holding. The regulation does not apply to any of the following:

- (1) Harvesting or transporting fish or fishery products, without otherwise engaging in processing.
- (2) Practices such as heading, eviscerating, or freezing intended solely to prepare a fish for holding on board a harvest vessel.
- (3) The operation of a retail establishment.

The proposed seafood HACCP regulation had support among seafood trade associations, businesses, consumer advocacy organizations, Federal and State agencies, professional societies,

academics, and a member of Congress. There were several reasons for this support including enhancement of consumer confidence, the superiority of HACCP-type preventive controls over traditional current good manufacturing practices (CGMP)-type controls and end-product sampling, the view that HACCP is the most efficient and effective way to ensure safety, and the view that a mandatory HACCP system reflects an appropriate assigning of primary responsibility to industry for producing safe food. Economic competitiveness contributed to additional reasons including leveling of domestic and international competition, the need for prompt adoption by USFDA of a mandatory HACCP program to enable the seafood industry to maintain its global market, greater productivity, and increased industry control over processing (USFDA, 1995).

The HACCP concept was introduced in the 1960s when foods were developed by the Pillsbury Co. for the US National Aeronautics and Space Administration. End-product testing of each food item

**Table 23.2** Chemical hazards.

**Naturally occurring chemicals**

Mycotoxins (aflatoxin)  
Scombrototoxin (histamine)  
Ciguatoxin  
Mushroom toxins  
Shellfish toxins  
    Paralytic shellfish poisoning (PSP)  
    Diarrheic shellfish poisoning (DSP)  
    Neurotoxic shellfish poisoning (NSP)  
    Amnesic shellfish poisoning (ASP)/Domoic acid  
Pyrrolizidine alkaloids  
Phytohemagglutinin

**Intentionally added chemicals**

Food Additives  
    Direct (allowable limits under GMP's)  
        Preservatives (nitrite and sulfating agents)  
        Nutritional additives (niacin)  
        Color additives

**Unintentionally or incidentally added chemicals**

Agricultural chemicals  
    Pesticides, fungicides, herbicides, fertilizers, antibiotics, and growth hormones  
Prohibited substances  
    Code of Federal Regulations, Chapter 21, Section 189  
Toxic elements and compounds  
    Lead, zinc, arsenic, mercury, and cyanide  
Polychlorinated biphenyls (PCBs)  
Plant chemicals  
    Lubricants, cleaning compounds, sanitizers, and paints

would assure safety, but was not a practical solution. HACCP involves conducting a hazard analysis to assess risks from any biological, chemical, or physical hazards (see Tables 23.1, 23.2, and 23.3) stemming from the species and process. Seven HACCP principles were formalized and adopted in 1997 by the National Advisory Committee on Microbiological Criteria for Foods:

- (1) Conduct a hazard analysis.
- (2) Determine critical control points.
- (3) Establish critical limits.
- (4) Establish monitoring procedures.
- (5) Establish corrective actions.
- (6) Establish verification procedures.
- (7) Establish record-keeping and documentation procedures.

Details on the seven HACCP principles are contained in the National Advisory Committee on Microbiological Criteria for Food (NACMF) Guide-

lines (NACMF, 1997) and the Seafood HACCP Alliance training curriculum (Seafood HACCP Alliance for Education and Training, 2000).

As noted in the HACCP discussion in Chapter 27 of this text, if any potential hazards are identified during a hazard analysis of the species and process, a HACCP plan must be created and included where the critical control point (the stage in the processing step where the hazard can be controlled or eliminated) is identified and critical limits are established. Each processor should establish the critical

**Table 23.3** Physical hazards and common sources.

Material	Sources
Glass	Bottles, jars, light fixtures, thermometers, gauge covers
Metal	Machinery, agricultural fields, buckshot, birdshot, wire, staples, buildings, employees

limits of the cook step in their process by a scientific study (USFDA, 1999). A critical limit defines the boundary (ies) needed to ensure that the product is safe.

Accurate, real-time monitoring records are required to verify that the critical limit has been met. If there is a failure in meeting the critical limit, then corrective actions are needed to bring the process back into safe operations. The corrective actions need to be documented in a corrective action record.

Verification procedures and records are needed to confirm that the HACCP program, procedures, and any equipment involved are operating properly. Verification measures the performance of a HACCP program. Certain verification steps are mandatory such as process instrument calibration, and review of processing, calibration, and corrective action records. Other procedures are left for the processor to decide, such as finished product testing.

In addition to being required to reassess the HACCP plan when an unexpected corrective action occurs, the regulation also requires a yearly reassessment of the HACCP plan (USFDA, 1995). Processors may conduct the reassessment in any manner that works for them. For example, a "HACCP team" could discuss changes in the firm's operations since the last reassessment. Or, reassessment could also include a review of consumer or trade complaints, finished product or in-line samples, or of monitoring or corrective action records. The USFDA will determine adequacy of the reassessment process based on the adequacy of the HACCP plan (USFDA, 1999).

Specific criteria defining the content requirements of the HACCP plan, monitoring procedure, corrective action, and verification records and retention are defined in the HACCP regulation, found in 21 CFR.

A single HACCP plan may include grouping different species that have the same hazards and controls (e.g., monitoring, corrective actions, verification procedures and records) other than the critical limits (USFDA, 1999, Questions and Answers (QAs)). Under the seafood HACCP regulation, the importer and the foreign processor share the responsibility for seafood safety. Foreign processors that ship fish or fishery products to the United States must operate in conformance with the seafood HACCP regulation. The importer is not required to perform a hazard analysis or

have a HACCP plan, unless it is also engaged in processing. The importer is only required to have and implement verification procedures to ensure that the foreign processor meets the seafood HACCP requirements, including sanitation monitoring, which is discussed in this chapter (USFDA, 1999, QAs). In addition, importers are required to take steps to verify that their imported products are obtained from foreign processors that comply with the seafood HACCP regulation specifications such as water activity, pH, histamine content, and pathogen limits. An importer's specifications are not necessarily the same as a processor's HACCP critical limits (USFDA, 1999, QAs). An importer may hire a competent third party to assist with or perform any or all of the verification activities specified in the seafood HACCP regulation. The importer must maintain records in English. If an inspection of imported products to the United States fails to be processed under conditions that are equivalent to those required of domestic processors, the product would appear to be adulterated and be denied entry into US commerce.

## HACCP training

The seafood HACCP regulation requires training, but there are options. A company can comply with the training requirement by having an employee attend a HACCP course, incur on-the-job training, or by hiring a consultant.

In 1994, the National Sea Grant College Program funded a 2-year proposal to support plans for a "Seafood HACCP Alliance" for training and education. This Alliance was initiated by the Association of Food and Drug Officials (AFDO) and their regional affiliate of Southern States in conjunction with a cadre of Sea Grant Seafood specialists, which originally assisted the National Fisheries Institute with their initial HACCP training programs. The first formal Alliance meeting in 1994 established a steering committee including members representing the three principal federal agencies, USFDA, US Department of Agriculture, and National Marine Fisheries Service, the various state agency organizations through AFDO regional affiliates and the Interstate Shellfish Sanitation Conference, and the industry trade associations: National Fisheries Institute and Food Products Association (formerly National Food Processors Association

and now currently Seafood Products Association). Since its inception, the Seafood HACCP Alliance has been chaired by Dr. W. Steven Otwell at the University of Florida in Gainesville, Florida.

Since HACCP course contents may vary, the person seeking HACCP training should select a course that introduces the seven principles, prerequisite programs, seafood hazards, seafood HACCP regulation, and hands-on practice in developing a HACCP plan. The Seafood HACCP Alliance developed the USDA-approved training curriculum and protocol (Association of Food and Drug Officials and Seafood HACCP Alliance, 2011); training curriculum consists of a 3-day course following the aforementioned course elements. The training materials include two manuals: (1) HACCP: Hazard Analysis and Critical Control Point Training Curriculum and (2) Fish & Fisheries Products Hazards and Controls Guidance. Upon completing the 3-day basic Seafood HACCP Alliance training course, recipients receive a certificate of course completion. The certificates are issued by the AFDO in York, Pennsylvania. A listing of available HACCP training courses is available at either the University of California, Davis Seafood Network Information Center Web site ([seafood.ucdavis.edu](http://seafood.ucdavis.edu)) or the AFDO Web site ([afdo.org](http://afdo.org)). The Alliance also sponsors the equivalent of the first 2 days of the 3-day basic HACCP course through Cornell University. A third day, called "HACCP Segment 2," is required to qualify for a certificate of course completion from AFDO. A caveat regarding the online course is that not all states offer HACCP Segment 2 and the participant may have to go out of state to fulfill the third day requirement.

The US Department of Commerce (USDC), National Oceanographic Atmospheric Administration (NOAA) Seafood Inspection Program offers a 3-day HACCP course that in contrast to the Seafood HACCP Alliance training course includes an examination requiring an 80% passing score. The USDC workshop also covers how firms can cover other regulatory compliance issues, including proper labeling and provides the basis for interested parties to participate in USDC/NOAA's HACCP Quality Management Program, a voluntary program that expands the principles of prevention to address quality defects. The USDC/NOAA/SIP HACCP courses are scheduled frequently throughout the year across the United States. Custom in-house training courses are available domestically

and internationally upon request. Further details are available on the NOAA Seafood Inspection Program (SIP) Web site ([seafood.nmfs.noaa.gov](http://seafood.nmfs.noaa.gov)).

Additional seafood HACCP Alliance equivalent training courses are available domestically and internationally. An equivalent course follows the HACCP training curriculum but is not registered with the Association of Food and Drug Officials. Equivalent courses that follow the AFDO prescribed curriculum are acceptable training alternatives.

HACCP training is important and required by the seafood HACCP regulation. However, possession of a HACCP training certificate is not required. Even if a certificate of HACCP training completion is presented, if the inspection report is unsatisfactory, the inspector can still issue warnings, citations, or close a plant. The critical element is to be able to demonstrate to the seafood inspector that the company understands and correctly implements the HACCP principles, knows how to modify the HACCP plan, take corrective actions, and review and maintain proper records that are in compliance with assuring a safe fish or fishery product.

## Internet HACCP resources

Completing the Basic Seafood HACCP Alliance course provides the participant with basic skills and understanding of the seafood HACCP regulation, HACCP program and required records and maintenance. Additional resources are available via the Internet to enhance competency and confidence in implementing the HACCP principles, seafood HACCP regulation, and control of hazards.

An invaluable resource available to guide the reader through the USDA HACCP regulation requirements is the USDA's "Fish & Fisheries Products Hazards & Controls Guidance" known to the industry as either the "Hazards Guide" or simply the "Guide" (USFDA, 2001). The USDA developed a web document on questions and answers pertaining to the seafood HACCP regulation (USFDA, 1999, QAs). Generic HACCP plans and examples offer insight on how to create viable HACCP documents (<http://seafood.ucdavis.edu>). The "Compendium of Fish and Fishery Product Processes, Hazards, and Controls" known as the "compendium" provides a summary of resources for controlling hazards (<http://seafood.ucdavis.edu>).



The National Sea Grant College Program Digital HACCP Library features a collection of resources (<http://nsgd.gso.uri.edu>). The Seafood HACCP Alliance Encore Course Manual (Seafood HACCP Alliance, 1999) gives additional information on developing a HACCP plan. And a seafood HACCP discussion list (<http://seafood.ucdavis.edu>) is available to post questions on the Internet to the seafood community.

## Hazards guide

To assist the industry in developing a HACCP plan and program, the USDA published the Hazards Guide (USFDA, 2001) to assist processors in the development of their HACCP plans and to provide information to help identify hazards that may be associated with their products and to formulate control strategies for those hazards (USFDA, 1999, QAs). The Hazards Guide is compiled by USFDA scientists who have reviewed all of the known scientific studies to date and have provided in the Hazards Guide advice on controlling hazards that are reasonably likely to occur and on developing a HACCP plan. Under the record retention requirements, the results of scientific studies and evaluations relating to the general adequacy of equipment or processes must be retained (USFDA, 1995).

When correctly applied and documented in a HACCP plan, seafood inspectors will accept the "Hazards Guide" as a scientific studies document. For processors, the most direct way to assure compliance with the HACCP regulation is to follow the Guide. The Guide contains USFDA's best advice on those hazards that are reasonably likely to occur and on the controls that are necessary to address them. Processors who choose not to follow recommendations in the Guide may adopt alternative control measures; however, the responsibility is on the processor to demonstrate that an equivalent level of control is in place (USFDA, 2001). To demonstrate an equivalent level of control may not be easy. It will always require scientific documentation (i.e., a study or literature search). These efforts may be burdensome and, in most cases, it is unlikely that processors will choose to take on that burden.

The Hazards Guide includes information on how to develop a HACCP plan, tables identifying the known hazards of species and processes, and a review with examples and suggested HACCP plan inclusions for biological, chemical and phys-

ical hazards. Coverage of the hazards includes a description of the potential hazard, a discussion on determining if the potential hazard is significant, identifying critical control points; setting critical limits; suggesting control strategies; and establishing procedures for monitoring (what, how, frequency, and who), corrective action, verification, and record keeping. Blank hazard analysis and HACCP plan forms are included along with a critical control point decision tree, bacterial growth and inactivation table, USFDA and US Environmental Protection Agency safety levels in regulations and guidance, and the seafood HACCP regulations.

Chapter 2 of the Hazards Guide provides important information on how to use and develop the HACCP plan and use the chapters in the Guide. The Hazards Guide includes 18 steps and details on how to develop a HACCP plan when a hazards analysis identifies biological, chemical, or physical hazards and critical control points. The HACCP Alliance Basic HACCP course gives detailed instruction on the definition and implementation of the 18 steps and demonstrates how to use the Hazards Guide. The 18 steps are as follows:

### *Preliminary steps*

- (1) Collect general information.
- (2) Describe the food.
- (3) Describe the method of distribution and storage.
- (4) Identify the intended use and consumer.
- (5) Develop a flow diagram.

### *Hazard analysis*

- (6) Set up the hazard analysis worksheet.
- (7) Identify the potential species-related hazards.
- (8) Identify the potential process-related hazards.
- (9) Complete the hazard analysis worksheet.
- (10) Understand the potential hazard.
- (11) Determine if the potential hazard is significant.
- (12) Identify the critical control points.
- (13) Complete the HACCP plan form.
- (14) Set critical limits.
- (15) Establish monitoring procedures.
- (16) Establish corrective action procedures.
- (17) Establish verification procedures.
- (18) Establish a record-keeping system.

## **HACCP regulation: questions and answers**

Many questions about the seafood HACCP regulation were raised by the seafood industry, regulators,

consumers, and others about interpreting the regulation. As a result, the USDA published "HACCP Regulation for Fish and Fishery Products: Questions and Answers" (USFDA, 1999, QAs) on the USDA Web site to provide answers to some of the more common questions. This guidance document is 43 pages and contains answers to 153 questions.

If processors still have further questions that are not addressed in the Hazards Guide (USFDA, 2001) or the "Questions and Answers" (USFDA, 1999, QAs), they may contact any of the following centers:

Office of Food Safety  
Division of Seafood Safety  
Seafood Technical and Policy Branch HFS (Health-care and Family Services)-325  
Center for Food Safety and Applied Nutrition  
Food and Drug Administration  
5100 Paint Branch Parkway  
College Park, MD 20740  
(Tel) 301-436-2300

## Generic HACCP plans and forms

Numerous generic HACCP plans and segments of plans are available in training course materials including the Seafood HACCP Alliance Training Curriculum (Seafood HACCP Alliance for Education, and Training, 2001), Hazards Guide (USFDA, 2001), and on the Seafood NIC Seafood HACCP web page (<http://seafood.ucdavis.edu>). There are no standard forms for keeping proper HACCP plans and records. The Hazards Guide and Seafood HACCP Alliance training curriculum include blank hazard analysis and HACCP plan forms that USDA encourages, but does not require. The pre-printed forms help reduce the processors' risk of omitting important information. These uniform forms may reduce the time necessary for USDA investigators who are familiar with and have been trained with these forms to review the information during an inspection.

Generic model HACCP plans should not be used as is. The models are merely examples and must be modified to reflect the actual processing and species conditions in the respective processing plant. The processor must conduct a hazard analysis and if hazards are identified, develop a HACCP plan. Model HACCP plans provide examples for gen-

eral case scenarios. But the processor must tailor the HACCP plan to actual conditions at each processing plant location. Most seafood inspectors are familiar with the generic models available. Generic forms are also available as sanitation standard operating procedures (Seafood HACCP Alliance for Education, and Training, 2000, 2001), monitoring, verification and corrective action records (Seafood HACCP Alliance for Education and Training, 2001).

The "Compendium of Fish and Fishery Product Processes, Hazards, and Controls" is an Internet HACCP Alliance document that is designed to supplement the resources available in developing a HACCP plan. The Compendium provides information that clarifies and supplements HACCP information from the training curriculum (USFDA, 2001) and Hazards Guide (USFDA, 2001). The Compendium includes sections on seafood processes and controls, plus biological, chemical, and physical hazards and controls. It provides the seafood industry with information on documented seafood process parameters, federal guidelines and tolerances for seafood contaminants, bacterial-growth parameters, and recommended hazard-control operations. Like the Hazards Guide, the Compendium can assist in developing effective HACCP plans by providing scientific information on food-safety hazards and controls.

The National Sea Grant Library hosts a HACCP digital library (<http://nsgl.gso.uri.edu>) containing a wealth of HACCP related web documents that are authored by Sea Grant programs across the nation.

## Encore manual

A 1-day HACCP refresher course sponsored by the Seafood HACCP Encore HACCP Training Program was designed to assist those processors who were experiencing difficulty in complying with the regulation. Moreover, the course was intended to give regulatory personnel a more thorough understanding of HACCP to assist them in evaluating the adequacy of industry developed HACCP plans. Although the course has not been offered in years, the training manual (Seafood HACCP Alliance, 1999) for the Encore course serves as a key resource for seafood processors that have had significant HACCP deviations noted during an inspection or are having difficulty in understanding HACCP as it pertains to their product or process. The manual is

also valuable to seafood inspectors who would like further training in HACCP plan development and sanitation monitoring. The manual addresses topics related to performing a hazard analysis and developing HACCP plans for fresh/frozen finish, cooked ready-to-eat crustaceans, smoked fish; and how to comply with the sanitation monitoring requirements of seafood HACCP regulations.

## Discussion list

To assist the industry and seafood inspectors understand and implement the seafood HACCP regulation, the University of California Seafood HACCP Discussion List (Internet Mailing List) was established in 1995. The List is hosted at the University of California, Davis, by the California Sea Grant Extension Program seafood technology unit and the Division of Agriculture and Natural Resources. The HACCP discussion list provides an open Internet forum for seafood technology information exchange. Topics focus on seafood HACCP, safety, quality, processing, species, regulations, training programs, conferences, and more. Subscriptions are free and available to anyone with e-mail access. More than 1000 seafood professionals (industry personnel, inspectors, extension specialists, trade associations, etc.) from over 55 countries are subscribed. Archived discussion list topics are available at the UC Davis home page ([www.ucdavis.edu](http://www.ucdavis.edu)) by entering your inquiry in the search engine located in the top right corner. Questions posted on the discussion list may receive a reply within a few hours or days.

## HACCP inspection

During a HACCP inspection, the seafood inspector will first conduct his or her own hazard assessment by identifying the species and walking through the process in the plant. Then, the inspector will review the HACCP plan and records (monitoring, corrective action, and verification) of the processor.

Record review permits USFDA and other competent authorities (including the processing company) to review the daily operations of the processor for days, weeks, months, or years preceding the actual day of inspection to assess the safety and compliance of the operations. Inspectors are no longer left with only a small sampling of a manufacturing operation based on the activities observed

in the few hours or days of a periodic inspection. The written HACCP plan demonstrates the processor's recognition of the hazards associated with its products and processes and the processor's understanding of the activities necessary to control and prevent hazards from occurring. The monitoring records reveal if appropriate actions have been undertaken with every lot produced. These plans and records provide revealing information prior to, or in absence of, an actual on-site inspection, which can be extremely advantageous in assessing less accessible foreign processing operations (von Eschenbach, 2008).

The USFDA does not approve HACCP plans. Preapproval would burden the FDA's resources and slow down the plan modification process that is necessary for processors to operate with. Also, USFDA believes that the effectiveness of a plan is best evaluated under actual operation conditions (USFDA, 1999, QAs).

The USFDA verifies the performance of the industry-wide HACCP program by evaluating the results of reports of HACCP-based inspections performed by USFDA investigators and by cooperating with state and local agencies (USFDA, 2009). Every 2 years, the USFDA releases the report, USFDA's Evaluation of the Seafood HACCP Program; the latest is for fiscal years 2004/2005. Seafood HACCP inspection and training efforts have resulted as evidenced by the steady improvements over the years. Yet, despite increased USFDA efforts, certain industry segments are improving at a slower pace. Based on the most current evaluation of 2004/2005, the USFDA has nine recommendations for improving HACCP programs and implementation as follows:

- (1) Continue to prioritize all processors of high-risk potential fishery products, particularly processors of scombrototoxin forming species and cooked ready-to-eat products, for annual inspection.
- (2) Increase the inspectional priority of processors and importers of aquaculture products.
- (3) Issue the fourth edition of the Fish & Fisheries Products Hazards and Control Guidance to facilitate compliance by processors of scombrototoxin forming species, issued in 2011.
- (4) Work on developing strategic, measurable goals for industry segments that have traditionally lagged behind.

- (5) Increase the number of importer inspections to reflect a more accurate representation of the size of the industry.
- (6) Implement outreach programs to educate importers with regard to their responsibilities and the options available to them.
- (7) Develop a system that creates a follow-up mechanism for foreign inspections based on domestic importer inspectional findings.
- (8) Continue foreign inspections targeting processors of high-risk products. Implement outreach programs for foreign competent authorities and industry groups to provide guidance in USDA's safety recommendations.
- (9) Continue to plan and implement the "Histamine (Scombrototoxin Forming) Outreach Project" (USFDA, 2009).

In addition to HACCP record review, USFDA collects and analyzes samples of products from processors that are operating under compliant HACCP programs, in an effort to determine whether safety defects are occurring in such products. Traditional program evaluation methods, such as reviews of consumer and trade complaints and regulatory actions, are also used (USFDA, 1999, QAs).

### Monitoring sanitation control procedures

With the introduction of the seafood HACCP regulation, sanitation is recognized as a prerequisite to HACCP and provides a foundation for safe food production (Seafood HACCP Alliance, 1999). Even if no hazards are identified resulting in no need for the HACCP plan, the HACCP regulation still requires processors to monitor eight sanitation control procedures (SCP) based on potential contamination caused by environmental and personal hygiene factors (see Chapter 27). The sanitation monitoring requirements are new to the industry, but sanitation standards have been in place for many years as part of USFDA's Good Manufacturing Practice Regulation—21CFR 110 (GMP's). Not all eight sanitation conditions may be relevant to a processor (i.e., many of the eight sanitation control procedures may not be relevant to warehouses that store packaged fish). In this situation, only the relevant conditions require monitoring. Processors are not required to have a written sanitation standard operating procedure (SSOP). Yet, a written plan is

strongly recommended, because an SSOP would help the processor identify the tasks necessary to meet the sanitation monitoring requirement in 21 CFR 123.11 (USFDA, 1999, QAs).

Under the HACCP regulation, seafood processors are required to maintain monitoring and correction records, but the firm does not need to review those records (USFDA, 1995). In contrast, processors must review HACCP monitoring, corrective action and calibration records within certain time constraints. For practical purposes, it is prudent for processors to perform a review of sanitation records to ensure that they are maintaining sanitation control in the plant (USFDA, 1999, QAs). All records required by the seafood HACCP regulation, including sanitation records, must be retained for 1 year for refrigerated products and 2 years for frozen preserved or shelf stable products (USFDA, 1995).

Although training is not mandatory for the eight sanitation control procedures, the Seafood HACCP Alliance developed a SCP course to assist the seafood industry in complying with the SCP requirements. SCP course announcements are located on the coming events page of the University of California Sea Grant Seafood Network Information Center (Seafood NIC) Web site (<http://seafood.ucdavis.edu>). The training manual (Seafood HACCP Alliance for Education and Training, 2000) and a video-streaming version of the Sanitation Control Procedures Course produced by the University of Delaware Sea Grant and Delaware State University are hosted on the SeafoodNIC Web site. Written sanitation standard operating procedures are not required, but recommended. Complete examples of the SSOPs are available (Seafood HACCP Alliance for Education and Training, 2000, 2001).

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# 24

## Aquaculture

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Brian G. Bosworth

Aquaculture is defined as the rearing of aquatic organisms under controlled conditions. An aquaculturist has control over all or a part of the organism's life cycle. This control sets aquaculture apart from traditional capture fisheries in which organisms are harvested from natural stocks. Aquaculture is similar to terrestrial (land-based) agriculture, except that in aquaculture the crop is reared in water.

This chapter gives a brief overview of aquaculture rather than providing detailed descriptions of culture systems and techniques. Several excellent texts on aquaculture (Stickney, 1979; Huner and Brown, 1985; Tucker, 1985; Stickney, 1986; Laird and Needham, 1988) are available if more detailed information is desired.

### History of aquaculture

Aquaculture probably was first practiced in Asia and has long been a part of the rural economy there (Liao, 1988). Records indicate that aquaculture began about 1000 BC in China, probably due to the desires of an emperor to have a constant supply of fresh fish. Many aquaculture techniques devel-

oped centuries ago are still used in Asian countries. Techniques developed in Asia were later adapted and used by aquaculturists on other continents.

Compared to Asia, aquaculture development in the United States is a very recent industry. US fisheries biologists began hatching and stocking fish throughout much of the country during the late 1800s. However, it was not until the late 1950s that large-scale commercial production of aquatic organisms as a food source began (Dupree and Huner, 1984).

Until recently, aquaculture has been a subsistence production system in which aquatic species were grown primarily to produce food for personal consumption (Aiken, 1988). Increased demand for seafood products coupled with a leveling off of traditional fisheries harvest have provided the stimulus for rapid growth in aquaculture. Worldwide, aquaculture production (including plants) has increased rapidly from less than a million metric tons (mmt) in the early 1950s to approximately 60 mmt with a value of US\$70 billion (FAO, 2006). World aquaculture production has increased at an annual rate of 8.8% from 1950 to 2004. The rapid increase in production has resulted in a wide variety of species being cultured in various production systems.

## Types of aquaculture

Several criteria are used to describe different types of aquaculture. A common system of classification is based on the taxonomy of the cultured organisms. Included among these are finfish aquaculture (trout, catfish, carp, etc.); crustacean aquaculture (shrimp, crawfish, lobsters, crabs); mollusk aquaculture (clams, mussels, oysters); and plant aquaculture (kelp, algae).

The level of management is another criterion used to define the various types of aquaculture. Level of management is usually defined as the quantity of an organism produced per area or volume of water and includes extensive, semi-intensive, intensive, and highly intensive aquaculture.

Extensive aquaculture involves very little if any input of energy (feed, fertilizer, aeration, etc.). The animals are simply placed in a pond, allowed to feed on naturally occurring materials, and harvested when they reach an appropriate size. Production from extensive aquaculture is usually low, less than 566 kg/ha (500 lb/acre). Generally, as the level of intensity increases, so does production, but with a parallel increase in the amount of energy put into the system. Semi-intensive aquaculture, 2240–4480 kg/ha (2000–4000 lb/acre), involves higher energy inputs, including feeds and perhaps aeration. Intensive aquaculture, 4480–22,417 kg/ha (4000–20,000 lb/acre), is usually practiced in tanks or raceways and requires very high energy input. High feeding rates, continual aeration, and large water exchanges (old water flushed out and replaced with new) are usually required to maintain animals under intensive culture conditions. Highly intensive systems, up to 400 g/L (3.5 lb/gal), are energy costly but allow very high production in a relatively small amount of water. Oxygen injection, water filtration, and continuous water exchange are commonly used in highly intensive systems.

Although the vast majority of aquaculture production is from extensive or semi-intensive systems; the trend is toward intensification. The field of highly intensive aquaculture is fairly new, but is receiving increased interest due to its potential for increased production in a highly controlled environment.

Water temperature is also sometimes used to classify the type of aquaculture being practiced. The following arbitrary temperature ranges

are often used to describe aquaculture: 0–10°C (32–50°F) cold water aquaculture—trout, salmon; 10–20°C (50–68°F) cool water aquaculture—perch, bass; and greater than 20°C (68°F) warm water aquaculture—catfish, tilapia.

The salinity of water is another criterion used to describe aquaculture. Classifications based on water salinity include: freshwater aquaculture (less than 1 ppt salinity), brackish water aquaculture (1 to 17 ppt salinity), and mariculture (greater than 17 ppt salinity).

Sometimes, it is desirable to grow only one species in a given pond or tank; other times, it is more efficient to grow several species. The number of species reared is another method for describing the type of aquaculture practiced. **Polyculture** is used to describe systems in which more than one species is cultured in each pond or tank; **monoculture** refers to situations in which only one species is reared.

Obviously, there are many ways to describe aquaculture. The criteria and ranges given here are arbitrary and are only intended to give some descriptions of the many types of aquaculture. Other authors may use slightly different ranges or classifications to define different types of aquaculture.

## Advantages and disadvantages of aquaculture

The advantages of aquaculture over traditional fisheries include predictability of supply, reduced time from harvest to processing, and control over the organism's environment. Because aquaculturists know approximately how many animals they have and when the animals will be ready for harvest, they can guarantee a certain amount of product at a particular time. Aquaculture facilities are usually based on or near land; therefore, the harvested animals can be quickly processed assuring a high-quality product. The aquaculturist has at least some control over the animals' environment (water quality, feed quality, etc.) which can also result in improved product quality.

The main disadvantage of aquaculture compared to capture fisheries is the amount of energy (costs) used in aquaculture production. Although a fisherman can have a considerable investment in his boat and harvesting equipment, the aquaculturist has additional costs in facility construction, seed stock, and feeds. Aquaculture is unlikely to ever

completely replace traditional capture fisheries, but it can help meet demands not met by the harvest of natural stocks.

Aquaculture possesses certain advantages and disadvantages when compared to terrestrial agriculture. Among the advantages are (1) water is a three-dimensional culture medium, (2) most aquatic animals are able to maintain neutral buoyancy, and (3) most aquatic animals are poikilothermic (cold-blooded) (Bardach et al., 1972).

Because water is three-dimensional, several species of fish can be cultured in the same "space." Fish that normally live on the bottom can be cultured in the same volume of water as fish that prefer to reside near the surface. This arrangement allows for efficient utilization of available space.

Most fishes have an air bladder, an organ which allows them to move up or down in the water column while maintaining neutral buoyancy. This feature allows fish to save some of the energy terrestrial animals must expend "fighting" gravity. Other aquatic organisms such as mussels, clams, and oysters live on the bottom and expend little energy for movement. Energy saved can be used for body growth or other physiological activities. The result is that aquatic organisms are often better at converting feed to flesh than terrestrial animals.

Probably a primary factor contributing to the efficient feed conversion for most aquaculture species is the fact that most aquatic organisms are poikilothermic. Aquatic animals' internal temperature will be very near that of the surrounding water. Most terrestrial livestock species are homothermic (warm-blooded) and must maintain a constant internal body temperature to maintain physiological functions. Warm-blooded animals expend a great deal of energy maintaining their body temperature when environmental temperature fluctuates. Cold-blooded aquatic animals do not use energy to maintain body temperature and the energy saved can be used for growth, resulting in high feed conversion.

Compared to traditional livestock production, aquaculture also has some disadvantages, including (1) physical and chemical contamination of the medium, (2) difficulty in observing the crop, and (3) poikilothermic nature of aquatic animals. Aquatic organisms are in direct contact with the water they are reared in. High concentrations of metabolic end products (particularly ammonia) produced by the fish can result in reduced growth, poor health, and

even death. Aquatic organisms are often sensitive to pollutants or naturally occurring metals found in some water supplies. To provide an adequate environment for the cultured species, these contaminants must be removed or avoided.

Aquaculturists often have difficulty observing their crop because it is under the water's surface. A cattle rancher can quickly assess his animals' environment by simply riding through the field containing the cattle. It is not as easy for aquaculturists, who must instead depend on instruments and chemical tests to evaluate the conditions experienced by their animals. For example, an oxygen meter must be used to determine the dissolved oxygen concentration (a very important parameter) in the water. Many salmon aquaculture facilities have underwater camera systems that allow observation of fish feeding, behavior, and indications of disease problems.

Although being cold-blooded has some advantages, it also can be a disadvantage because most fish have evolved to grow well only in a fairly small temperature range. Outside this range, reduced growth and even death can occur. When environmental temperatures fall outside the preferred range, production rates and thus profits will decline. Unsuitable water temperatures are one of the main constraints to culturing some species in certain parts of the world.

## Basic requirements of aquaculture

The prime requirement for a successful aquaculture operation is an adequate supply of suitable quality water. The terms "suitable" and "adequate" vary somewhat with the species being cultured, the type of culture system, and the intensity of production, but water supply is the first thing a potential aquaculturist should check when selecting a site. It is advisable to have an experienced water quality expert evaluate a potential site's water supply before beginning construction of an aquaculture facility.

Along with a good supply of water, the aquaculturist must know which water quality parameters are important and at what levels they can begin adversely affecting the species being cultured. Dissolved oxygen, water temperature, hardness, alkalinity, pH, ammonia, and nitrite are important water quality parameters that must be measured regularly. Monitoring of water quality can be performed

easily using water test kits and instruments produced by several companies. Boyd (1979) gives a detailed description of important water quality parameters, methods for measurement, and toxic levels.

Another obvious requirement, but one that is often overlooked, is that the organism being cultured should have good market demand. Often, the culture techniques and biology of an organism are well known, but unless the organism can be reared profitably it is not a good candidate for aquaculture. For example, carp are cultured on a large scale in Asia where they are in high demand, but probably could not be cultured profitably on a large scale in the United States where they are generally considered trash fish. Product value, regional and seasonal trends in demand, availability of processing facilities, and cost of production are all issues to be considered before beginning to culture an organism.

A certain amount of knowledge is needed to become a successful aquaculturist. An understanding of the organism's biology is very important. Information on optimum water temperatures for growth, nutritional requirements, possible diseases, and their treatments all must be known to successfully culture an organism. In the case of some species (e.g., catfish, trout, crawfish), the biological requirements have been documented (Huner and Barr, 1984; Tucker, 1985; Solbe, 1988). The requirements of organisms which have not been cultured previously or cultured only recently may not be known. Often, the general principles of aquaculture (e.g., good water quality, adequate feed) will suffice, but a lack of information on a critical life stage could hinder culture of a particular species. As the science of aquaculture continues to grow, many of the requirements of certain organisms will be determined through research and through trial and error.

An aquaculturist must have some engineering and mechanical skills. Because aquaculture is such a young industry, the equipment needed is often unavailable or requires modification. The abilities to design and build certain equipment can save the aquaculturist time and money. Routine maintenance and repair of equipment are also essential.

Finally, an aquaculturist must possess at least basic business skills if they want to be successful. Knowledge of bookkeeping, accounting, marketing, finance, personnel management, and so on, is necessary in all businesses including aquaculture. Often, an aquaculture enterprise will fail not

because the aquaculturist was a poor biologist, but because he or she lacked good business and personnel management skills.

## Aquaculture production

### Worldwide

China accounted for 41.3 metric tons (mt) (69.6%) of the total global aquaculture production of 60 mmt in 2004 and the rest of Asia and the Pacific region accounted for an additional 21.9% of production (unless otherwise noted, production estimates listed in the text are derived from FAO, 2004, 2006). Although world aquaculture production is dominated by Asia, significant aquaculture production does occur in other countries (Table 24.1).

Of the total aquaculture production in 2004, fish accounted for 47.4% of production and 53.9% of value, aquatic plants were 23.4% of quantity and 9.7% of value, crustaceans were 6.2% of volume and 20.4% of value, and mollusks comprised 26.5% of volume and 14.2% of value. Of the total production, 43.4% was from freshwater, 50.9% from marine water, and 5.7% from brackish water.

Approximately 440 aquatic species are listed as being under some sort of culture since 1950. The cyprinids (primarily carp species) represented the taxonomic group with the greatest

**Table 24.1** Top ten countries in aquaculture production of species of aquatic animals (not including plants) in 2003.

Country	Production (tons)	Production of world total (%)
China	28,892,005	68.3
India	2,215,590	5.2
Indonesia	996,659	2.4
Vietnam	937,502	2.2
Japan	859,656	2.0
Bangladesh	856,956	2.0
Thailand	772,970	1.8
Norway	582,016	1.4
Chile	563,435	1.3
USA	544,329	1.3
Rest of World	5,083,023	12.0
Total	42,304,141	99.9

Source: FAO, 2004. Reproduced with permission from the Food and Agriculture Organization of the United Nations.

**Table 24.2** Top ten species groups for aquaculture production of aquatic animals (not including plants) in 2003.

Species group	Production (tons)	Production of world total (%)	Value (million US\$)
Carp/other cyprinids	17,215,123	40.7	15,531
Oysters	4,496,659	10.6	3794
Clams	3,788,296	9.0	4276
Salmon/trout	1,828,760	4.3	5602
Shrimp/prawns	1,804,932	4.3	9323
Tilapia/other cichlids	1,677,751	4.0	2036
Mussels	1,589,464	3.8	996
Scallops	1,178,468	2.8	1693
Miscellaneous marine mollusks	1,232,293	2.9	628
Miscellaneous freshwater fishes	4,250,076	10.0	5636
Other species	3,242,319	7.7	11,649
Total	42,304,141	100.1	60,984

Source: FAO, 2004. Reproduced with permission from the Food and Agriculture Organization of the United Nations.

production (18.2 mmt) and value (US\$16.3 billion) in 2004. Several carp species dominated world aquaculture production; other groups contributing significantly to the total included oysters, mussels, tilapias, salmonids, catfishes, clams, and shrimps (Table 24.2).

## United States

US fish farmers produced 420 million kg (926 million lb) of product in 2003 with a value of US\$961 million. Domestic farm-raised catfish continued to strongly dominate US aquaculture production, although production of catfish has dropped significantly between 2003 and 2008. The US aquaculture is primarily from three species: channel catfish (*Ictalurus punctatus*), rainbow trout (*Oncorhynchus mykiss*), and red swamp crawfish (*Procambarus clarkii*). Crawfish and catfish culture are centered in the southeastern United States; the majority of cultured trout are produced in the state of Idaho. Other significant species cultured for food in the United States included Atlantic salmon, tilapia, hybrid striped bass, clams, oysters, mussels, and prawns. Aquaculture in the United States is not limited to food production. Culture of baitfish (golden shiners, fathead minnows, etc.) and tropical fish are fairly large and growing industries. Production of fish for stocking programs is a major form of aquaculture in the United States. More than

800 million juvenile sport fish are produced in federal, state, and private hatcheries and stocked each year (Sandifer, 1988).

## Culture systems and techniques

The following sections briefly describe systems and techniques used to culture some of the more important cultured species. The organisms discussed include catfish, salmon, trout, carp, shrimp, crawfish, oysters, and marine algae.

### Catfish

The channel catfish (*I. punctatus*) is the production and total value “king” of aquaculture in the United States. In 2004, the US catfish harvest totaled over 270 million kg (600,000 million lb). Approximately 68,796 hectare (170,000 acres) were devoted to catfish culture in 2004 with the majority of the acreage in Mississippi, Arkansas, Alabama, and Louisiana. Since 2004, production acreage and volume have decreased due to high feed and fuel prices, and competition from imported catfish from Asia. However, catfish farming remains the largest sector of US aquaculture industry and is an important part of the rural economy in the southeastern United States.

Channel catfish can be grouped into four production categories: brood fish, fry, fingerlings, and



marketable fish. Brood fish are adults used to produce offspring for the culture operation. Male and female brood fish are usually placed in a pond together and spawning occurs in the spring when water temperatures reach approximately 24.5–26.5°C (76–80°F). The female lays her egg mass in a container (milk cans are often used) placed in the pond by the culturist. The male fertilizes the eggs and chases the female away. The male will continue to guard and care for the eggs until they hatch; about 7 days at 27°C (81°F).

Although eggs can be allowed to hatch in the pond, the farmer usually removes them and incubates them in a hatchery. Use of the hatchery method gives the farmer better control over fry production. The young fry (newly hatched fish) begin to feed 5–7 days after hatching and are fed a high protein starter ration several times each day. After a week or two, fry are transferred to earthen ponds and are fed larger rations as they grow to fingerling size. After a few months in these ponds, the fingerlings are harvested and transferred to larger, 10–20 acre (4–8 ha) production ponds. In the production ponds, the fish are fed a floating, pelleted ration to approximate satiation daily during the feeding season (April through October). A size selective seine is used to harvest the catfish when they have reached a marketable size of 0.68–1.81 kg (1.5–4.0 lb). In the southern United States, it takes a catfish fry 2–3 years to grow to harvestable size. The production schemes described here for catfish and other species are based on general approaches, and many variations in production schemes exist in reality.

## Salmon and trout

The Atlantic salmon (*Salmo salar*) and the rainbow trout (*O. mykiss*) are the most commonly cultured salmonids. The life cycles of these two species are among the most well understood and controllable of all cultured species, which, along with the high market value, make them ideal candidates for culture.

The majority of Atlantic salmon production is located off the coasts of Norway, Scotland, and Chile. Salmon farming accounted for 2.7 million metric tons in 2003 which was about two-thirds of total annual salmon production.

A typical salmon production scheme involves fry, smolt, and market fish production. Domesti-

cated brood fish selected for improved production characteristics are used to produce seed stock. When brood fish are ready to spawn, the males and females are “stripped” of their gametes. Stripping is accomplished by applying pressure to the fish’s abdomen, causing the eggs and sperm to be released. Eggs and sperm are mixed and the fertilized eggs are placed in incubators. The eggs are incubated in cold water, 8–12°C (46–54°F), and hatch in about 30 days.

When the young fry have absorbed their egg sac and start to feed, they are fed a high protein starter ration. The young salmon are reared in freshwater in large tanks. Later, they go through a process called smoltification, a series of physiological changes that prepare them for life in seawater.

Smolts, salmon that have gone through this process, are transferred from freshwater to large net pens or cages in the ocean. The enclosures retain the salmon but allow water to flow through and wash away wastes. Salmon are fed high protein pelleted rations and harvested at a size of 3.5–4.5 kg (8.0–10.0 lb).

An ideal site for net pen culture is sheltered from the wind, easily accessible, and has a good flow of high quality, and appropriate temperature water. The coasts of Norway, Scotland, and Chile provide ideal conditions for salmon culture. There has been considerable interest in culturing the Atlantic Salmon along the coasts of the United States and Canada, but development has been slow. Conflicts with commercial and recreational fishermen, interference with boat traffic, and environmental concerns may hinder the development of salmon farming in these areas.

Rainbow trout are cultured primarily in Europe, the United States, and South America. Similar techniques are used to culture both trout and salmon although trout remain in freshwater their entire life. Trout are usually cultured in concrete or earthen raceways (long, rectangular tanks) with water continuously flushed through the raceways to carry away wastes.

Trout are stocked at high densities and fed high protein rations. They are graded and harvested when they have reached marketable size. The availability of an adequate quantity of high-quality water (appropriate temperature and high dissolved oxygen) are necessary for profitable culture of rainbow trout. Commercial trout production is limited to areas such as Idaho, where free flowing

groundwater is available in sufficient quantities needed for production.

## Carp

Four species of carp: the common carp (*Cyprinus carpio*), grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalmichthys molitrix*), and bighead carp (*Aristichthys nobilis*) dominate world aquaculture production. Carp are widely cultured in Europe and Asia but are not grown to a large extent in the United States.

In Europe, common carp are cultured extensively in earthen ponds. Manure from other farm animals is often added to the pond to stimulate production of natural food organism. Grains are sometimes added as supplemental feed. Yield from this type of culture is low but the production costs are also low.

In Asia, a more intensive carp culture is practiced. Often, all four of the previously mentioned species of carp are grown together in heavily fertilized ponds in an efficient polyculture scheme. Because each species has a different food preference there is little competition between species for available food, and production is very efficient. The common carp is an omnivore and feeds along the bottom. The silver carp feeds on phytoplankton which it filters out of the water. The bighead carp feeds on zooplankton, and the grass carp feeds on aquatic plants. Polyculture of carp can result in production of up to 7850 kg/ha (7000 lb/acre).

## Shrimp

Culture of Penaeid shrimp is a significant aquaculture business worldwide. Cultured shrimp comprised about 25% (1.6 million tons) of the total shrimp production worldwide of over 5 mmt in 2003. About 75% of farmed shrimp is produced in Asia, primarily in China and Thailand, and the remaining production comes mostly from Latin America. The value of farmed shrimp was approximately US\$9 billion in 2003.

Typically, shrimp are hatched in modern hatcheries, postlarval (very young) shrimp are stocked into large earthen ponds, fed a pelleted ration, and harvested when they reach 15–20 g (0.5–0.7 oz) each. If the stocking rate is high (intensive culture), the water is periodically exchanged

to maintain suitable quality. Shrimp grow to harvestable size fairly quickly, and usually two or three crops can be harvested each year in tropical areas. Advances in hatchery techniques have allowed production of hatchery-reared postlarvae needed for stocking shrimp production ponds.

Shrimp culture is practiced only on a very small scale in the United States and may be limited by low winter temperatures and a lack of suitable pond sites. However, recent research on intensive culture of shrimp in South Carolina has shown some potential for development of this industry (Sandifer et al., 1988).

## Crawfish

Freshwater crawfish culture is the major crustacean culture endeavor in the United States. The majority of crawfish are produced in Louisiana, where approximately 40,000 ha are devoted to crawfish culture (100,000 acres) and 25–30 million kg (55–66 million lb) are harvested annually (Romaine et al., 2005). Red swamp crawfish, *P. clarkii*, account for approximately 90% of the pond harvest in Louisiana. The red swamp crawfish is also cultured in several other southeastern states and several European and Asian countries.

Crawfish are usually grown in shallow earthen ponds with rice as forage. The production cycles of rice and crawfish complement each other nicely. Ponds are usually drained in the late spring, the crawfish burrow into the pond bottom, and the rice is planted. During the summer, crawfish remain in their burrows as the rice grows. In the early fall, female crawfish lay eggs and hatch their young. About this time the rice is flooded and the young crawfish emerge from their burrows and feed on the rice as it decays. They reach harvestable size (greater than 75 mm (3 in) total length) by mid to late winter.

Baited wire mesh traps are used to harvest the crawfish. Fifty to hundred traps are placed per hectare of culture pond. Because the traps must be emptied and baited every day, crawfish farming is a very labor-intensive business. During the late spring, the pond is drained, rice planted, and the production cycle begins again. Crawfish are sold live, frozen whole, or are processed and sold as fresh or frozen abdomen meat. Most crawfish produced in the United States are currently sold as live whole

product due to competition from lower priced frozen tail meat imported from China.

## Oysters

Approximately 8 million kg (18 million lb) of oysters were produced from aquaculture in the United States in 2002. Several species are cultured worldwide, but most of them belong to the genus *Ostrea* and *Crassostrea*. Oysters produce a mobile larva that eventually attaches itself to a suitable substrate and becomes sessile (nonmobile) for the remainder of its life. Once attached, shell development begins and the young oyster is called a spat. Oysters feed by filtering phytoplankton and other organic particles out of the water. Spat grow to harvestable size oysters in 1–3 years.

US oyster growers usually use extensive culture techniques. Wild or hatchery reared spat are collected and transferred to privately leased oyster beds. Oysters are filter feeders and feed off naturally occurring plankton and algae. The aquaculturist periodically checks the “crop” and harvests the oysters when they reach marketable size. Although this system is generally classified as aquaculture, it has also been referred to as a highly managed natural fishery.

More intensive, off-bottom culture of oysters is practiced in Europe, Japan, and to a small degree in the United States. Oyster spat, attached to sticks or strings, are suspended in the water column in off-bottom culture, which generally allows higher production per unit volume of water, faster growth, and easier harvest.

## Aquatic plants and algae

One of the largest, yet often overlooked, segments of the aquaculture industry is the culture of plants and algae. Plants and algae comprised 23.4% of the 60 million metric tons of worldwide aquaculture production in 2004, accounting for 9.7% of total aquaculture value. The majority of cultured algae are macroalgae (kelp, red and brown algae).

Macroalgae, usually referred to as seaweeds, have been cultured for over 300 years (McCoy, 1987). Algal products are used in foods, cosmetics, pharmaceuticals, and for industrial purposes. Seaweeds can be grown extensively in ocean bays

or intensively in large tanks. In China, for example, kelp is grown suspended from long bamboo rafts and is fertilized to increase production. Methods of harvesting seaweeds range from labor-intensive hand picking to the use of mechanized harvesters, a kind of underwater hay bailer.

The lack of unused, protected coastal bays necessary for extensive culture of seaweeds limits production in the United States. Intensive tank culture of seaweeds has generated considerable interest and may be a suitable alternative to extensive culture. Recent advances in propagation and genetic manipulation of algae have improved the potential for intensive culture. Although algae culture receives less notice than other types of aquaculture, it is a substantial industry in certain parts of the world and has excellent potential for growth. Use of algae for renewable biodiesel production is being promoted as a replacement for traditional fossil fuel resources.

## Current issues related to aquaculture production

Since the writing of the first edition of this text, several issues related to aquaculture production have become more important. Although the issues are multiple and diverse, they can primarily be categorized as issues of sustainability and regulation.

Recent literature on agriculture production frequently refers to the concept of “sustainability.” However, the term sustainable can be difficult to define and may have different meanings for various groups in society. It is beyond the scope of this chapter to discuss in detail the various viewpoints and definitions related to sustainable aquaculture. Certainly, sustainability must include, at a minimum, concepts of production that is environmentally and economically sustainable. Boyd and Schmittou (1999) define sustainable aquaculture as that “where ecological and economic viability persist indefinitely.” Currently, various environmental groups are developing rating criteria for the sustainability of various aquaculture practices and species. These guidelines will help provide consumers and producers criterion to evaluate the sustainability of various aquaculture production practices. However, the concepts and criteria needed to consistently and accurately compare the sustainability of various aquaculture practices

are still being defined. As the process of defining and assessing sustainability of aquaculture develops, the concept of sustainability will help guide the development of aquaculture to promote both economically and environmentally sound practices.

As aquaculture production continues to expand, various regulatory issues are becoming more important. Conflicts between various competing user groups will increase as aquaculture continues to expand. Interest in expanding marine, off-shore aquaculture facilities will likely meet with opposition from other user groups. Issues related to escape of animals from farms into natural environments, discharge of wastes from aquaculture facilities into the environment, and animal welfare will all continue to increase in importance. Issues related to product safety, identification, and certification will require more strict regulatory oversight. Many of these issues are unavoidable and the aquaculture community will benefit by taking a proactive approach to addressing and finding solutions to these issues that will allow continued expansion of aquaculture.

## Future of aquaculture

Aquaculture is an established industry and appears to have a bright future. The demand for high-value seafood products is growing, and capture fisheries will be unable to keep pace with the demand. Per capita consumption of seafood has increased in the last 30 years due, at least in part, to the health benefits of eating fish and the greater availability of seafood products.

Future trends in aquaculture, at least in the United States, will be more toward increasing the intensity of production than increasing area devoted to production. Research on genetic improvement, nutritional requirements, diseases, and marketing of aquatic organisms should result in increased production and profits.

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# 25

## Waste Treatment

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Gregory D. Boardman

Most seafood processing requires a volume of clean water for preparation and preservation of final products. Clean water is used to wash, thaw, transport, cook, formulate, and/or package seafood products. The usual consequence of this water use is the addition of some foreign matter or waste materials which pollute the original water supply. The type and amount of pollutants entering the water will depend on the product forms, processing methods, and amount of product and volume of water used.

Regulations have been developed to encourage industrial wastewater management programs to prevent, control, or remove certain pollutants which could cause adverse environmental problems. These programs can include methods to treat the water and utilize any waste materials (see Chapter 11). Waste treatment is an additional operating cost, but waste utilization could represent additional profits or a least-cost treatment option. Waste management is not unique to the seafood industry. All industrial users of water must provide some program to prevent water pollution. Fortunately, water pollution from seafood processing is relatively mild compared to hazardous pollution resulting from many other industrial processes. Regardless of the source or amount of pollution,

the seafood industry must recognize and support the need for controls to preserve the quality of our nation's waters. The seafood industry depends on production from clean waters.

### Seafood wastewater

Materials which can cause water pollution during seafood processing include viscera, offal products, skin, scales, shell, and body parts. Most of these materials are large, visible with the naked eye, and can be removed with simple cleanup procedures, filtering, screens, and settling basins. Smaller, dispersed pollutants, which may be visible only as clouding in the water flow, may be dissolved or suspended in the water when the flow or spray runs along the product surface removing slimes, soluble proteins, body fluids, blood, and small particles of meat. Additions from breadings, batters, and oils also may cause small-size dispersed pollution. If some of these pollutants are not removed, the wastewater could cause adverse environmental consequences.

For example, when the polluting materials in a seafood processing effluent are discharged into the environment (e.g., stream, lake, or bay) they are



usually biodegradable, meaning oxygen is required to decompose the materials into their simplest chemical form. The result can be a decreased oxygen level in the environment and an addition of various chemicals as basic nutrients for growth of plants and plankton. Excessive nutrients can cause over-fertilization, or eutrophication, which disrupts the ecological balance of the receiving water. Eutrophication may cause a further decrease in the oxygen levels essential for established aquatic life.

These results are a basic explanation of adverse consequences; the actual results are far more complicated. Changes in the existing environmental water chemistry (e.g., altering pH) could influence survival of certain animals and plants. Addition of materials which discolor, cloud, or float in the water can be visually degrading and can influence water transparency, thus altering the penetration of essential sunlight. By attracting certain fish or crustaceans looking for food, pollutants may cause an adverse imbalance in aquatic species competing for the food supply. Therefore, pollutants in seafood wastewater can disrupt the existing ecology of the receiving waters.

Similarly, seafood processing effluents can affect the operation of local wastewater treatment facilities. Although the facility is designed to treat wastewaters, the concentrations and volume of pollutants flowing from a local seafood processing operation could disrupt or overload the facility's treatment capacity. This outcome is especially true for seafood processing plants operating in a batch-type mode, sending irregular amounts of wastewater for treatment. The intermittent surge of wastewater from the seafood processing plant can disrupt the treatment operations, requiring extra time and labor to readjust. The consequence can be increased costs for water use and treatment.

Various analytical methods have been developed to characterize and predict the consequences of wastewaters. These characteristics are commonly called pollutant parameters. The parameters of major significance to seafood processing wastewater are biochemical oxygen demand (BOD), total suspended solids (TSS), and fats, oil and grease (FOG or simply O&G). To establish certain guidelines, pH is included as a parameter that must fall within a specified range. Of occasional importance are temperature, phosphorus, coliform bacteria, chloride, chemical oxygen demand (COD), settleable solids, and various nitrogen species (i.e.,

ammonia, nitrite, and nitrate). All of these parameters are considered conventional pollutants.

Fortunately, most seafood processing effluents do not contain toxic pollutants such as heavy metals and pesticides. In high concentrations, both chloride and ammonia could represent a toxic condition for aquatic life, but usually these are not a problem in seafood processing effluents. Discharge of concentrated salt solutions (NaCl brines, etc.) could represent an adverse condition if not diluted and gradually released to prevent sudden impacts.

## Pollution parameters

### Biochemical oxygen demand

BOD is a measure of the amount of oxygen needed to stabilize or biologically decompose (oxidize) the organic matter in water. The BOD does not cause direct harm to a water system, but it does exert an indirect effect by decreasing the dissolved oxygen (DO) content in the receiving waters. DO in the water must be maintained at an appropriate level to support biological organisms including certain bacteria, fish, and plants. The BOD analytical method actually simulates the influence waste materials have on the DO. If high BOD is present, the quality of the water is usually visually degraded by the presence of cloudy decomposing materials. However, detrimental levels of BOD may be present without visual detection. The standard BOD test is performed over 5 days at 20°C (68°F) in the dark (to avoid the influence of algae), and the resulting data are reported as BOD<sub>5</sub> values.

### Total suspended solids

TSS includes suspended matter (undissolved solids) in the wastewater, with the exception of coarse or floating materials. TSS is measured by laboratory filtration through a specified filter (glass fiber) to collect a specified material size  $\leq 2 \mu\text{m}$  (American Public Health Association (APHA), 2005). The suspended matter can include organic materials (shell fragments, fats, grease, particles from products, etc.) and inorganic materials such as sand and silt. The level of organic materials can correlate well with the BOD, thus representing a potential source of demand for DO. At high concentrations, these materials can be aesthetically displeasing and can increase water turbidity, which

reduces light penetration and photosynthetic activity of algae and other aquatic plants. In time, some of these materials can accumulate at the bottom of a water body and adversely affect the organisms living in or on the surface of the natural sediments.

Suspended solids which settle readily under quiescent (calm) conditions are called settleable solids. Measurements for these solids is especially applicable to the analysis of wastewaters being treated by screens, clarifiers, and flotation units. It not only defines the systems, in terms of settleable materials, but provides an estimate of the amount of deposition that might take place under quiescent conditions in the receiving water after discharge from the processing operation. The standard laboratory test for settleable solids involves placing a liter sample in an Imhoff cone and recording the amount of sediment in mL that collects after 1 hr (APHA, 2005). Therefore, the resulting measurement is expressed in terms of mL/L, as opposed to mg/L, the units for TSS.

### Fats, oils and grease

FOG can cause surface slicks, scum accumulation, and clogged filters. FOG can contribute to oxygen demand and influence the reaeration of water at the surface. Certain oils can form an oil-water emulsion which could damage aquatic plant and gills of fish. FOG is not a common problem for most seafood processing operations; it is more typical as an adverse consequence of canning and cooking operations which may incorporate oil as an additional ingredient or "cooking" oils from the raw materials. However, it is possible for fish processing operations to yield unacceptable effluent levels of FOG. Through the years, different solvents have been used in the laboratory test for FOG, but currently the common choice is *n*-hexane. The *n*-hexane is used to extract the FOG in a sample, and then through evaporation and/or distillation, the *n*-hexane is separated from the extracted FOG. In the literature, authors often refer to FOG as simply oil and grease (O&G).

### pH

The pH of water is a measure of the hydrogen ion concentration. The p stands for  $-\log$ , so pH is the  $-\log[H^+]$ . Values for pH range from 0 to 14. Low pH values indicate acidic conditions (high  $H^+$  level), and high pH values indicate alkaline or less acidic

conditions (low  $H^+$  level). Aquatic life often prefers a pH near 7.0, which indicates a neutral condition. Extremes or rapid changes in pH can stress or kill aquatic life.

### Concentrations for pollution parameters

Concentrations for pollution parameters are usually expressed as pounds of a particular pollutant per 1000 pounds of product processed. Thus, a pollutant concentration in lb/1000 lb or kilograms/1000 kg (kg/kkg) can be specific for a certain firm, and all processors must meet a specified limit of similar units. This system prevents excessive water use as a possible method to dilute pollutants. The following formulas are for calculating waste concentrations as lb/1000 lb or kg/kkg, and backcalculation as milligrams/liter (mg/L) or parts per million (ppm):

$$\begin{aligned}
 & (\text{mg/L}^a \times \text{MGD}^b \times 8.34^c) / (\text{tons/day}^d \times 2^e) \\
 & \quad = \text{lb pollutant} / 1000 \text{ lb raw material} \\
 & \frac{(\text{mg/L}^a \times \text{m}^3/\text{day}^f \times 10^{-3g})}{\text{kkg/day}^h} = \frac{\text{kg}}{\text{kkg}} \\
 & \text{mg/L} \times \frac{10^{-6}\text{kg}}{\text{mg}} \times 10^3 \text{ L/m}^3 \times \frac{\text{m}^3}{\text{day}} = 10^{-3} \quad (25.1) \\
 & \quad \times \text{kg/day} \\
 & \text{mg/L} = \frac{\text{lb}/1000 \text{ lb}^i \times 2^j \times \text{tons/day}}{\text{MGD}^k \times 8.34^l} \\
 & \text{mg/L} = \frac{\text{kg/kkg}^m \times \text{kkg/day}^n \times 1000^o}{\text{m}^3/\text{day}^p}
 \end{aligned}$$

where

<sup>a</sup>The concentration of pollutant (BOD, suspended solids, etc.) determined by chemical analysis; expressed as milligrams per liter, mg/L

<sup>b</sup>Flow of wastewater measured in million gallons per day (MGD) or gal per day/ $10^6$ , gpd/ $10^6$

<sup>c</sup>Factor to convert from metric to US measure,  $\text{mg/L} \times 8.34 = \text{lb/MG}$

<sup>d</sup>Production data for tons raw material processed per day

<sup>e</sup>Converts tons to 1000 lb units

<sup>f</sup>Flow in cubic meters per day,  $\text{m}^3/\text{day}$

<sup>g</sup>Composite factor

<sup>h</sup>Production data in thousand kilogram units per day

<sup>i</sup>Effluent limitation or production-based waste loading in lb waste component per 1000 lb raw product processed

**Table 25.1** Raw wastewater characteristics: canned and preserved seafood processing industries.

Subcategory	Flow gpd	BOD (mg/L)	TSS (mg/L)	O&G (mg/L)
Farm-raised catfish	21M–45M	340	400	200
Conventional blue crab	700	4,400	620	220
Mechanized blue crab	20M–73M	600	330	150
Nonremote Alaskan crabmeat and remote Alaskan crabmeat	65M–99M	270	170	22
Nonremote Alaskan whole crab and crab section and remote Alaskan whole crab and crab section	36M–84M	330	210	30
Dungeness and tanner crab	38M–74M	280–1200 <sup>a</sup>	60–130	28–600
Nonremote Alaskan shrimp and remote Alaskan shrimp	300M–400M	1M–2M <sup>a</sup>	1.3M–3M	100–270
West Coast shrimp	90M–160M	2000 <sup>a</sup>	900	700
Southern nonbreaded shrimp	180M–240M	1000 <sup>a</sup>	800	250
Breaded shrimp	150M–200M	720 <sup>a</sup>	800	–
Tuna processing	65M–3.5MM	700 <sup>a</sup>	500	250
Fish meal	92M–10M <sup>b</sup>	100M–24M <sup>a,b</sup>	0–20M <sup>b</sup>	20–5M <sup>b</sup>
All salmon	58M–500M	253–600 <sup>a</sup>	120–1,400	20–5,550
Bottom and finfish (all)	6M–400M	200–100 <sup>a</sup>	100–800	40–300
All sardines	80M	1,300 <sup>a</sup>	921	250
All herring	29M	1200 <sup>a</sup> –1600 <sup>a</sup>	600–5,000	600–800
Hand-shucked clam	86M–170M	800 <sup>a</sup> –2500 <sup>a</sup>	600–6,000	16–50
Mechanized clam	300M–3MM	500–1200 <sup>a</sup>	200–400	20–25
All oysters	14M–320M	250–800 <sup>a</sup>	200–2,000	10–30
All scallops	1M–115M	200–10,000 <sup>a</sup>	27–4,000	15–25
Abalone	10M–14M	430–580	200–300	22–30

Source: Table adapted from Carawan et al., 1979.

<sup>a</sup>Seafood processing wastewater may contain high concentrations of chlorides from processing water and brine solutions, organic nitrogen (0–300 mg/L) from processing water.

<sup>b</sup>Higher numbers representative of bailwater only.

k = 1,000

kk = 1,000,000

<sup>j</sup>Converts tons to 1000 lb units

<sup>k</sup>Flow of wastewater in million gallons per day, MGD

<sup>l</sup>Converts lb/MG to mg/L

<sup>m</sup>Effluent limitation or waste loading in kilogram waste component per thousand kilogram raw product

<sup>n</sup>Production data in thousand kilogram units per day

<sup>o</sup>Composite factor, see aforementioned note g

<sup>p</sup>Flow in cubic meters per day, m<sup>3</sup>/day

Some average measurements for the primary pollution parameters for wastewaters from various seafood processing operations are listed in

Table 25.1. These measurements represent what can actually occur as a result of seafood processing, thus providing a characterization of the initial wastewater before it enters the environment. Using the first formula, the average pollutant concentrations in Table 25.1 can be expressed as pounds pollutant/1000 pounds (or kg/kkg) raw product processed in a particular seafood plant.

## Wastewater guidelines

Realizing that wastewaters from seafood processing could adversely impact the quality of receiving waters, guidelines were necessary to specify

limits for pollution parameters. A brief review of the regulatory history will provide a better understanding of how the guidelines were established and justified. This regulatory process is constant; thus, new guidelines are periodically proposed and adopted.

No set of guidelines can suit all situations. The specified guidelines are just general guidance to direct regulatory decisions. Experience is showing that regulatory decisions must consider and incorporate some modifications to suit particular situations, industries, and locations.

The prevailing waste management guidelines were originally mandated by the Federal Water Pollution Control Act Amendments of 1972 and 1977, commonly referred to as the Clean Water Act (CWA). Basically, these Acts were to “restore and maintain the chemical, physical, and biological integrity of the Nation’s waters.” The primary administrative authority to plan and enforce these Acts was the US Environmental Protection Agency (EPA). Various state environmental regulatory departments were established and adopted programs patterned on the original federal laws.

The philosophy of the CWAs is different from previous regulatory schemes. The major difference is that the legislation mandated waste treatment guidelines that would be established relative to technological and economic considerations rather than depending on existing environmental quality. The guidelines would be established if waste treatment was technologically and economically available. Thus, extensive field studies were done to review actual operations from various seafood processing categories (Table 25.1), and waste treatment technology was selected that represented the highest level of control which could be practically applied. The review and selection process included an involved cost-benefit assessment which is beyond our scope here, but it will suffice to conclude the economic consequences of various treatment technology options were considered.

The original regulatory plan was to specify a series of interim guidelines or goals which would gradually approach zero pollution discharge into navigable waters by 1985. These guidelines were actual specified concentrations of various pollution parameters which could be permitted for discharge. The pollution parameters for seafood processing plants were the conventional pollutants previously noted (BOD, TSS, O&G, and pH). The schedule for interim guidelines is commonly referred to with

**Table 25.2** Schedule of interim guidelines for wastewater regulations.

Source	Date of compliance		
	July 1, 1977	July 1, 1984	1985
Direct discharge	BPT	BCT (BAT)	Zero
Municipal discharge		Pretreatment Standards	
New source		Standards (NSPS)	

BPT, best practical technology; BCT, best conventional technology; BAT, best available technology.

acronyms (Table 25.2). Companies have not been able to reach a zero discharge of pollutants, but many have made a concerted effort to reduce the amount and strength of discharges, and to conserve water.

In 1987, the first major amendment to CWA, the Water Quality Act, was promulgated. The amendment strengthened the existing regulations through improving the permitting process and adding increased fines for permit violations. There were also provisions related to sludge and storm water management which might have impacted certain seafood companies.

In 2002, although the regulation was actually promulgated in 2000, states were directed in Section 303(d) of the CWA to identify and prioritize bodies of water that were threatened or polluted. State agencies were then to determine the maximum amount of pollutants that the body of water could receive and still meet water quality standards. The maximum pollutant load is typically referred to as the total maximum daily load (TMDL). A TMDL might be defined for one or more pollutants, including contaminants such as coliforms, organic matter (e.g., BOD), TSS, and others. Developing a TMDL for a 303(d) listed water body can be difficult, time consuming, and costly.

## Direct discharge

Currently, all seafood processing firms which discharge wastewaters directly into the environment have to be in compliance with the Best Practical Technology (BPT) guidelines, which means the concentration of the primary, conventional pollution parameters must not exceed the concentrations specified in the 1977 guidelines (Table 25.3). The regulations include some reference to the

**Table 25.3** Existing (1977) and proposed (1984) EPA pollutant guidelines for the seafood processing industries.

Seafood category	BPT = BCT <sup>a</sup> pollutant limitation, lb/1,000 lb raw material					
	BOD		TSS		O&G	
	d. max <sup>b</sup>	mo. avg.	d. max	mo. avg.	d. max	mo. avg.
Catfish, farm raised	— <sup>c</sup>	—	28	9.2	10	3.4
Blue crab, <b>conventional</b>	—	—	2.2	0.74	0.60	0.20
Blue crab, <b>mechanical</b>	—	—	36	12	13	4.2
AK <sup>d</sup> crabmeat, nr <sup>e</sup>	—	—	19	6.2	1.8	0.61
AK crabmeat, r <sup>e</sup>	—	—	16	5.3	1.6	0.52
AK crab process., nr	—	—	12	3.9	1.3	0.42
AK crab process., r	—	—	—	—	—	—
Dung./tanner crab	—	—	8.1	2.7	1.8	0.61
AK shrimp, nr	—	—	320	210	51	17
AK shrimp <sup>f</sup> , r	—	—	—	—	—	—
North. Shrimp processed	—	—	160	54	126	42
South. Shrimp processed, nb <sup>g</sup>	—	—	110	38	36	12
Shrimp processed, b <sup>g</sup>	—	—	280	93	36	12
Tuna processing	—	—	8.3	3.3	2.1	0.84
Tuna processing, b	7.0	3.9	3.7	1.5	1.4	0.6
Fish meal processed, with solubles unit <sup>h</sup>	4.7	3.5	2.3	1.3	0.80	0.63
Fish meal processed w/o solubles unit <sup>i</sup>	3.5	2.8	2.6	1.7	3.2	1.4
AK salmon, hand butchered	—	—	2.6	1.6	0.31	0.19
Ak salmon, <b>mechanical</b>	—	—	44	26	29	11
WC <sup>d</sup> salmon, hand butchered	—	—	2.6	1.6	0.31	0.19
WC salmon, <b>mechanical</b>	—	—	44	26	19	11
AK bottomfish, processed	—	—	3.1	1.9	4.3	0.56
NA <sup>d</sup> bottomfish, <b>conventional</b>	—	—	3.6	2.0	1.0	0.55
NA bottomfish, <b>mechanical</b>	—	—	22	12	9.9	3.9
Clam, hand shucked	—	—	59	18	0.60	0.23
Clam, <b>mechanical</b>	—	—	90	15	4.2	0.97
Oysters, can. and steam	—	—	270	190	2.3	1.7
Sardine <b>processed</b>	—	—	36	10	3.5	1.4
AK scallop <b>processed</b>	—	—	6.6	1.4	7.7	0.24
AK herring fillets	—	—	32	24	27	10
NA herring fillets	—	—	32	24	27	10
PC <sup>d</sup> oysters, BPT	—	—	47	38	2.4	1.8
PC <sup>d</sup> oysters, BCT	—	—	45	36	2.2	1.7
AC <sup>d</sup> oysters, BPT	—	—	24	16	1.2	0.81
AC <sup>d</sup> oysters, BCT	—	—	23	16	1.1	0.77
NA <sup>d</sup> scallop <b>processed</b> , BPT	—	—	6.0	1.4	7.7	0.24
NA <sup>d</sup> scallop <b>processed</b> , BCT	—	—	5.7	1.4	7.3	0.23
Abalone, BPT	—	—	27	15	2.2	1.4
Abalone, BCT	—	—	26	14	2.1	1.3

BPT, best practical technology; BCT, best conventional technology.

<sup>a</sup> BPT = BCT; BPT, 1977 guidelines equal BCT, 1984 proposed guidelines.

BPT < BCT; BPT, 1977 guidelines less than BCT, 1984 proposed guidelines.

<sup>b</sup> d. max., daily maximum; mo. avg., average of daily values for 30 days.

<sup>c</sup> No limitation.

<sup>d</sup> AK, Alaskan; NA, Non-Alaskan; WC, West Coast; PC, Pacific Coast; AG, Atlantic and Gulf Coasts.

<sup>e</sup> nr, nonremote; r, remote.

<sup>f</sup> No pollutants may be discharged which exceed 1.2 cm (0.5 in.) in any dimension.

<sup>g</sup> nb, nonbreaded; b, breaded.

<sup>h</sup> Any menhaden or anchovy fish meal reduction facility which utilizes a soluble plant to process stickwater or bailwater.

<sup>i</sup> Any menhaden or anchovy fish meal reduction facility except facilities which utilize a soluble plant to process stickwater or bailwater.



BPT which can achieve these guidelines. For most seafood categories, the BPT wastewater treatment technology is some form of screening and general in-plant controls.

To assure compliance, all firms with direct discharge must obtain National Pollution Discharge Elimination System (NPDES) permits. These permits can be issued by the regional EPA office and/or by the respective state environmental regulation office which has been approved for NPDES permitting. Permit applications require a detailed description of the processing operation with specific data on water volumes used, various processing steps, operational schedules, and responsible individuals. After a regulatory review, a permit is issued that specifies the daily average and maximum concentrations of conventional pollutants which can be discharged from the plant.

The sampling point for measuring concentrations is near "the end of the pipe," rather than after discharge into the receiving waters. Monitoring requirements for periodic sampling, tests, and records are stated in the permit.

By July 1, 1984, seafood plants with direct discharge had to comply with the second series of interim guidelines. Initially, the 1984 guidelines were established and designated as Best Available Technology (BAT). The pollutant limitations specified by the initial BAT guidelines were far more stringent than the first interim, BPT. After numerous debates and comments, EPA has reconsidered the 1984 BAT guidelines, applied a modified cost-benefit analysis, and proposed the new 1984 guidelines BCT (Best Conventional Pollution Control Technology) in the Federal Register (October 29, 1982). For most seafood categories, the proposed 1984 BCT guidelines are equal to the 1977 BPT guidelines (Table 25.3).

Reviewing the development of the 1984 guidelines is confusing, but important to understand and appreciate the special consideration for the seafood industry. In most cases, the proposed BCT guidelines were the same as the BPT guidelines. This development is a result of an increased awareness of potential economic damage implied by stringent and certain unreasonable regulations for the seafood industry.

Realizing the seafood industry is not a primary culprit in water pollution, regulatory authorities have adjusted many general cover-all regulations to suit the specific industry situation. The development of proposed BCT guidelines appears

more lenient than the original BAT guidelines, but BCT does not compromise the original regulatory scheme. Although a seafood wastewater discharge can comply with BCT, more stringent guidelines can be enforced if site-specific considerations warrant. States are authorized to enforce more stringent discharge regulations considering the water quality in a specific site. Site-specific considerations seem to be the rule of the future and will require more state and local authorization and industry input to establish reasonable, adequate guidelines.

### Water quality guidelines

Water quality guidelines are distinct from the direct discharge guidelines specified for BPT and BCT, but are similar in purpose. Water quality criteria are used to define a body of water by its physical and chemical properties, most commonly pH, DO, and amounts of suspended material. Founded on these parameters, four classes were created on the basis of the designated use of the waters:

Class A or I	Primarily for water contact recreation (swimming, water skiing, etc.)
Class B or II	Propagation of desirable species of fish and wildlife
Class C or III	Public water supplies (suitable for treatment and use as drinking water)
Class D or IV	Agricultural and industrial uses

Each state has to define, designate, and protect water classifications. To provide adequate protection in certain waters or locations, wastewater treatment standards can be more stringent than those outlined by the interim direct discharge guidelines.

### Municipal discharge

Seafood processors discharging into municipal systems or publicly owned treatment works (POTWs) should not take this service for granted. The demand for municipal treatment is ever increasing, especially in coastal regions where most seafood processing firms locate. The consequence for most seafood processors will be increased pretreatment requirements before discharge, higher use charges, and/or discontinued service. It is not uncommon for industrial and public demand to exceed municipal treatment capability. Additional pressures may come from seafood processors which were

originally discharging directly to the environment but were forced to select municipal treatment as their only viable option for compliance.

Pretreatment standards for discharge to municipal facilities can include restrictions on water volume and temperature, BOD, and pH, or simply the timing and duration of flow. The standards were established to ensure that wastewaters would not overload the facility, interfere with the treatment process, or pass untreated. These standards are typically specified in a sewer use ordinance and can be altered to suit changes in demand for treatment. The sewer use ordinance, which governs the use of the public sewer system, may specify pretreatment standards as well as list charges for service. Charges can include cost for water consumption metered into the plant, a computed sewer water cost, a surcharge based on measured wastewater pollution parameters (i.e., BOD, TSS, O&G, pH), and/or an industrial cost recovery established to recover a portion of original construction costs.

Because most seafood processing operations work in a batch-type mode and generate wastewater with relatively high BOD, they are subject to critical review by POTWs that have reached their maximum treatment capacity. A simple solution may be to alert the POTW of your mode of operation, thus avoiding unexpected surges of wastewater. If the problems continue, more expensive pretreatment and a surge tank for temporary wastewater storage and metered release may be required. Regardless of the solution, the seafood plant is linked with a waste treatment option which can continue to dictate standards and costs. The best approach to avert problems and unreasonable costs for municipal treatment is to understand and partake in the development of the sewer use ordinance. Legal and engineering counsel is advisable. Maintain and understand records for user charges and compare with similar users. Negotiate reasonable standards and charges, realizing that the proper operation of the POTW facility and the economic welfare of the seafood firms are both essential for the welfare of the community.

### **New source discharge**

New source dischargers are new seafood processing operations being constructed so that the installation may discharge wastewater directly into the environment or to the local POTW. Pollutant guide-

lines or pretreatment standards permitted through NPDES or use ordinances are usually intended to be more stringent for new source dischargers than for existing facilities with comparable operations. This form of regulation plans to prevent installation of obsolete technology. Often this consideration is not included in planning new operations. The results can be limiting to the size or success of the new firm. As cautioned, the seafood processor should always check with the NPDES or user ordinance authorities to learn of any specific new source requirements.

### **Waste treatment**

Seafood processors must be prepared to install and practice treatment methods to prevent water pollution. Methods used can include alterations in daily processing which prevent pollutants from entering the processing effluent or specific equipment installed to remove pollutants from the wastewaters. Regardless of which methods are used, every employee should be made aware of the importance of wastewater treatment as an integral part of the entire processing scheme. A good text dedicated to the treatment of wastewater was written by Metcalf and Eddy (2003). Although not focused on the treatment of seafood wastewaters, the text does cover most of the treatment technologies presented in the following sections (Metcalf and Eddy, 2003).

### **In-plant controls**

The most cost-effective controls to assure wastewater management are basic in-plant changes to prevent the initial polluting of the processing waters. Seafood processors might consider in-plant controls to decrease water usage and minimize water contact with processing materials and products. The suspended solids and BOD loads generally increase as water use and water/material contact increase. Thus, the philosophy of in-plant controls is to avert costly waste treatment by decreasing the volume and concentration of wastewater. These measures have come to be known as pollution prevention practices (PPP) or are simply referred to as pollution prevention (P2).

### **Plant surveys**

Plant surveys to document all water use, flow, and contact with materials is the first step for planning

effective in-plant controls. The survey should record all water flowing into the plant, and diagram the flow and amount of water used in all processing operations, including cleanup procedures.

Timing water use can provide some indication of contact time with various materials and products. A comprehensive survey records water leaving the plant and then, realizing a volume differential, attempts to account for water losses during processing. Thus, the survey provides an outline of the plant's total water flow. Water analysis for conventional pollutants can provide information indicating the various sources of contamination.

Survey information can be used to direct alterations for in-plant controls. In addition to water conservation, the decision to implement controls should consider consequences for sanitation and efficient processing. Cost comparisons should include assessments for total water use, water treatment requirements, both by the plant and/or contracted facilities, extra piping, control valves and equipment, labor adjustments, and general loss of processing flexibility due to an integrated water system. Thus, the decision for in-plant controls should include input from management, engineers, quality maintenance, and production and financial concerns.

## Education and training

Education and training for all plant personnel is essential to assure a successful water management program. Employees must learn the importance and potential adverse consequences of water use. Training seminars and demonstrations are recommended and would be ideal for personnel assigned to monitor water use and/or treatment. Employees must realize that water conservation and wastewater management are an integral part of the production process. This attitude must be established and maintained.

## Water conservation

Water conservation begins with basic improvements in housekeeping techniques. Uncontrolled water flow for no specific reason should not be tolerated. Water valves and pipes should be continually inspected and repaired, as necessary. When possible, spring-loaded valves should be installed to restrict water flow; a spring-loaded nozzle is a sim-

ple, but often overlooked method to control flow from hoses. Check water flow through machines or processing segments which are not currently in operation. Controls should be installed to shut off or redirect water flow from processing operations that are not being used. Likewise, controls should be installed to prevent overflows from cleaning and cooling tanks. In general, controls should be installed to prevent any water use that is not necessary or results from careless practices.

Dry cleanup can be the most effective housekeeping procedure to conserve water and prevent additional water contamination. This can remove potential waste materials, such as viscera, offal products, skin, shell, breaching, or batter, without using water to dissolve, transport, or wash down. Dry cleanup can be practiced continually during processing and as the initial step for general cleanup. Continuous use may be made of drip pans to catch breaching and batters; trash cans for body parts, shell; and conveyors to transport waste to designated disposal. Cleanup procedures would utilize more brooms, pans, and vacuum systems to remove solid material prior to the initial wash down. The objective is to minimize water contact with potential waste material, thus preventing these materials from becoming an additional substance in the processing effluent.

Experience has shown that it can be more cost effective to prevent water contamination during processing and cleanup than removing contaminants from the processing wastewaters. Similarly, some processing modifications to minimize water use can be more cost effective than wastewater treatment. Excessive use of water fluming to transport products has been a common feature in many seafood processing operations. Where possible, dry transport with conveyors, pneumatic systems, and vacuums should be considered. If fluming is essential, then necessary water flow should be controlled as needed for the level of product and processing scheduled. Wash procedures can be more effective and water conservation improved with high-pressure, low-volume sprays than with low-pressure, open-flow systems. Likewise, thawing procedures should minimize use of cool water and consider processing options for scheduled refrigerated thaw, partial microwave tempering, vibrational shatter packs, and other nonwater methods.

For certain processing applications, closed-loop systems, such as a hydrostatic cooker-cooler for canned products, can be installed. The cooker water

is reused continuously, and supplemented with necessary water to account for minimal evaporation loss. This system conserves water as well as energy by reclamation of heat between cooks.

The variety of controls to conserve water and minimize water/product contact are numerous, depending on the inventiveness of the operators and on the specific requirements of different seafood processing methods. Each option must be evaluated relative to potential savings versus subsequent treatment costs and production efficiency. In no way should conservation operations compromise product quality, sanitation, or safety.

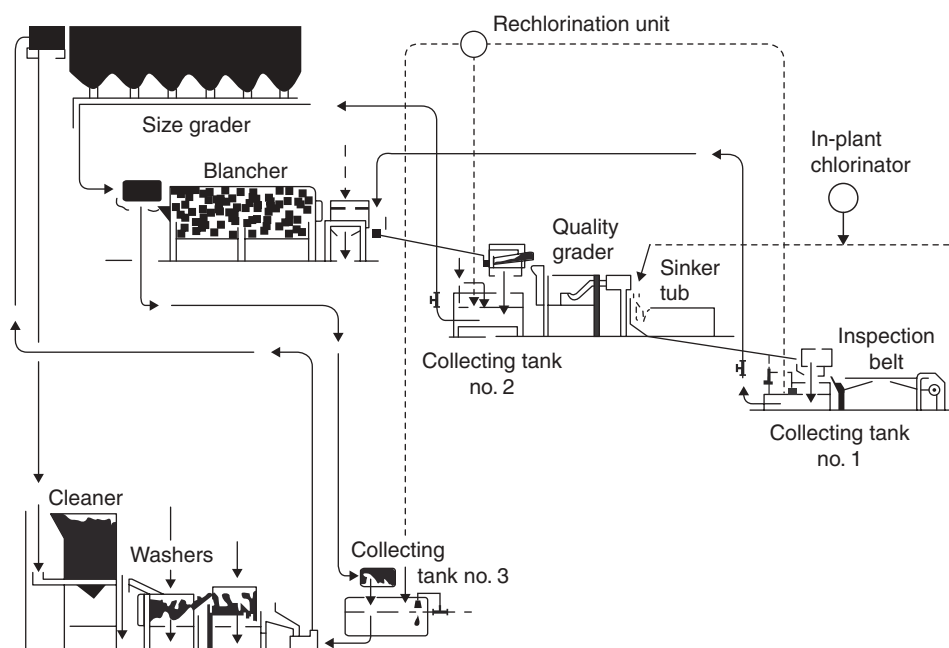
## Reuse and recycling

Water reuse and recycling are processing concepts which deserve consideration as options for water conservation and treatment. These options involve utilizing water more than once before it leaves the processing plant. This method is accomplished by collecting waters from one or more processes, then directing it for use in another process. The quantity and quality of the collected waters will determine potential reuse. A comprehensive in-plant survey is essential to implement these concepts.

Usually, reused water is redirected for successively dirtier application. This scheme is called a countercurrent flow or counterflow reuse. For example, water used in a final product rinse can be redirected for initial product wash or thaw. Between uses, a partial water treatment and/or dilution with additional clean water may be necessary. Chlorine could be added to prevent bacteriological conditions which could jeopardize fresh product quality.

Recycling refers to using treated water in the same application(s) for which it was previously used. Water treatment between uses is necessary to remove any microorganisms of public health significance and any substances which could adversely affect product color, flavor, or odor. Thus, recycling is reuse with more emphasis on water quality. Neither reuse nor recycling are new concepts; in fact, the entire municipal water treatment concept is reuse and recycling.

In food processing, reuse is employed in fruit and vegetable plants and other canning operations (Figure 25.1). The distinction for water reuse in most seafood processing is that processing waters are in direct contact with the edible, proteinaceous portion of the final products. Food processing plants for such products as red meats and poultry must use water that is of potable quality. Federal



**Figure 25.1** Counterflow reuse system.

standards require that potable water must be used for cleaning all equipment which contacts such foods. Additional state health and water quality regulations for food processing can be even more stringent. The regulatory concern is for potential health risk and hazards, and the current regulatory attitude is that renovated wastewater is not suitable when other sources are available.

Regulatory concern for water reuse in seafood processing is justified, but with experience and cooperative demonstrations, reuse and recycling can be developed as a beneficial in-plant method of wastewater management. Recognizing the potential risk for bacteria, suspended materials, and other possible contaminants, the processor should explore options with the advice and assistance of regulatory authorities.

The final decision on whether to initiate such options depends on a careful comparison of cost for reuse and recycling, with necessary treatments, versus the initial costs for water and wastewater treatments.

### Segregation of waters

Wastewater segregation is the separation of various processing waters according to their waste load or required level of treatment. Just as the sanitary wastewaters are directed separate from the processing flows, a review of the in-plant survey could indicate additional wastewaters for separate treatment.

The benefits are decreased cost for wastewater treatment. For example, noncontaminated waters may require no treatment and can be discharged directly. Contaminated waters may be further segregated according to their levels of BOD, suspended solids, and other pollution parameters. Another segment of the processing waters could be treated by simple on-site methods prior to direct discharge (e.g., by settling basins and screens), while more contaminated waters would be directed for municipal wastewater treatment. Therefore, the processing firm does not have to incur municipal cost for treating all processing wastewater volume.

### End-of-pipe treatment

Assuming the seafood processor has employed all practical and economic methods to conserve water

use, to minimize water/material contact, and to segregate wastewaters, additional treatment may be required before the water leaves the plant. The final treatment prior to discharge is called end-of-pipe treatment. If the water is discharged to a municipal facility, the final controls are called pre-treatments.

### Sedimentation

Sedimentation, or settling, is the separation of solids in water by means of gravity. This treatment requires some form of water retention (e.g., grit chamber, catch basin, or clarifier) and a necessary residence time in this position. The design of the retention facility depends on the characteristics (e.g., density, size, discrete vs. flocculent solids) of the solids to be removed. For example, Stewart et al. (2006) were able to achieve high levels of TSS removal from trout farm effluents through sedimentation. However, a fraction of the particles were either too small and/or not dense enough to be removed through plain sedimentation (meaning sedimentation without chemical addition) in a reasonable time period.

Grit chambers, which will remove particles such as sand and shell, have been useful for certain industries, but finer, less dense suspended solids limit their practical application in other industries. Large settling ponds or tanks provide more retention time to assure effective settling, but land availability around typical seafood coastal locations limits such installations. Likewise, frequent removal of captured solids is essential to avoid putrefaction which may result in odors and floating solids, and the collected solids may have to be dewatered before final disposal.

### Screening

Screening implies any device used to actively separate solids from the processing wastewater. The screen can be a crude, coarse series of bars or a fine mesh overlay with agitation. Screens can be classified as:

- (1) basket screens;
- (2) bar screens;
- (3) drilled plates, and so on;
- (4) gratings;



- (5) revolving drums with perforations (inclined, horizontal, and vertical);
- (6) vibrating, shaking, or oscillating screens (linear or circular motion);
- (7) tangential screens (pressure or gravity fed);
- (8) centrifugal screens.

Screens typically are installed in combinations to provide a series of progressively finer solids removal. The system should be built large enough to handle the maximum anticipated water and solids loading. This arrangement prevents clogging or restricted water flow and backup.

The best installation utilizes controlled gravity flow to direct water through the screens. If pumps are necessary to lift water across the screens, positive displacement or progressing cavity non-clog pumps are recommended. Centrifugal, non-clog pumps can be used, but the pressured flow should not force small particles to clog the screening mesh. Mechanical brushes or sprays can help prevent clogging. The functionality system will have a longer life if the materials used are resistant to saltwater corrosion.

The screened solids must be frequently or continuously removed to prevent clogging or putrefaction. Some method of dewatering, either mechanically with pressure or simply drainage, is usually necessary before final disposal.

Revolving drum screens are basically a cylindrical frame with both ends open. The frame or drum surface is a perforated or sliced mesh of size to suit the particular operation. If the drum is inclined, wastewater can be fed into the raised end and solids are captured as the water seeps through the interior mesh. The revolving action causes the solids to migrate out the lower end of the drum, and the revolving speed can be controlled to provide a variable screening performance. Some revolving drums are used in a horizontal position with the lower side of the drum immersed in the wastewater (Figure 25.2). Screened solids are held by ribs on the inside of the drum and rotated upward for deposit on a central conveyor belt. Regardless of drum position, backwash sprays can be used to prevent clogging.

Vibrating screens are typically employed as unit operations or to handle a segregated water flow rather than as a total wastewater treatment. The vibrating screen is usually more sensitive to variations in water flow and solids content. These screens

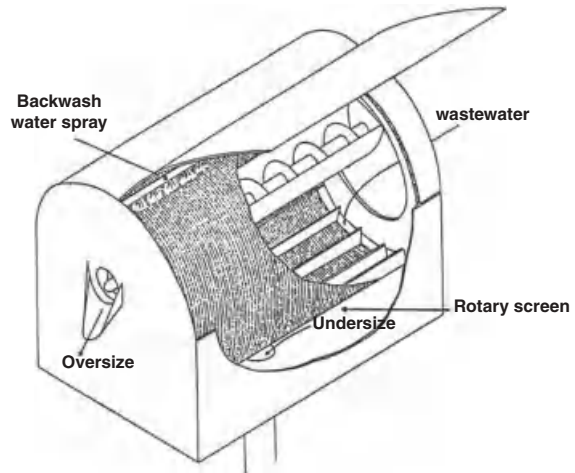


Figure 25.2 Typical horizontal drum rotary screen.

are mounted on springs to allow either circular or linear vibrations as wastewater flows through the vibrating plate. The solids vibrate to the sides of the plate for removal. Blinding or clogging is a common problem for vibrating screens; therefore, they are better suited for nonfibrous, nonoily wastewater.

Tangential screens, the most popular screens for treating seafood processing wastewaters, are effective and generally maintenance free because they require no moving parts. The screen surface is usually inclined and curved about  $45^{\circ}$ – $60^{\circ}$ . The screening feature can be a series of parallel, triangular, or wedge-shaped bars oriented perpendicular to the water flow, or a sheet with fine perforations or slits. Solids are screened as water flows down the surface and through the inclined screen. The solids migrate downward, off the screen for disposal. Gravity-fed tangential screens are common, but pressure-fed units can operate with a finer mesh.

Before selecting a particular type and arrangement of screens, the processor should check performance to ensure effective removal of solids. Performance will be determined by the particular characteristics and volume of wastewaters. Likewise, the final installation should be designed to anticipate further treatment requirements. Although screening appears to be the most commonly required treatment technology for seafood processing effluents, it only removes a portion of the solids. The screened solids may assure compliance with guidelines for suspended solids, but the remaining BOD could be a problem. The regulatory

concern for BOD remaining after screening seafood processing effluents is primarily at the state and local levels and addresses water quality standards.

## Biological treatments

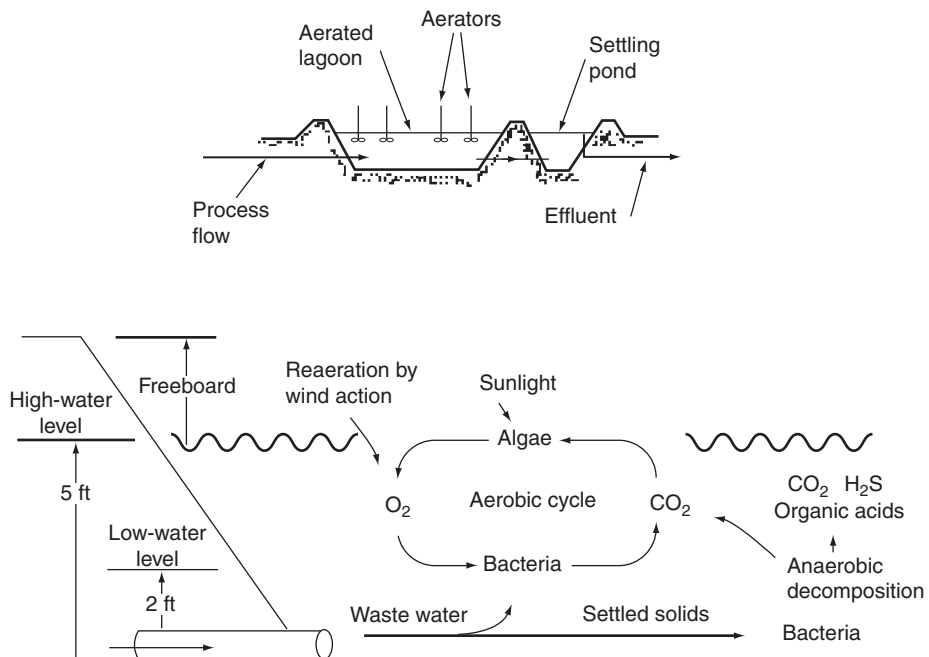
Biological treatments (aka secondary treatment) can be used to decrease wastewater BOD, but most of these methods are not practiced in the seafood industry. As screening requirements become more common, the potential use of biological systems to remove BOD should be reconsidered. Basically, biological treatments are designed to enhance the microbial processes which would occur naturally in the aquatic environment. Microbes, both anaerobic (no oxygen required) and aerobic (uses oxygen), can be cultivated and managed in treatment systems to reduce the organic matter of wastewaters (or sludges). In general, biological treatments can be used to reduce BOD so that an effluent is more compatible with the receiving water or municipal facility.

The two basic categories of biological treatment are units with attached microbial growth (e.g., rotating biological contactors (RBCs), trickling filters, biotowers, and downflow and upflow submerged processes) and systems with suspended microbial growth (e.g., activated sludge and lagoons). There are also hybrid systems in which the microbes attached to some solid surface are suspended in the wastewater (e.g., activated sludge with fixed film packing (Metcalf and Eddy, 2003) and fluidized bed reactors (Sandhu et al., 2002; Botrous et al., 2004)). And, too, there is a rather specialized system in which aerobic or anaerobic microbes are encouraged to form granules through introducing the wastewater in an upflow mode. The granules consist of communities of microbes and exhibit some unique properties that enable them to better survive and operate at higher loadings (Boardman and McVeigh, 1997). Biological treatment systems generally require some initial pretreatment to remove FOG which could limit oxygen transfer and to decrease solids which can clog filters. A treatment scheme that includes equalization might be necessary to avoid shock loadings of flow and/or organic matter, and to maintain a balanced microbial growth. If saltwater or other added chemicals are present in the wastewater, they could be toxic to the microorganisms. After biological treatment, clarification is often used to separate biomass (the

microbes) from the wastewater, and the final effluent is disinfected (e.g., with chlorine or UV light) to destroy pathogens. The required train of operations will, of course, be dependent upon the particular situation and where the effluent is discharged. For example, the effluent would probably not be disinfected if it were discharged to a sewer. And, if a chlorinated effluent was to be discharged to the environment, it would first be necessary to neutralize the chlorine to prevent in-stream toxicity.

RBCs, or biodiscs, are fixed-growth biological units with a series of cylindrical discs mounted parallel on a shaft placed across a wastewater basin or tank. The discs rotate slowly through the wastewater and air above, thus providing some aeration of the waters. In the presence of oxygen and the organic BOD load, microorganisms begin to grow on the disc surface. Growth of these aerobic organisms reduces the BOD. As growth becomes excessive, the biomass will flake from the disc surface and settle while remaining organisms continue the oxidation process. To ensure growth during limited or no-flow situations, the unit can be operated in a closed loop fashion, depending on effluent recycling. A series of RBC units could be the most effective design depending on available space. The primary limiting factor is ambient air temperatures. The unit(s) should be housed to insulate the organisms from colder temperatures, which reduce or eliminate growth.

Trickling filters are a similar, attached growth biological process which contains small rocks or plastic media (sheets, bales, or random-dump medium) to provide surface area for microbial growth. The wastewater flows through the filter for treatment, and is then recycled to the filter to enhance removals, ensure even flowrates and good distribution of the wastewater across the filter, and control the thickness of the biofilm. In some cases, fixed nozzles are used to disperse the wastewater over the filter medium. The size and shape of the filter depend on available space and volume of wastewater. Contact time in the filter and recycle rates must be considered to ensure effective treatment. The biomass will "slough off" the filter medium as growth continues, so continuous flow is necessary to promote growth. Insulation may be required to control ambient temperatures. Jegatheesan et al. (2007) demonstrated the use of three filters in series with a floating medium, sand, and activated carbon in the treatment of aquacultural wastewater.



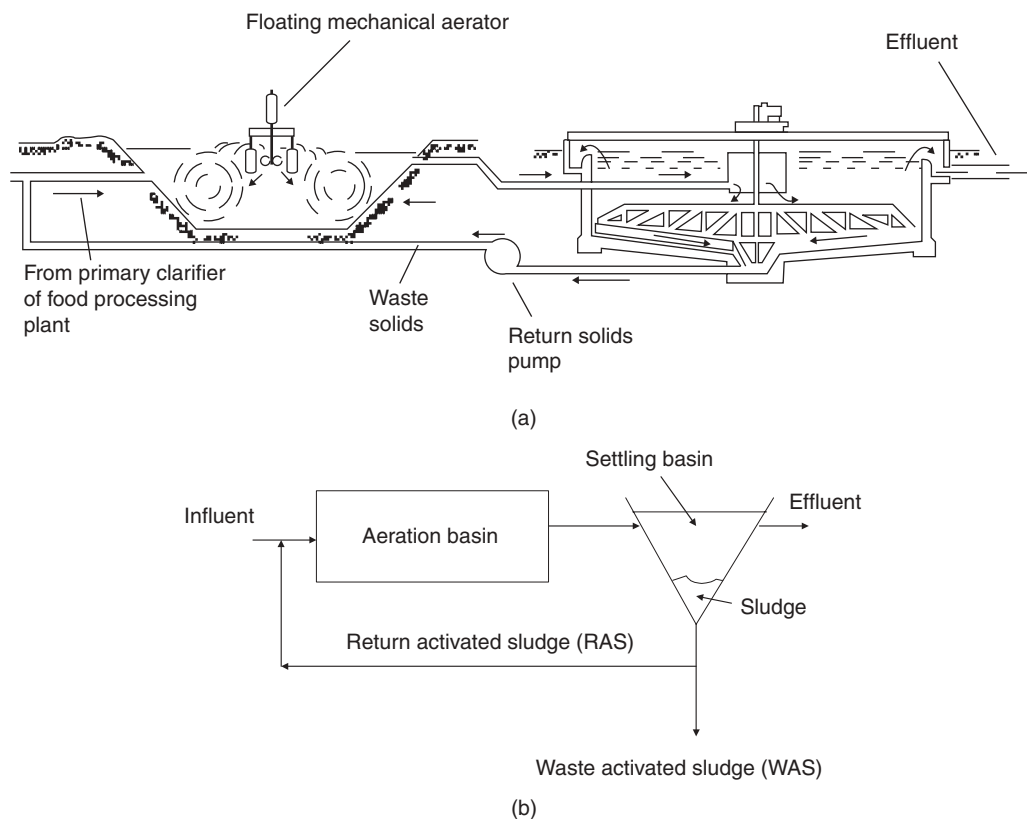
**Figure 25.3** Typical lagoon and pond systems for biological treatment of wastewater.

The main focus of the work was to treat the water for reuse and among the main issues was to reduce the concentration of oxidized nitrogen in the wastewater.

Lagoons and ponds utilize the same basic microbial growth concept to remove BOD, but the biomass is suspended in the water rather than fixed on a surface (Figure 25.3). Supplemental oxygen provided by surface, mechanical aerators, or air diffusers may be necessary to support growth for the bio-oxidation process. Lagoons and ponds can be large or consist of a series of smaller units. Typical depths of ponds that rely on natural aeration range from 0.92 to 1.2 m (3 to 4 ft), while aerated lagoons often have depths in the area of 2–5 m (6.6–16.4 ft). Lagoon and pond design must account for ambient temperatures, winds, water runoff, appropriate detention time, and wastewater strength and volume. In addition to the aerobic process, some ponds can incorporate anaerobic treatment that decomposes solids which settle in the depths. One might also design lagoons to be aerobic, anaerobic, and/or anoxic (oxidized forms of nitrogen present, but no DO), which can be combined in different ways to accomplish biological nutrient removal. For example, an aerobic–anoxic combination can be used to

remove nitrogen, and an aerobic–anoxic–anaerobic system can remove nitrogen and phosphorus. The primary limiting factor for the use of lagoon or pond treatment, especially for the coastal seafood industries, is land availability and soil conditions.

The typical activated sludge process is similar to the pond concept, but the suspended microbes are cultured on wastewater constituents (nutrients for microbes) in an aeration basin, concentrated in an external clarifier, and recycled to the aeration basin in order to maintain a high level of biomass in the aeration basin (e.g., the concentration of microbes is often in the area of 2500–4000 mg/L). When the desired amount of biomass is reached in the aeration basin, excess biomass (sludge) can be wasted (Figures 25.4a and 25.4b). Therefore, the activated sludge (i.e., the microbes) is cultured and maintained in a controlled mixture of organic material from the wastewater, DO, and other nutrients (e.g., nitrogen and phosphorus). The hydraulic detention time of the aeration basin in a typical activated sludge system is 5–10 hours. Longer or shorter times might be used. The length of time that microbes stay in the activated sludge system is longer than the water's detention because the microbes are being recycled. The detention time for



**Figure 25.4** (a) Activated sludge system for treating wastewater. (b) Schematic diagram of the activated sludge process.

microbes in the system, also known as mean cell residence time or sludge age, is often in the area of 5–15 days. One of the primary limiting factors for use of activated sludge to treat seafood wastewater is the necessity for more careful controls versus those of batch-type processes (noncontinuous flow), typical of many seafood processing operations. Of course, the capital, operating, and maintenance costs associated with activated sludge are relatively high, and trained personnel are needed to operate the system.

As alluded to above, a number of variations to conventional activated sludge systems have been developed through the years. For example, different types of plastic media might be added to the aeration basin to increase biomass levels; thus, both attached and suspended microbes feed on the wastewater. Or, a membrane filtration unit can be placed in or outside the aeration basin to concentrate biomass. These systems are referred to as membrane bioreactors (MBRs). MBRs are effective because the membrane can efficiently sepa-

rate solids/microbes from the wastewater, which enables the systems to operate well at high biomass levels and to generate effluents with low concentrations of suspended solids,  $<1$  nephelometric turbidity unit (NTU), and  $<5$  mg/L  $\text{BOD}_5$  (Metcalf and Eddy, 2003). Trussel et al. (2006) reported on the use of a pilot scale, submerged membrane bioreactor (SMBR) for the treatment of municipal wastewater. The ultrafiltration membrane had a nominal pore size of  $0.035 \mu\text{m}$  and was operated at a flux of  $30 \text{ L/m}^2\text{-hr}$ . The mixed liquor suspended solids (MLSS; reflects level of biomass) was maintained at  $8 \pm 2 \text{ g/L}$ . Effluent levels of COD ( $22\text{--}34 \text{ mg/L}$ ) and TSS ( $<2 \text{ mg/L}$ ) were excellent.

As with the variations possible for lagoon design, activated sludge systems can be designed to remove nitrogen and/or phosphorus, as well as carbon, through connecting in series aerobic, anoxic, and anaerobic reactors. Mosquera-Corral et al. (2003) reported on the successful use of sequentially arranged anaerobic–anoxic–aerobic reactors to treat

fish cannery wastewater. Sage et al. (2006) demonstrated the potential of activated sludge to denitrify dairy effluent that yields lessons for the use of such systems in the seafood industry.

Another variation in the types of reactors used for biological treatment is the sequencing biological reactor (SBR). The system has been available for many years, but is not used widely by the seafood industry. It is basically a batch, suspended growth reactor with 4–5 cycles: fill with wastewater, react (e.g., aerate), settle solids, withdraw clarified wastewater, and sometimes “rest.” For smaller flows, perhaps only one SBR will be needed, because wastewater can be stored until the time of the fill cycle. In other cases, the cycles of two SBRs (or more) are alternated to accommodate the continuous flow of wastewater.

In recent years, more attention has been directed at the use of a specialized group of organisms that can oxidize ammonium ( $\text{NH}_4^+$ ) to nitrogen gas ( $\text{N}_2$ ) through using nitrite as an electron acceptor (Mulder et al., 1995). Development of this technology is of interest because the costs associated with aeration and addition of carbon for nitrification–denitrification can be significantly reduced. However, the Anammox (anaerobic–ammonium–oxidation) process is rather unstable because the organisms are slow growers, exhibit a low yield, and are inhibited by very low levels of DO.

## Land applications

Land applications or land disposal can be a low cost and effective wastewater treatment option if sufficient and suitable land is available. Some seafood wastewater applications have been found to improve certain soils and actually support crops and grasses. The waters are usually pretreated (screening) prior to application. Three basic methods of application are (1) irrigation with sprays or trickle outlets, (2) overland flow with an option to dike or furrow the flow, and (3) infiltration–percolation with natural flow or pressure (septic system, etc.). The concept is to use the filtering and biological features in the soil to eliminate and assimilate the pollutants.

The ability of the soil to effectively treat wastes depends on (1) the soil characteristics and profile, (2) depth of groundwater, (3) terrain and ground cover, (4) ambient temperature and seasons, and

(5) wastewater volume and characteristics. Preliminary trial work is recommended to assess soil suitability and estimate maximum loading rates. Adverse concerns include the accumulation of dissolved solids, particularly sodium, and of virus and bacteria production which could present a potential health hazard. Those who apply wastes directly to their land should be mindful of long-term effects and should not compromise land value by disrupting surface vegetation or by polluting ground waters.

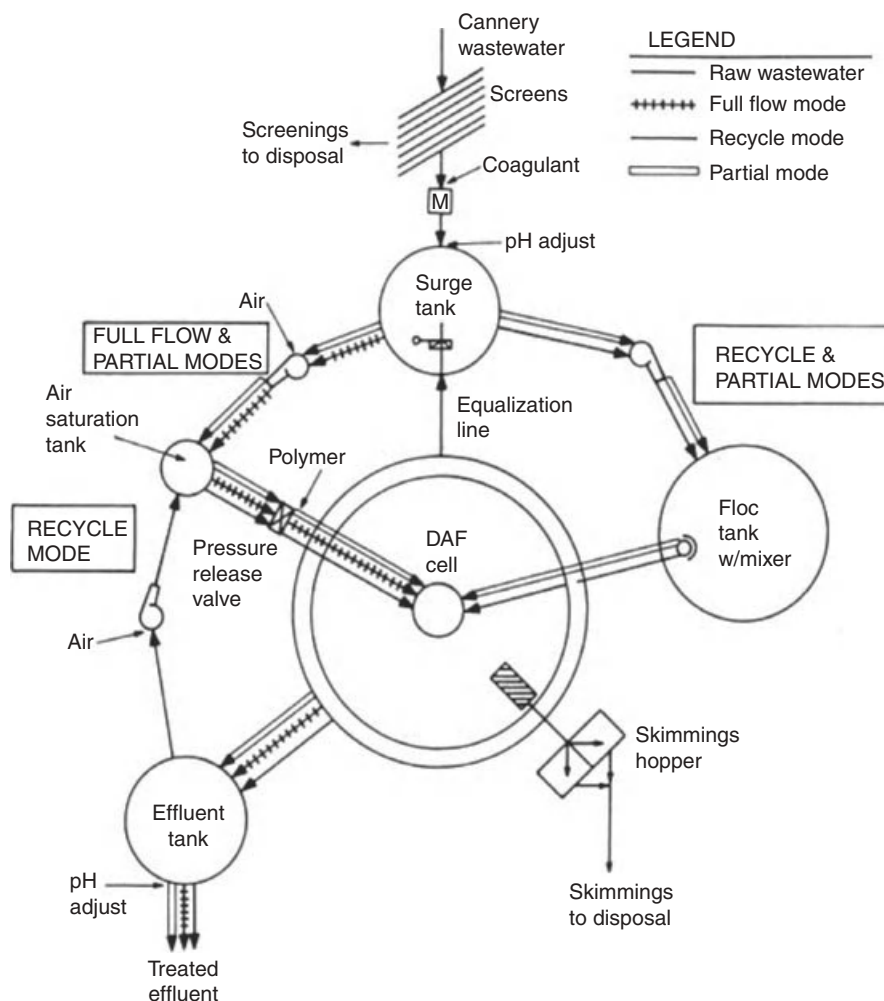
## Constructed wetlands

Constructed wetlands have been studied for some years and may be a viable option for companies with sufficient land area. Yirong and Puetpai-boon (2004) demonstrated how well a constructed wetland would serve as a tertiary treatment for a seafood waste in Thailand. For a wastewater flowrate of between 500 and 4660  $\text{m}^3/\text{d}$ , a wetland area of 29,920  $\text{m}^2$  was able to effect removals of BODs, TSS, ammonia ( $\text{NH}_3$ ) and organic-N of 84%, 94%, 52% and 82%, respectively. The wetland was 0.3 m deep and contained cattails (*Typha angustifolia*). Sindilariu et al. (2007) studied the treatment of effluents from a trout farm in a constructed wetland. The authors noted that TSS removals at a hydraulic loading rate of 13.6  $\text{m}^3/\text{d}$  were 68%. Total ammonia nitrogen (TAN) removals reached as high as 88%. One of the main findings of the study was that the wetland performed better than plain sedimentation, which is not surprising, but important to establish. Other investigators have also reported on the merits of wetland treatment for shrimp wastewater (Lin et al., 2005), rainbow trout effluents (Schulz et al., 2003), and primary treated domestic wastewater (Manios et al., 2003a, 2003b). In the studies by Schulz et al. and Manios et al., a variation of wetland design was used in which water is directed horizontally below the ground surface. This type of system is referred to as a horizontal flow subsurface wetland. It is important to note that often plants are incorporated into wetland design, but they remove only a small fraction of the pollutants (Manios et al., 2003a, 2003b, 2003c).

## Physicochemical treatments

Physicochemical treatments for seafood wastewater have often been judged ineffective and/or financially impractical. Although promoted as





**Figure 25.5** Dissolved air flotation wastewater treatment system.

options which require less space than biological methods, the installation and operational costs often exceeded benefits. There are, of course, exceptions where regulations have dictated that a more rigorous treatment system be applied. Among the operations included in this category are precipitation, coagulation, oxidation, reduction, carbon adsorption, filtration, reverse osmosis, electrodialysis, ion exchange, and air stripping (Boardman and McVeigh, 1998). Regarding the use of coagulants/flocculants followed by sedimentation, Ebeling et al. (2005) reported that several polymers accomplished greater than 90% removals of TSS and reactive phosphorus from aquacultural wastewater.

Therefore, the addition of chemicals may be a viable option.

Dissolved air flotation (DAF) has been recommended for use by various seafood companies (Figure 25.5). In the DAF process, minute air bubbles attach to and float oil, grease, and suspended matter from the bulk liquid. One of the primary design variables is the air to solids ratio; introducing too much air is wasteful and too little air will decrease efficiency. The separation process can be optimized by using flocculating agents such as iron or aluminum salts, lime (a calcium salt), various polymers (alone or in combination with the inorganic salts), and pH adjustments.

Although flotation may be an effective treatment alternative, companies need to be aware of the following factors:

- (1) Operational mode of a DAF unit requires 1–3 hours for start-up, continuous flow during operations, and lengthy times for shutdown and clean-up times (if needed). Most seafood processing operations are not continuous and can vary daily and seasonally.
- (2) Trained, experienced labor is required to operate the DAF systems. This type of labor is generally limited and expensive, and the seasonal schedule of production would be an unattractive feature for such highly trained labor.
- (3) High costs for DAF equipment, chemicals, power (energy), maintenance, and operations may be prohibitive.
- (4) Disproportionate costs are higher for smaller size firms.
- (5) Sludge collected is a highly putrescible scum (95% water) which must be disposed of in an environmentally sound manner.
- (6) Sludge disposal may be an issue. Fewer landfills will accept sludge (95% water), and future environmental regulations could limit sludge disposal in landfills. The chemical additions during DAF treatment limit the use of sludge as a precursor in feeds or fertilizers. Ocean disposal, which has been permitted for raw screened seafood solids, would be restricted for chemically treated seafood sludge. However, it may be possible to incorporate the resulting sludge into the train of sludge management operations at a local municipal plant (e.g., into a digester and subsequent dewatering operations).

## Residuals management

After wastewater treatment, accumulated solids or waste materials collected by settling, screening, or other methods must be removed from the seafood plant and disposed of in an appropriate manner. These solids usually have a high moisture content which can be evident as drip or actual flow. Dewatering prior to disposal is recommended to minimize problems with handling, transportation, and disposal. Dewatering systems can apply heat to dehydrate the solids and/or use pressure to force

moisture from the solids. Cost for dewatering must be compared with reduced costs for transportation and disposal. In some cases, dewatering costs are unavoidable in providing solids which are compatible with the available disposal option. Disposal methods must consider odor, insect, and decomposition problems, as well as a general adverse public attitude objecting to the unpleasant aesthetic aspects.

Several investigators have studied the digestion of residual solids or sludges. Sludges are digested to reduce organic matter, increase dewaterability, reduce odors, and/or destroy pathogens. Digestion processes can be aerobic or anaerobic, mixed or unmixed, conducted at different temperatures and detention times, operated at different cell ages (like activated sludge systems), and configured differently (e.g., single reactors or reactors in series). Great strides have been made in recent years related to the operation of digesters to achieve better reductions in organic matter and odors. Gebauer and Eikebrokk (2006) studied the treatment of sludge from salmon smolt operations in mesophilic anaerobic reactors. The hydraulic retention time (HRT) of the continuously stirred tank reactor (CSTR) was 55–60 days and the temperature was 35°C (95°F). COD was reduced by about 45–54% and methane yields were in the area of 0.15 L/g COD. The production of methane in anaerobic digestion is, of course, of particular interest in this age when energy sources are limited and costly. Use of the technology has been demonstrated by several investigators through the years. Rodenhizer and Boardman (1999) studied the production of methane from anaerobic treatment of crab processing waters; Gebauer (2004) studied the production of biogas from the mesophilic anaerobic treatment of sludge from saline fish effluents; Mshandete et al. (2004) evaluated the yield of biogas from digesting sisal pulp and fish waste; and, Kim et al. (2002) reported on the production of methane from a three-stage anaerobic process.

Land disposal in private or municipal sanitary landfills is the most common disposal method. Although most seafood waste solids are suitable for landfills, the availability of sites is decreasing due to (1) increasing public and regulatory concern for potential adverse environmental consequences, (2) state and federal restrictions and operational guidelines to control use of landfills, and (3) decreasing availability of suitable sites due to

population growth around certain seafood processing locations and public resistance.

Seafood processors using or considering landfill disposal should not take this option for granted. Regional and local regulations should be studied and future fill capacity determined. A cooperative approach would be to install and emphasize the dewatering systems and controls for temporary storage and transport to the landfill site.

Ocean dumping may be a viable option for seafood waste solids disposal. In the original Marine Protection, Research, and Sanctuaries Act of 1972, commonly called the Ocean Dumping Act, Congress established policy for disposal of materials in the ocean. This policy clearly stated disposal of "fish (and shellfish) wastes" did not require a permit to dump at sea. Seafood waste solids were given this special exclusion because these materials were compatible with the environment whence they came. The EPA retained the right to designate appropriate dump sites. Dumping would not occur in harbors or other protected or enclosed coastal waters, or any other location where EPA finds such dumping may cause adverse results. In general, EPA views ocean dumping as a last resort option.

The original EPA criteria for the dump site included (1) geographic location, (2) location relative to reproduction and growth of marine resources, (3) location relative to amenity areas such as swimming beaches, (4) amount and characteristics of waste, (5) ability to observe and monitor, (6) diffusion, dispersion, mixing, (7) interference with shipping, fishing, recreation, and so on, (8) water quality and ecology, (9) previous dumping effects and cumulative effects, (10) attraction of nuisance species, and (11) the cultural and historical aspects of the site.

Although ocean dumping is an alternative for seafood solids disposal, the necessary logistics and cost are usually prohibitive. In addition to costs for operating vessels, such as barges, there must be a system to accumulate and store the waste so it does not cause offensive odors or attract insects, with potential health problems. If chemicals are added to stabilize or minimize decomposition of the solids, the chemical addition is a separate solid atypical in raw seafoods; thus, an EPA permit would be required to allow disposal of the treated materials. Despite these concerns, seafood processors may consider their option for ocean dumping. A successful system may be integrated with commercial

or recreational fisheries, for example, artificial reefs could be considered as sites for solid waste utilization as feed and attractants.

Incineration of seafood waste solids has been suggested, but practical aspects seem unfavorable. Most seafood operations are batch-type operations, and would probably depend on an established incineration system for municipal wastes and sludge. The arrangement would avoid costly start-up and shut-down costs, but with increasing fuel costs this option can be expensive and wasteful. By-products generated by combustion could be a problem in populated regions.

## Conclusions

Typically, most efforts to prevent waste and pollution are motivated by regulations. Future regulatory schemes will become more regional and localized, thus requiring more site-specific and industry-specific considerations. Seafood processors would be wise to review current waste management methods and prepare to address concerns for local water quality standards. In addition to end-of-pipe guidelines proposed by the EPA, more processors will be faced with water use and effluent limitations, and with increasing treatment costs, to maintain the quality of waters as designated by the states and localities.

Wastewater treatment options for seafood processing require more development and practice. Requirements for in-plant controls and screening seem reasonable for most situations, but the industry should explore further treatments to lower BOD, decrease operating costs, and recover by-products. Continued dependence on municipal wastewater treatment and solids disposal should not be taken for granted. In most coastal regions, these options are vulnerable to expanding populations. More industry self-control may be available with segregation of processing waters, water use and recycling, land and ocean applications, and biological treatments.

Seafood waste management, including treatment and by-product utilization, should be considered an integral part of all seafood processing and handling operations. The goals are to comply with existing regulations and prevent pollution, while maintaining seafood productivity and safety.

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# 26

## Fish Meal and Oil

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Anthony P. Bimbo

### Introduction

Global landings of fish (including freshwater production but excluding plants, crustaceans, mammals and mollusks) have reached about 112 million, metric tons (mmt) and appear to have leveled off at that volume. Figure 26.1 shows the growth in total fish landings and the components over the period 1990–2009 (the most recent statistics available).

From these data, we see that the marine capture fisheries have leveled off around 70 million mt, the inland capture has leveled off at roughly 10 million mt, and all of the growth in landings comes from the aquaculture segment of the industry. In fact, various experts project that by 2025–2030 aquaculture landings will equal marine capture landings and that this will be necessary to sustain the growing demand for fish protein in the world today.

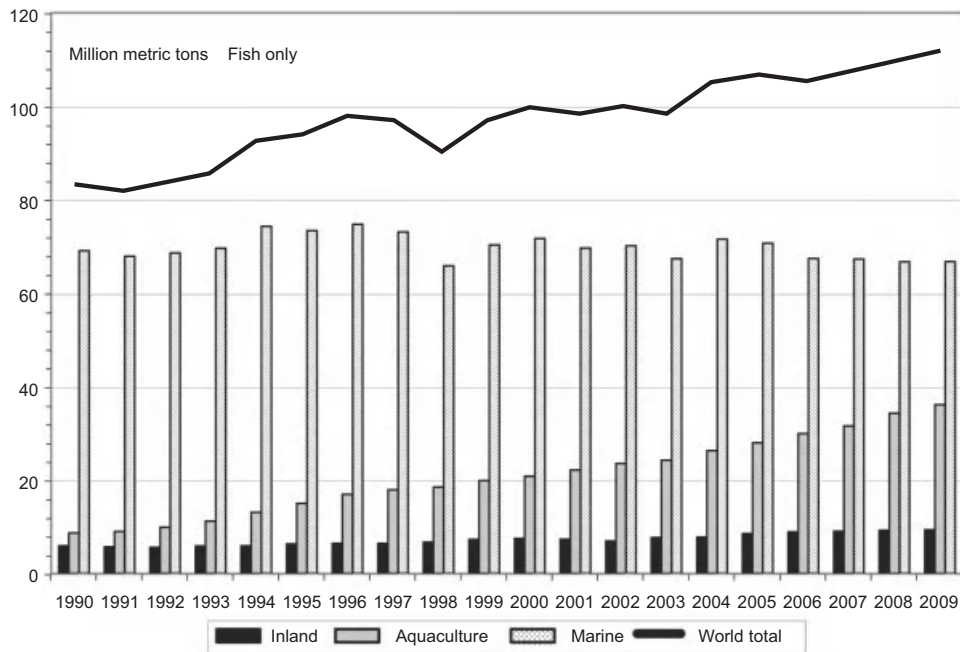
Worldwide, approximately 15–18% of the landings are specifically utilized for fish meal and fish oil production. Figure 26.2 shows the disposition of the world catch as a percentage of the market.

It has been estimated that conservatively only about 50% of the edible landings are actually used as food. The remaining portion of the fish is waste

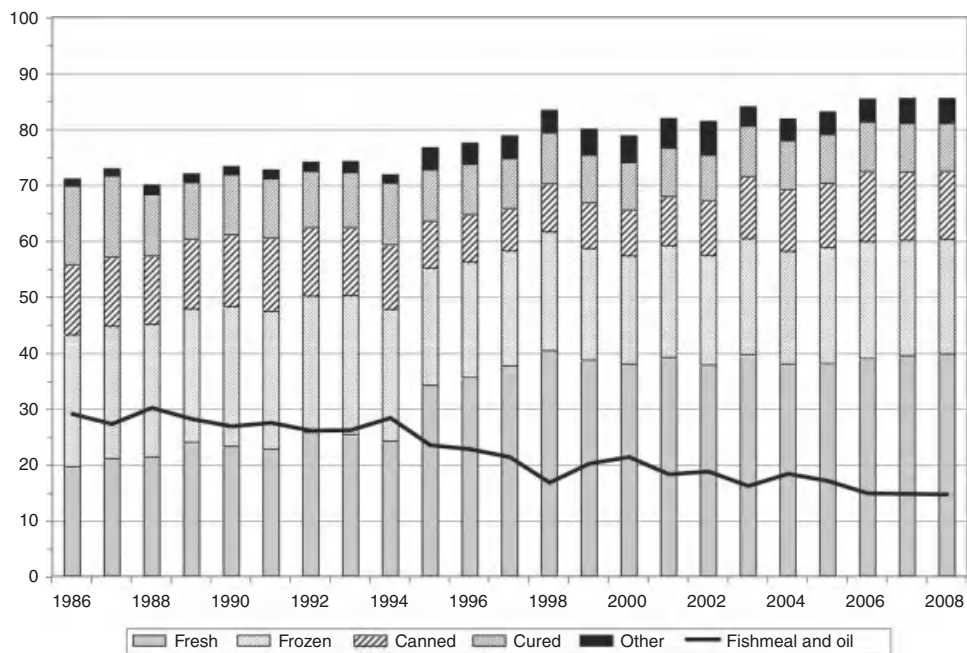
and offers the potential for increased utilization in fish meal and fish oil production, silage, and other products. However, Figure 26.2 also shows that available tonnage is dropping. The amount of fish utilized for freezing, canning, and curing (the main source of available fish waste) is decreasing, while that used for fresh fish is increasing. The reason for this is that most of the global landings are in areas where third world countries are slowly developing and this increases the demand for fish protein. Therefore, the fish are consumed at home instead of being processed by canning, curing, or freezing for export. Waste generated from consumed fresh fish normally is not available for processing unless it is concentrated in relatively small areas.

Fishing is the last major industry that still relies on hunting and gathering. Unlike agriculture where seeds are planted, crops fertilized, protected, and harvested, fishermen still leave their families before dawn, and travel many miles to seek the fish. They must then capture and preserve the fish and return to port irregardless of weather or other conditions.

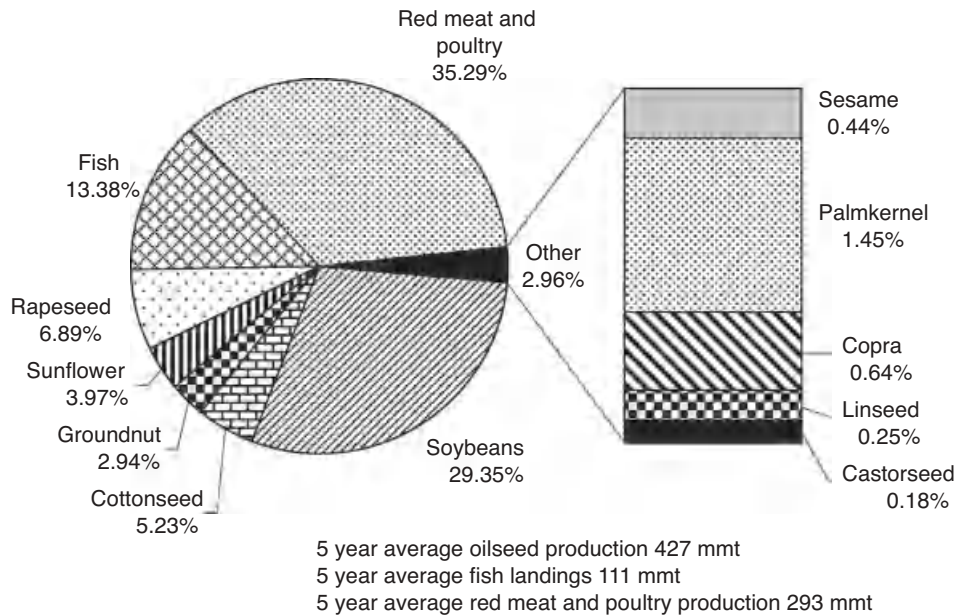
For the most part in the human and livestock diet, fish protein competes with vegetable, poultry, and red meat proteins. Figure 26.3 compares fish landings with that of the major oilseed crops harvested



**Figure 26.1** Growth in total global landings and the components (FAO, 2011).



**Figure 26.2** Disposition of the catch (USDC, 2010). Reproduced with permission of the United States Bureau of the Census.



**Figure 26.3** Fish landings compared to the major oilseed crops and red meat and poultry (Oil World Annual, 2011; USDC, 2010). Reproduced with permission of the United States Bureau of the Census.

around the world and red meat and poultry production.

From this perspective, fish as a source of protein is one of the major raw materials in the world after soybeans, poultry, and red meat. Fishing is the major industry in many countries and the production of fish meal and fish oil is considered one of the major sources of protein and fat commodities in world trade.

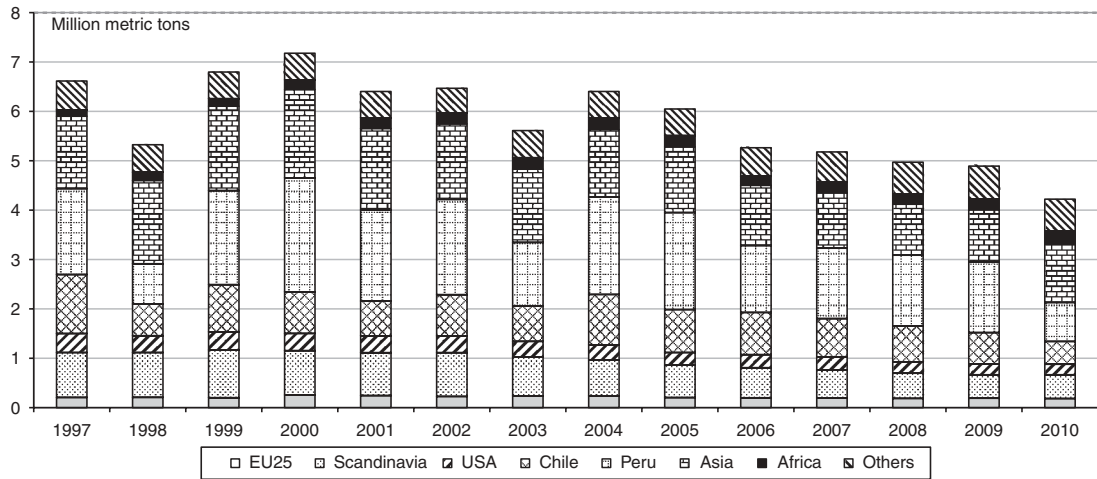
The fish meal and oil industry started in northern Europe and North America at the beginning of the nineteenth century and was based mainly on inshore herring fisheries. This was essentially an oil production activity with the oil used industrially in the tanning of animal skins, the production of soap, the waterproofing of wooden ships, for illumination, and for other nonfood products. The cake residue was originally used as fertilizer, but since the early 1900s, it has been dried and ground into fish meal for animal feeding. Its main use was in the diets of poultry, pigs, and fish that need higher quality protein than other farm stock such as sheep and cattle (FAO, 1986). Over the years, the markets for fish meal have evolved away from poultry and toward aquaculture, specialty pig feeds, and companion animal or pet foods.

Seven entities account for almost all of the global fish meal produced with Peru and Chile representing about 50% of global production. For this document, Denmark and Sweden have been removed from the EU27 and added into Scandinavia. This can be seen in Figure 26.4.

Six entities account for almost all of the global fish oil produced with Peru and Chile accounting for about 50% of global production. For this document, Denmark and Sweden have been removed from the EU and added into Scandinavia. This can be seen in Figure 26.5.

In the US, between 12% and 13% of the total landings are specifically for reduction to fish meal and fish oil while globally the figure ranges from 15% to 18% (USDC, 2010). Menhaden, *Brevoortia* spp., one of the principal species of fish landed in the US accounts for most of the US production of fish meal and fish oil. The other sources are primarily by-products from the salmon, pollock, catfish, and other edible fisheries. The composition of the US major fisheries is shown in Figure 26.6.

Menhaden caught along the Atlantic and Gulf coasts of the US represent approximately 18% of the total annual pounds of fish and shellfish landed. Historically, the catch has been



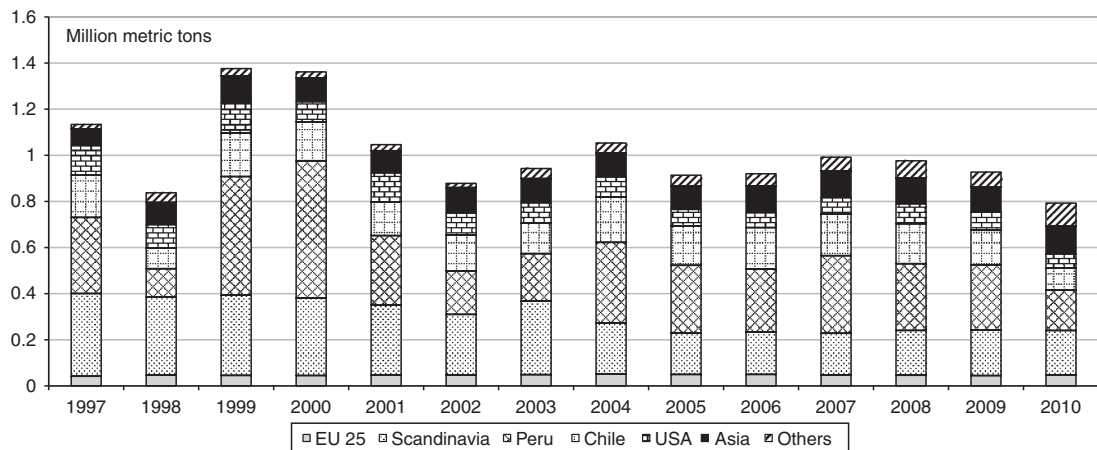
**Figure 26.4** Global fish meal production (Oil World Annuals, 1980–2011–2011, 2011). Reproduced with permission.

dropping and depending on who you talk with, it is either from overfishing or simply the fact that there is less effort to catch them. There are now only two companies catching menhaden when there were as many as 10–15 companies not too many years ago. The historical catch of Gulf and Atlantic menhaden through July 31, 2011, is shown in Figure 26.7.

Menhaden, cousins of herring, are characterized by having big heads, a slight hump on their backs, and no teeth. Like herring, they are dependent on plankton for their food, unlike herring they are seldom eaten as food, yet nearly everyone has at some

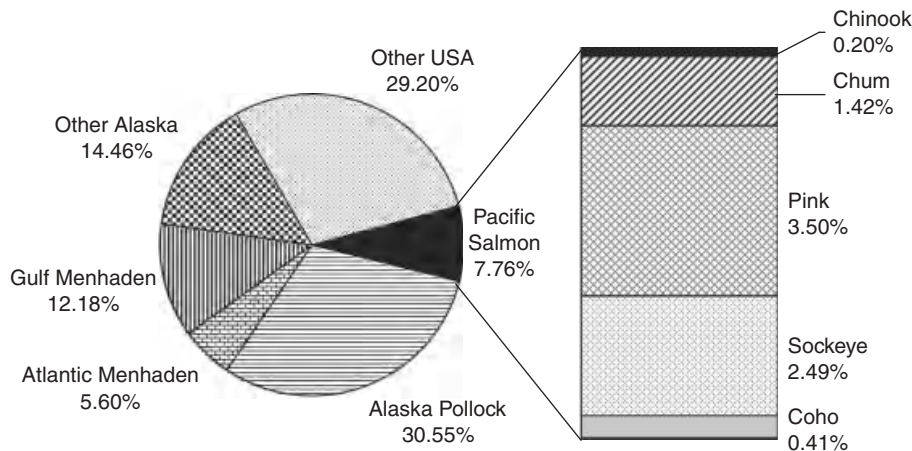
time been indebted to them for something they use (Bimbo, 1970).

No one is sure of the geographical origin of the menhaden industry, but a wealthy Long Island farmer experimented with menhaden as a side dressing in his potato fields as early as 1801. It was in Rhode Island in 1812 that the first crude process for oil recovery was developed, followed by production facilities in Maine in 1850 and in Monmouth County, New Jersey, in 1850–1860. By 1877, there were 14 plants in Maine, 13 in Rhode Island, 5 in Connecticut, 4 in Chesapeake Bay, 23 on Long Island, and 5 in New Jersey (McCay, 1980).



EU members Denmark and Sweden included in Scandinavia

**Figure 26.5** Global fish oil production (Oil World Annuals, 1980–2011–2011, 2011). Reproduced with permission.

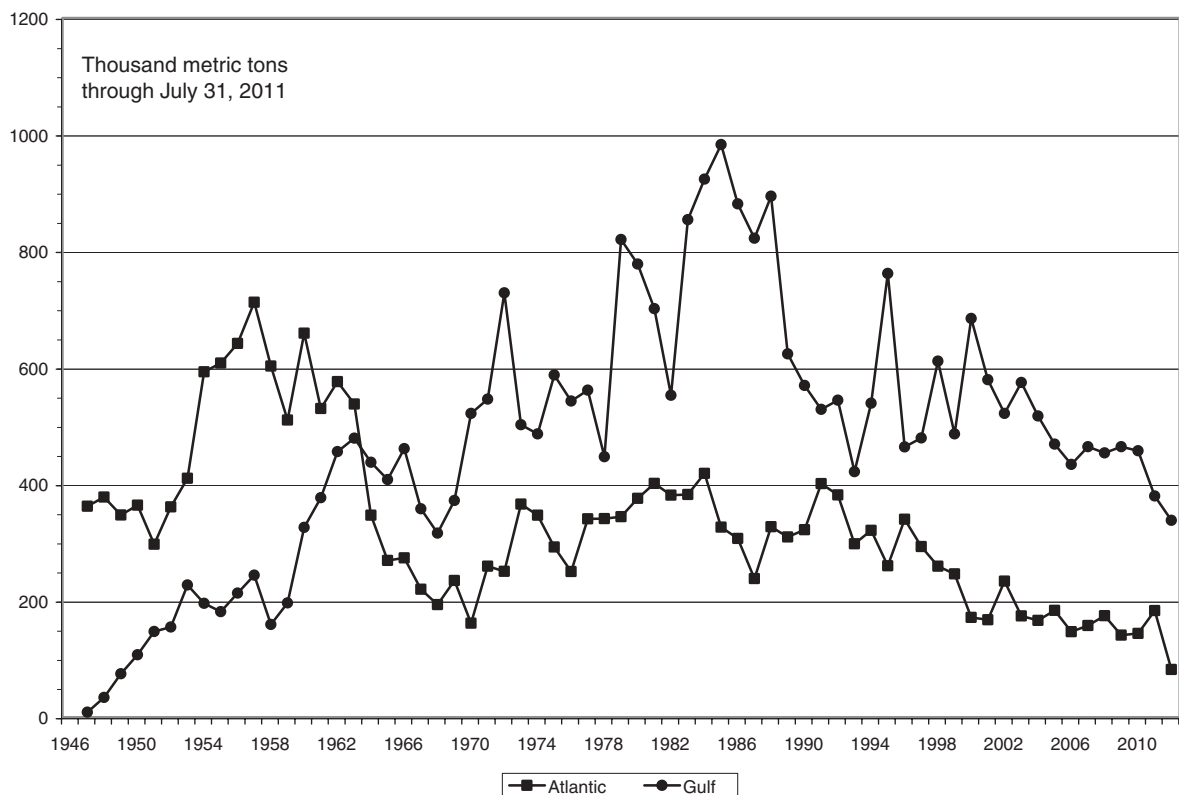


**Figure 26.6** US landings of fish and shellfish. (Data from FAO, 2011; NMFS, 2010a).

The early plants were small, very crude, and usually located in out of the way places away from populated areas. As the process developed, a tub drilled with holes was used to hold the fish under pressure from heavy rocks. Finally, in the 1850s,

the mechanical screw press was developed and the production of menhaden fish oil reached the small factory operation (Lee, 1952; Bimbo, 1970).

The fish were unloaded with pitchforks from boats into tanks or directly into small wooden tram



**Figure 26.7** US Atlantic and Gulf menhaden landings (NMFS 2008a, 2008b).



cars holding 20 barrels each. These cars were hauled to the upper floor of the plant where the fish were dumped into large reservoirs. From there, the fish flowed as desired into the cooking tanks. These were constructed of wood staves, sometimes with a false bottom, and had perforated pipes in the bottom for the introduction of steam. The tanks held from 50 to 75 barrels of fish and were filled to a depth of 15–30 cm (6–12 in) with seawater, which was sometimes preheated before addition of the fish. Cooking time was usually 30 minutes, though in one plant the fish were simmered for 5 hours. After cooking, the hot water and oil were drawn off, and the mass of fish allowed to drain and cool. A man then climbed into the tank and pitch forked the fish into “curbs,” that confined the fish during the pressing operation. The curbs were built of heavy wooden slats, iron-bound, or of iron with 0.125 in holes, and held from 3 to 10 barrels of fish each. They were usually mounted on small trucks running on tracks leading to the press. The first presses received their pressure by weighted rocks or by using a lever to squeeze the oil from the fish. Oil and water draining from the cooking tanks and presses ran to a series of settling tanks. The operators were aware of the fact that the oil contained finely divided fleshy material that settled out more slowly than the press water and that for the best grade oil this should be removed before putrefaction started. The top oil was skimmed off and held in open tanks for 1–2 weeks to sun bleach for the best grade of white oil. The lower levels of oil were run off into another tank and yielded progressively poorer grades.

The wet press cake in the curbs was dumped through a trap door in the floor to a room or open space beneath the plant. In some plants, it was allowed to accumulate until fall or winter before disposal. Frye (1978) reported that by the middle of the nineteenth century disposal of the residue after oil removal had become a problem. The residue was removed and given to farmers to compost the fields and this replaced the use of whole fish. By 1917, because of animal feed shortages, the fish scrap began to find use in animal feeds and by 1935, virtually all of it was used in this way. Some of the menhaden scrap continued to sell as fertilizer until the late 1920s. Smith (1940) described the rapid changes that took place in the industry along the Atlantic coast. Prior to 1940, the process consisted of cooking the fish in large vats, pressing the cooked fish

and catching the pressed liquor in a series of settling tanks. By a series of skimmers, the oil was separated from the water phase and an emulsion layer was recooked to recover the oil. The remaining “gurry” was then allowed to decompose to form dark, low-grade oil that was removed by hand dippers. In 1940, the industry began to use centrifuges to separate oil from water and thus eliminate this emulsion phase. The oil was the most valuable product recovered from the fish and was used in soap, paints, and linoleum. It was the introduction of the centrifuge that started the rapid increase in production of menhaden oil in the United States, the “Industrial Revolution” of the menhaden industry. With the discovery of vitamin B12 as a source of the animal protein factor in 1949, Menhaden scrap’s use in animal feeds was reemphasized. About this same time, the water from the pressing operation was also found to be rich in vitamin B12 and this became a new by-product after concentration to 50% solids, condensed fish solubles (Lee, 1952; Frye, 1978).

## Production of fish meal

### Raw material

Fish used in the production of fish meal and fish oil can be divided into three categories:

- (1) Fish caught specifically for fish meal production such as menhaden in the United States, anchovy and sardines in Latin America, capelin, mackerel, and sprat in Scandinavia, and sardines in Japan.
- (2) Bycatches from another fishery, such as shrimp bycatch.
- (3) Fish bycatch or cuttings from edible and aquaculture operations such as from filleting plants, surimi operations, and canneries. Tuna, pollock, salmon, and catfish meals are examples of this.

In all cases, the fish are usually small pelagic species, oily and bony and swim in large schools, or the raw material is waste of no edible value or the fish are classified as industrial and of no economic value when compared with the major fishery in which they are caught (FAO, 1986).

There have been many suggestions and attempts to upgrade these industrial species of fish to human

foods. The literature abounds with papers on this subject (Hansen et al., 1980; Ackman et al., 1981; Hansen, 1981; Billy and Dreosti, 1983; Bimbo, 1988b., 1988c). Production and catching costs continue to make fish meal production a low margin/break-even industry, and there is worldwide research in progress to upgrade markets for these fish. As this concept continues to progress, we will see more of the traditional fish meal coming from cuttings as opposed to whole fish, but we will not see an end to fish meal production. In general, the industrial species are relatively small and oily. They are subject to rapid bacterial and enzymatic spoilage and to rapid oxidation and rancidity.

In edible fish operations the fish must be degutted or at any rate, the gut contents must be removed, and the fish must be deboned. All these operations will produce waste or offal for the fish meal plant, and it is, therefore, envisioned that small packaged fish meal plants will be an integral part of any large edible operation (Kreuzer, 1974; Hansen et al., 1980; Ackman et al., 1981; Hansen, 1981; Luna, 1981; FAO, 1982; Billy and Dreosti, 1983). These packaged plants require little space, produce high-quality products, are automatic and require only one person on a part-time basis to operate the system. Plants with capacities of as little as 10 tons per day have been built and installed on factory trawlers. They can be fitted into a room 3.4 m × 5.4 m × 3 m high (Anonymous, 1993).

## Harvesting

The method used to catch fish depends largely upon their feeding habits. For fish that school near the surface, such as menhaden, tuna, mackerel, herring, sardines, and anchovy, the easiest and most efficient method of capture is the purse seine. For fish that live near the floor of the ocean or in mid-water areas, trawling is the most efficient method.

The type of fishing gear used determines, at least in part, the kind of fishing vessel employed. Purse seiners and trawlers are large vessels with carrying capacities that range to 1000 tons or more and travel several days from the fishing grounds. Some factory ships are capable of staying on the fishing grounds for many months and use smaller fishing vessels to deliver catch to them for processing. Finished product is then shipped back

home on carrying vessels (Sanford and Lee, 1960; Sola, 1978).

## Unloading

There are many methods used for the discharge of fish from the fishing vessel to the processing plant:

- (1) Grabs
- (2) Elevators
- (3) Vacuum
- (4) Air Suction (giant vacuum cleaners)
- (5) Direct pumping

The grab and elevator methods are not used to any great extent if at all.

In the vacuum discharge method, fish and air are sucked from the hold of the vessel to the separator section where the fish slide down into a tube that is closed with a rotating valve. When the weight of fish in the tube overcomes the vacuum, the fish will press the valve flap to the open position and slide out. The air escapes from the separating section through a cyclone. The unit is hydraulically controlled from a control box. It is quite maneuverable, can be used with different types of boats, and can be moved from hold to hold without moving the vessel.

The air suction discharge method differs from the vacuum discharge method in the design of the unit. Both remove fish from the hold without the use of water, but the air suction method employs a slide box valve instead of the rotary valve. The equipment consumes a great deal of energy and is very loud when operating (Beugelink, 1978; Konge and Rasmussen, 1978).

Direct pumping of fish can be divided into wet and dry pumping. Dry pumping of fish employs a pump that may be mounted either on board the vessel or lowered from the dock into the vessel's hold by a crane. In either case, the pump is driven by a directly coupled static hydraulic motor. With the pump mounted on the crane and the hydraulic drive power unit placed on the dock, the pump operates submerged or partly submerged in the fish mass and delivers the fish through a vertical telescopic tube via a self-cleaning rotary tube strainer to the measuring device that is located on the dock. If the fish mass contains no free water, it is necessary to add a certain amount of water at the beginning

of the unloading process. The water is then strained off in the rotary strainer and recirculated to the fish hold. With the pump mounted on board the vessel, it is placed in a chute in the center of the hold. The hold is sloped toward the sump to which the pump suction tubes are connected via remote control gate valves. The fish mass is delivered through the self-cleaning rotary strainer and quick fit rubber hose to the bin or measuring unit on the dock. The strained off water is recirculated to the fish hold if necessary to wet the fish mass. This type of direct unloading without water has several advantages:

- (1) The system is sealed and causes no air or water pollution and is easy to clean.
- (2) There is very low power consumption.
- (3) Labor costs are low; the system can be operated with a minimum number of people.
- (4) The water-to-fish ratio is 0.5:1 as very little additional water is needed and this results in less yield loss to the water.

The direct pumping of fish using water as the transport medium requires a flexible suction pipe and flexible water hoses this being the only connection between the vessel and the shore. Service water is used to prime the fish mass initially and then provides the carrying medium for the fish during the unloading operation. The fish and water are pumped through either a centrifugal screw impeller pump or a piston pump. Water and fish are then separated in rotary strainers and the fish enter the measuring system while the water is recycled back to the vessel, and reused until it becomes too thick to pump (as is done in the US menhaden industry), then, if freshwater was used as the starting water, the used unloading water is added into the process where valuable protein and vitamins are recovered. If saltwater has been used, the water must be handled in such a manner that the addition of salt to the final product will not cause the product to exceed the salt limitations. In some areas (South America for example), the unloading water makes one pass with the fish and is then discharged overboard where it enters into the biological process of the receiving water, adding valuable nutrients (Gibbs and Green, 1978; Nordstrom, 1978; Tronstad, 1978). Unfortunately, when this method is used, a large amount of fish solids are lost and the yields are quite low, especially with soft fish. This unloading method has been thoroughly reviewed by Mueller-

Vollmer et al. (1998) and Bimbo (1996). Depending on the pump type, this system can use as much as 20 or 30:1 of water to fish and is, therefore, not very efficient. If the water is not processed, large volumes of fish protein and oil are lost resulting in very low yields.

A modification of the direct unloading with water method involves use of a pressure vacuum pump. In this method, the fish are pumped with water under vacuum suction to a chamber in the pump system. The chamber is then pressurized to move the fish to the plant for dewatering. The system usually has two chambers so that they work in tandem; while one is under vacuum, the other is pressurized. This system uses water-to-fish ratios of 1:1 and does very little damage to the fish.

As environmental issues continue to grow, the discharge of the water has become more critical and some companies have begun to use different methods to remove solids from the water stream before discharge. In doing so, they have discovered that fish meal and oil yields have increased and with the very high prices for these commodities today, the return on investment has been very fast and quite profitable.

## Cooking

Cooking denatures the fish protein and makes it possible to separate the fat mechanically. A number of parameters influence the quality of the cooked fish, including the following:

- (1) Heating temperature
- (2) Heating time
- (3) pH of the fish
- (4) Freshness of the fish
- (5) Particle size of the fish pieces
- (6) Type of fish

During the cooking process, the protein is coagulated into a firm mass capable of withstanding the pressure required to press out the liquid (stickwater and oil). During coagulation, a high proportion of the bound water is liberated and deposits of fat are released from the tissues and thus removed by water and oil separation.

The cooker is a cylinder having a steam-heated jacket throughout and a hollow steam-heated auger. The cooker is equipped with covers for inspection

and cleaning purposes and may be equipped with nozzles for the direct addition of steam to the fish mass. Generally, the cookers are of the indirect type where the condensed steam does not make contact with the fish but instead is returned to the boilers. This is more efficient and economical since no additional water is added to the fish mass that must be removed by evaporation or drying later in the process.

Cooking is an exacting operation in the process and at times it is difficult to control. The production of cooked material that can be readily pressed is dependent on the quality of the raw material and the process conditions. Good cooking results in good pressing of the mass that leads to proper removal of pressliquor and efficient recovery of oil giving a low-fat fish meal. Overcooking affects pressing and also causes the formation of fines or suspended particles in the stickwater that makes evaporation difficult (Ward et al., 1977; FAO, 1986).

## Pressing

The liquid portion of the fish (water and oil) can account for 80% of the fish mass. Therefore, deoiling and dewatering are two of the major steps involved in the manufacture of fish meal and fish oil. The objective of the pressing and screening operation is to produce a fish meal with the lowest possible oil content. There are a number of methods by which this is achieved, but the major method is in the use of presses (Kroken and Utvik, 1978).

Two types of continuous presses are used in the fish meal industry. The single-screw press works on the principle of a helical-screw conveyor rotating in a cylindrical cage, provided with perforations for the drainage of pressliquor. The screw, designed with a taper, exerts an increasing pressure on the mass by reducing the volume during its passage through the cage. Some problems are experienced when the press is used with poor raw materials. Slipping of the soft fish material may occur, and the screw is unable to convey and effectively press the material. This difficulty may be minimized by incorporating special devices in the press or by using twin screw presses.

In the twin screw press, pressing is carried out in a press chamber consisting of two hollow interlocked cylinders. The press consists of a stationary part, the stator, and a rotating part, the rotor or the screw, and

a gearbox with motor. The free space between the rotor and the stator decreases from inlet to outlet in a taper so that material introduced at the inlet will be compressed and pressure built up as the product travels to the outlet. The built up pressure causes the liquid to be squeezed through the perforated stator while the solids remain inside (Onarheim and Utvik, 1979).

A variation on pressing involves two-stage pressing. Double pressing or two-stage pressing is used when certain types of raw materials that are difficult to press are processed. This variation is also used when a lower fat content is required in the final meal for specialized end uses. The method involves pressing the cooked fish in the normal manner, cooling the presscake to 50°C (122°F) by adding chilled stickwater, and then pressing again. Fat reductions of 2–4% in the final meal can be achieved (Onarheim, 1978). Another variation on the pressing technique involves the use of decanters to separate liquid from the cooked fish. This alternative finds merit where the fish are old and in poor condition. The decanter appears to be able to deliver a meal product of consistent quality independent of the raw material quality. The cake is not as dry as that produced with a press and thus requires more energy to dry the meal, but the decanter lends itself readily to sanitary cleaning and thus would find applications in areas where fish protein might go into human food products (Rask, 1979). An off-the-shelf plant that uses decanters is called the ConKix process. The process employs a short-time heater cooker, decanter, and separator. A variation on the decanter process uses tricanter that allow for a three-phase separation of fish cake solids, oil, and water. An off-the-shelf process utilizing a tricanter is the ConDec process.

## Drying

The prime reason for drying fish is to reduce the moisture content of the nonaqueous material to such a level that insufficient water remains to support the growth of microorganisms that feed on it (Jason, 1980). There are two types of dryers used in the fish meal industry today: direct and indirect. In direct dryers, heat transfer is accomplished by direct contact between the wet fish solids and the hot gases. The vaporized liquid is carried away by the drying medium, i.e., the hot gases. Direct dryers

might also be termed as convection dryers. In indirect dryers, heat for drying is transferred to the wet fish solids through a retaining wall, steam tubes, steam coils, or steam discs. The vaporized liquid is removed independently of the heating medium. The rate of drying depends upon the contact of the wet fish material with hot surfaces. Indirect dryers might also be termed conduction or contact dryers.

There are several factors to be considered in the selection of a dryer system:

- (1) The dryer must handle all types of fish in all types of conditions.
- (2) The dryer must be able to handle stickwater concentrate (solubles).
- (3) The dryer must give a maximum meal yield.
- (4) The dryer must give a high-quality meal.
- (5) The dryer system must have an effective deodorizing system.
- (6) The dryer must have a reasonable cost and energy consumption (Hetland, 1980).

In direct dryers, the quality of the meal is influenced by the dryer inlet temperature and, therefore, should be below 600°C (1112°F). The dryer consists of a large rotary tube or drum in which presscake (wet fish solids that have been cooked and pressed) is tumbled rapidly in a stream of very hot air at inlet temperatures below 600°C (1112°F). Tumbling is provided by the rotating action of the dryer and a number of flights or baffles within the dryer that provide a cascading action and good air-to-particle contact. The hot air is provided by a current of flue gases from oil or gas combustion together with diluting secondary air. The particles of meal do not, themselves, reach this high temperature because of the rapid evaporation of the water from the surface of each particle, causing cooling by the loss of heat of evaporation. The temperature of the meal is normally 80°C (176°F). The fish and air move through the dryer in the same direction, and the rapid flow of hot air tends to help carry the meal particles through the dryer. Air velocity, is another important parameter in the direct dryer.

The indirect dryer is also a rotary dryer consisting of a large cylindrical drum in which the presscake is dried, but the heat is supplied indirectly by contact with steam or hot air heated discs, tubes, coils, or a jacket. A current of air is blown through the dryer to remove the water vapor produced but the air is itself not normally heated and travels counter-

currently to the meal flow. The rotary action of the discs, coils, or tubes together with a series of flights within the dryer causes agitation of the meal and enhanced drying. Blades or scrapers are often necessary to prevent the product from sticking to the drying surface and a subsequent deterioration of the drying efficiency. The temperature of the drying surface is decided by the temperature of the heating medium within the discs, coils, or tubes. This medium is normally steam and its temperature is related to its pressure (Windsor and Barlow, 1981). Both types of dryers are utilized in the fish meal industry today and for all practical purposes, there is very little nutritional difference between meals dried by direct or indirect means. Properly controlled cooking and drying procedures will produce products that are nutritionally sound with no deleterious effect on quality (FAO, 1986).

Compared with other methods of drying fish meal, low-temperature drying is a relatively new concept within the industry and has had its greatest acceptance in the production of fish meal for the aquaculture industry, early weaned pig market, mink feeds, and recently, pets or companion animal food. Low-temperature drying developed as the industry sought new ways to eliminate air pollution and recover wasted energy from dryers. By taking the existing hot air direct-fired dryers and adding a heat exchanger between the furnace and the dryer drum, it was possible to lower the drying temperature of the fish meal, recover the wasted heat that was going up the stack, and reduce air pollutants. Meal temperature exiting these dryers is low, normally 65°C (149°F) or less as compared with 90–95°C (194–203°F) in steam or direct-fired dryers. The nutritional quality of these meals is better since the protein has been exposed to lower temperatures and this type of meal has found markets in areas where the quality can demand a premium. Capital expenditure to install these dryers is high compared with direct-fired dryers primarily because of the low-volume throughput.

## Antioxidant addition

All fish meals will react with oxygen to some degree or other. The degree of reactivity of the meal is dependent on a number of items, but normally the amount of fat and its level of unsaturation are key issues. Reactive fish meals are stabilized by



the addition of antioxidants immediately after they leave the dryers. In practice, the meal is first cooled to a temperature below the vaporization temperature of the antioxidant, and then stabilized with the antioxidant. The amount of antioxidant required to prevent this spontaneous heating depends on the type of fish that has been processed and the degree of unsaturation of the lipid (fat) portion of the meal. Northern species of fish with relatively low unsaturation in the fat, such as herring or capelin, require low concentrations of antioxidant, while southern species such as anchovy, sardine, pilchard, and menhaden require higher concentrations of the antioxidant. Very careful control is necessary in the addition of the antioxidant, as the amount is quite small (typically 0.75–1.5 lb/ton of fish meal) and dispersion of the chemical in the meal becomes the critical factor. Normally, the antioxidant is added to the meal in a screw conveyor so that there is thorough mixing as the meal is conveyed. Automatic control devices and variable speed pumps are used to assure that changes in the rate of production receive the corresponding changes in antioxidant addition rate. Normally, meal exiting from the dryer is too hot for the addition of antioxidant and it is necessary to first cool the meal below the vaporization point of the chemical. This assures that the correct dosage remains in the fish meal. It has been reported that some factories add one half of the antioxidant to the presscake prior to drying and the other half after drying and cooling but there is very little data available to indicate whether this has any advantages.

Antioxidants are free radical acceptors and break the peroxide reaction chains. This may be regarded as the best way to stabilize fish meal. Oxidation is checked and the lipids in the fish meal remain fully available in the finished feed. The effectiveness of the antioxidant is measured by how quickly the product can be stored in bulk or bags with little or no turning of the piles. Ethoxyquin, 1–2 dihydro-6 ethoxy-2,2,4-trimethylquinoline, is the antioxidant of choice throughout the fish meal industry. Ethoxyquin may be safely used in animal feeds in the United States, when incorporated in accordance with the following prescribed conditions:

- (1) It is intended for use only:
  - (a) as a chemical preservative for retarding oxidation of carotene, xanthophylls, and

vitamins A and E in animal feed and fish food;

- (b) as an aid in preventing the development of organic peroxides in canned pet food.
- (2) The maximum quantity of the additive permitted to be used and to remain in or on the treated article shall not exceed 150 ppm.
- (3) To assure safe use of the additive, the label and labeling of the food additive container and that of any intermediate premixes prepared from it shall contain, in addition to other information required by the act:
  - (a) the name of the additive, ethoxyquin;
  - (b) a statement of the concentration or strength contained therein;
  - (c) adequate use directions to provide for a finished article with the proper concentration of the additive as provided in paragraph B of this section, whether or not intermediate premixes are to be used;
  - (d) the label of any animal feed containing the additive shall, in addition to the other information required by the act, bear the statement "Ethoxyquin added to retard the oxidative destruction of carotene, xanthophylls, and vitamins A and E (Code of Federal Regulations (CFR), 2008)."

Studies conducted throughout the fish meal industry, not only in the United States but also in South Africa, Canada, and Peru, during the mid-1960s, indicated that ethoxyquin was about 8–10 times more effective in stabilizing fish meal than BHT (butylated hydroxy toluene), which was then used throughout the industry (Bimbo and Crowther, 1990). Since that date, no other antioxidants have been routinely used for the stabilization of fish meal, although many others have been and will continue to be evaluated (Chahine, 1978). In recent years, certain users of fish meal have indicated a desire to have a fish meal stabilized with a natural antioxidant. Research on this continues and several products based on mixed tocopherols, citric acid, and rosemary extract are on the market and are used in fish meals destined for the pet-food market. However, the shipment of fish meal over the world's oceans is regulated by the International Maritime Organization that is part of the United Nation. According to their regulations, only ethoxyquin and BHT are permitted for the transport of fish meal over the oceans. Several attempts

to amend this regulation and allow the use of the natural antioxidants have failed due to lack of sufficient information on the safety of the cargo stowed in the ocean-going vessels.

## Storage and shipping

Storage methods for fish meal depend on many factors including climatic conditions, production capacity, use of antioxidant, and transport and marketing arrangements. Factories usually have a storage capacity for a reasonable quantity of finished product. During times of difficult marketing conditions or glut catches of fish, it may be necessary to go to "outside" locations away from the actual processing plant. Fish meal must be stored in weather-proof, well-ventilated spaces with a clear space between walls and the product piles or stacks.

About half of the world's fish meal is stored in bulk in either warehouses or silos. Bulk storage is advantageous for the following reasons:

- (1) All handling, from production to loading, becomes simpler, cheaper, and results in considerable savings in manpower and maintenance over the facilities used in bagging fish meal.
- (2) Most transport vessels and international receiving centers are geared to the handling of bulk, so factory bulk storage is compatible. However, this appears to be changing and the distribution between bulk and ocean containers holding 50 kg bags or 1-ton bulk bags is about evenly split.

Facilities for bulk storage are either of the open type (access of air through doors and windows) or of the sealed type such as silos. The open shed or warehouse predominates in the fish meal industry today and is equipped with floor and overhead conveyors for turning of the fish meal. The sheds may be of single or multi-unit construction with concrete walls and floors. Newer warehouses may have bins or partitions so that different quality grades of fish meal can be separated.

Silos offer good protection to meal in storage. Specially designed silos keep the meal in motion by continuously extracting the meal from the bottom and returning it to the top with an automatic conveyor system. This keeps the meal from compacting and or bridging.

In addition to bulk storage, fish meal may be bagged and stored on pallets. The bags usually hold 50 kg (100 lb), and may be open ended and stitched, or with tuck-in valves. Bag material ranges from hessian or multilayer paper, both with and without a plastic liner. The hessian bag made from woven jute or burlap is frequently used in the tropics or in areas where heat and humidity may be problems. The open texture allows heat and humidity to escape but also allows for rapid entry of oxygen that leads to further oxidation, penetration by insects and rodents, seepage of meal, and under extreme humidity conditions, to the absorption of moisture from the air with resultant moldy conditions. Hessian and jute bags are being replaced by woven plastic bags. The paper bag, on the other hand, keeps insects and rodents out, retards oxidation and absorption of moisture, and does not leak unless broken. While the barrier offers excellent protection of the product from external sources, it could lead to a moldy product if the moisture content of the meal in the bag is 8% or higher. The moisture tends to migrate outward and condense forming wet spots that could cause mold growth. Wooden pallets holding approximately 1 ton are often used to facilitate handling and storage of the bagged meal. Pallets may be stacked three high with fork lift trucks after the meal has cooled (Dreosti, 1980; FAO, 1986). New packaging systems called bulk bags or ocean-going totes are designed to hold 1 ton of product in a protected package that is suitable for export. Since the bag holds a ton of product, there is less human handling and the bags are dumped or ripped open to allow the product to fall into a conveyor for storage in bins or for direct feed to the blending operation. Some companies now utilize ocean-going containers to ship bulk fish meal. The containers may or may not be lined with plastic. If the container is exposed to changes in ambient temperature, there is a tendency for the moisture to migrate to the surface, evaporate, and then condense back onto the fish meal surface. When this happens neatly spaced rows of mold grow on the surface of the meal. To prevent this, some companies add a mold inhibitor such as propionic acid to the fish meal.

## Production of crude fish oil

During the pressing operation, two intermediate products are produced: presscake and pressliquor.

The pressliquor (oil plus water) squeezed from the cooked fish contains coarse particles of fish and bone that must be removed before the liquor can be centrifuged. Removal of these solids is accomplished by passing the liquor over a vibrating screen with 5–6 mm perforations. The recovered solids go back on the presscake and are dried.

Separation of the screened presswater is then carried out in three steps. These steps involve:

- (1) decanters that are used to remove fine suspended solids including sand from the pressliquor in order to obtain a liquor suitable for the separation step;
- (2) separators that are used to remove as much oil as possible from the pressliquor and thus produce a stickwater with the least amount of fat;
- (3) polishers or purifiers that are used to remove the final traces of moisture and impurities from the oil prior to its pumping to storage.

In some plants, there is also a fourth step, the subsequent separation of oil (deoiling) from the solubles after partial evaporation (Bimbo, 1987).

### Solids removal

Decanters are cylindrical bowls with a cylindrical conveyor turning inside. The pressliquor is pumped into the bowl and the solids are forced to the outer periphery and conveyed out of the system by the conveyor. The conveyor turns at a slower speed than the bowl and through a combination of conveyor speed and liquid depth, the desired clarifications can be achieved (Gloppestad, 1979). Solids removed from the decanters are mixed with the presscake and dried.

### Oil–water separation

Pressliquor discharged from the decanters is pumped into a holding tank, heated if necessary, and then directed either by gravity or by pump to the separators. Today, the separator is a modern, high-capacity machine capable of handling many times more volume of feed per hour than the machines described by Smith in the 1940s. These machines are self-cleaning, that is, they either have

a sensor in the bowl capable of interrupting the separation cycle long enough to discharge the solids accumulated in the bowl or discharge the contents of the bowl on a timed cycle. The machines make a three-phase separation of the pressliquor into an oil phase, water phase, and sludge phase. The sludge phase is pumped away either to the cooker or to the presscake where it is dried back on the fish meal (Bimbo, 1987).

### Polishing or oil purification

The oil phase recovered from the separators is continuously washed and separated into two phases, water and crude fish oil. The water phase is mixed with the stickwater and evaporated. The fish oil is pumped into storage tanks where it is tested and sold for a variety of uses. The crude oil can also be further refined and processed into a number of other food and industrial raw materials (Bimbo, 1988a, 1989).

### Production of stickwater concentrate

The third part of the wet rendering process is the production of stickwater concentrate or condensed fish solubles. Production of fish solubles begins with the separation of oil and water in the production of fish oil as previously described.

### Evaporation

The water removed from the pressliquor is called stickwater and the concentration of the stickwater to various percent dry matter is called evaporation. The concentration of stickwater is carried out in multiple effect evaporators with natural or forced circulation. Multiple effect evaporators are used extensively throughout the industry. Steam requirements decrease with an increase in the number of effects. In the conventional operation, dilute stickwater is fed to the first effect where steam is introduced to heat the stickwater. In the conventional operation, live steam is introduced into the steam jacket in stage I through a manually operated regulating valve. The capacity of the plant is determined by the quantity of steam and, as the evaporator surfaces become fouled, the pressure in the steam jacket must be increased correspondingly

so that capacity is maintained. The condensate is released by a steam trap through a preheater where it preheats the stickwater feed.

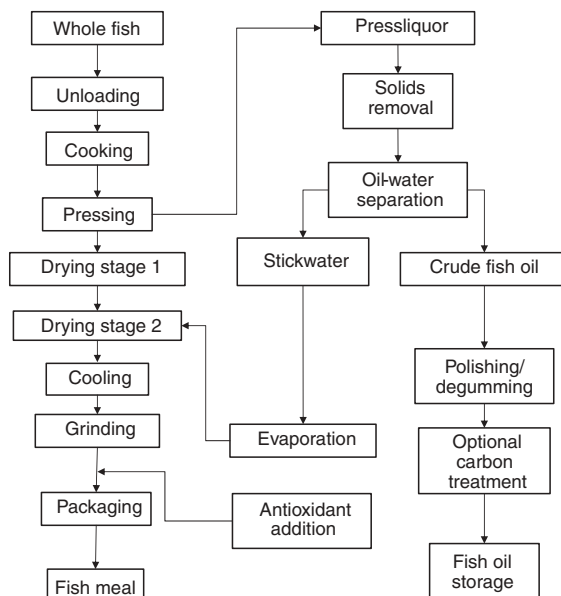
The main problem associated with the evaporation process is in the reduced capacity as the tubes become coated and the heat transfer is reduced. The main disadvantage of the evaporator compared with the other equipment is that during the evaporation process, proteins and calcium phosphate are deposited on the inside walls of the tubes. The deposits have an insulating effect that increases with time and must be removed periodically. Most evaporators are designed with a heating surface that ensures 6 days continuous operation at nominal capacity. If not, the evaporator becomes the bottleneck in the production that may have serious consequences such as loss of stickwater, reduced meal yield, reduced capacity, or even a stop in production. The protein deposits are easily removed by water or a dilute caustic soda solution, while the calcium phosphate must be treated with 14–15% caustic soda solution (Onarheim, 1978).

Oil separation from partly concentrated stickwater is practiced by some manufacturers. The density of the stickwater is higher in the concentrate than in the dilute state. This greater difference between the density of oil and stickwater produces an increase in the centrifugal potential and thus contributes to extra oil removal. Consequently, oil removal from the concentrate leads to a leaner wholemeal and increases the oil yield. The stickwater concentrate may then be added back on the presscake and dried to produce whole or full meal, or it can be centrifugally deoiled to further reduce the fat content, concentrated back to 50% solids, acidulated to about pH 4.0, and sold as condensed fish solubles. Most of the solubles are added back on the presscake to produce wholemeal (Christensen, 1978).

The separated oil tends to be rather dark in color, high in free fatty acids, and of less value than oil separated from the pressliquor (FAO, 1986). A typical flow diagram of the wet reduction process is shown in Figure 26.8.

## Other production methods

There are several alternative production methods primarily designed to produce fish meal or its equivalent with the oil phase as a minor by-product. They are mentioned here because they have some



**Figure 26.8** Flow diagram of the wet reduction process (Bimbo and Crowther 1992a).

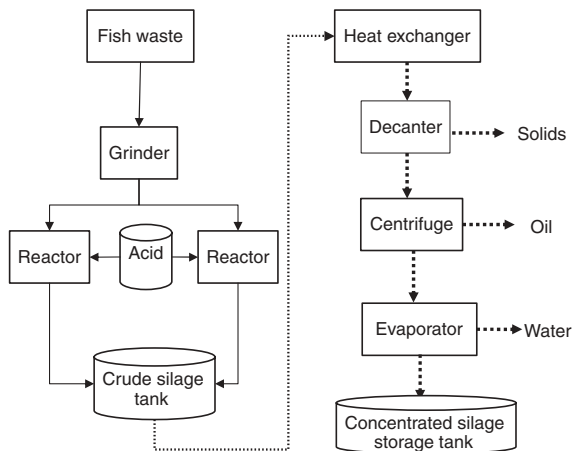
general use for the recovery of protein and oil from fish and fish waste and these uses come up for review now and then.

## Dry rendering

The dry rendering process that is commonly used to prepare meat and bone meal is not normally used in the manufacture of fish meal and oil. It would only find some limited use when the raw material was extremely low in oil. For fish meal production, the process is usually continuous, involving a combined cooking and drying step. In many parts of the world, this is accomplished by the use of a series of rotating coil dryers. The wet material enters the first dryer and then the discharge goes to the second dryer, and so on down the line. Since there is very little oil in the raw material, no pressing step is needed (Bimbo, 2005).

## Various silage products

Fish silage is liquefied fish stabilized against bacterial decomposition by an acid. The process involves grinding of the fish followed by the addition of an

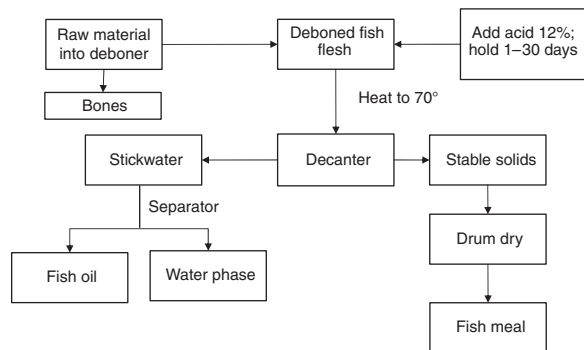


**Figure 26.9** Crude and advanced silage flow diagram (Arason, 1994; Bimbo, 1996).

acid for preservation. The enzymes in the fish break down the fish proteins into smaller soluble units and acid helps to speed up their activity while preventing bacterial spoilage. Formic, propionic, sulfuric, and phosphoric acids have been used. Normally, about 3–4% of acid is added so that the pH remains near 4.0. Strong mineral acids require neutralization before feeding the final product. There are several modifications to the silage process: modified silage, advanced silage, and bacterial fermentation silage (Arason, 1994; Bimbo, 1996). These processes are outlined in Figures 26.9, 26.10, and 26.11. Figure 26.9 combines the standard crude fish silage process with the further processing that is known among other things as the advanced silage process. The advanced silage process, denoted by the dotted line, takes the crude silage and concentrates the solids by evaporation after removing the oil. If the fish are lean, then the oil separation process is not needed.

## Hydrolyzates

Silage might be defined as a crude form of hydrolyzate. Hydrolyzates differ from silage in that in hydrolyzates, the raw material is first pasteurized to destroy the bacteria and natural enzymes in the fish. An external enzyme is then added to reduce the protein chain size to the desired length and functionality. A flow diagram of the hydrolyzate process is shown in Figure 26.12.

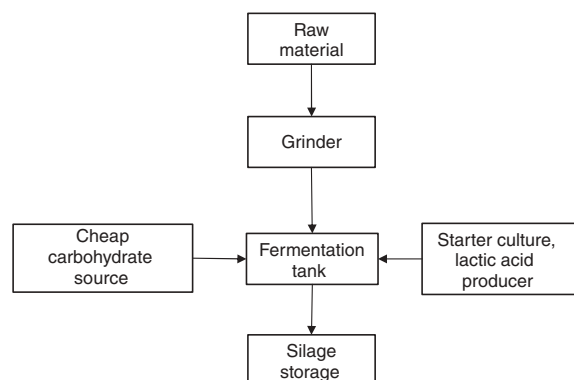


**Figure 26.10** Modified silage flow diagram (Nicklason et al., 2002).

Silage made from whitefish offal does not contain much oil, but when made from fatty fish such as herring it is necessary to remove the oil. The composition of the silage will be very similar to the material from which it is made. Fish silage of the correct acidity is stable at room temperature for at least 2 years without decomposition. The protein becomes more soluble, and the amount of free fatty acids increases in any fish oil present during storage (Tattersson and Windsor, 1974). Silage production offers a solution to the handling of fish waste when the logistics of delivering to a fish reduction plant are not economical. Silage can be produced in large or small containers both on the vessel and on shore.

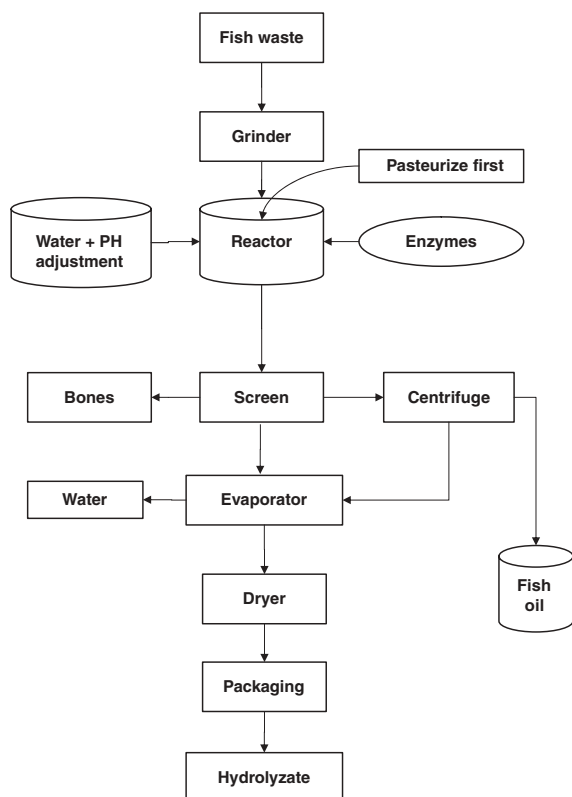
## Pollution control

Pollution control in the fish meal industry can be divided into water and air pollution categories.



**Figure 26.11** Silage production through bacterial fermentation process flow.





**Figure 26.12** Fish protein hydrolyzate flow diagram.

### Water effluent

The sources of wastewater produced in the fish meal processing industry can be summarized as follows:

- (1) Pump water (fish unloading water)
- (2) Stickwater (water from the fish after oil removal)
- (3) Equipment wash up waters
- (4) Boiler blowdown water
- (5) Evaporator condensate water
- (6) Evaporator cooling water or condenser water
- (7) Air scrubber water
- (8) Miscellaneous waters
- (9) Blood water (liquid from the fish during storage before processing)

Of the aforementioned water sources, pump water, stickwater, and blood water will have the most protein and oil and, therefore, the highest biological oxygen demand load if these are discharged

overboard. Normally, the stickwater is recovered as fish solubles and added back to the fish meal. The pump water and blood water streams can be rich in protein and oil especially if the fish are not fresh and beginning to decompose.

Mueller-Vollmer et al. (1998) and Bimbo (1996, 2000) reported that in the Peruvian fish meal and oil industry the pumpwater, blood water, and stickwater constituted the effluent from these plants and with the installation of a technology package valuable fish meal and oil could be recovered adding to the profitability of the operation. In fact, in many cases the technology package could pay for itself in one fishing season.

### Gaseous effluent

Smells emitted from fish meal plants and other processing factories formerly caused less concern than they do today. Fish meal plants may be threatened by closure for this reason alone, though public reaction is sometimes tempered by the dependence of the local community on fishing activities. Production of bad smells affects the public image of the industry and permits to construct new plants are sometimes difficult or even impossible to obtain. It is not that the emissions from the process are harmful to health; the odorous substances are present at such low concentrations that the question of toxicity does not arise but the substances responsible are so intensely odorous that they can often be detected a long way from the factory. The sources of gaseous effluent in a fish meal plant are as follows:

- (1) The raw material unloading, transfer of fish to the factories, and storage conditions at the factory.
- (2) Processing cooking, pressing, deoiling, and evaporation are carried out at elevated temperatures, and odorous compounds are produced.
- (3) Drying probably accounts for 60–80% of the total emissions from a fish meal plant. Direct flame dryers produce more gaseous effluent than indirect steam-heated dryers.
- (4) Pneumatic conveying and grinding.

Odor emissions from the fish meal process originate from several sources:

- (1) Dryers 60–80% of the total emissions
- (2) Cookers 10–20%

- (3) Raw material conveying 10–20%
- (4) Pneumatic fish meal conveying 2–5%

Odor control in fish meal plants can include one or several of the following steps:

- (1) Condensation of the dryer exhaust to remove water and decrease the air volume.
- (2) Scrubbing with seawater and chemicals.
- (3) Biofilters.
- (4) Incineration in the boilers.
- (5) Chemical oxidation (Anonymous, 1977; Cambell, 1978; Hansen and Knud, 1978; Onarheim and Utvik, 1978; Wignall, 1978; FAO, 1986; Bimbo, 2000).

## Markets

### Fish meal

Fish meal is a major source of protein and as such competes with other protein sources worldwide. Fish meal production is a major industry in many countries and the export of fish meal is the primary or secondary source of revenue for some countries.

Fish meal is used in the feeds of poultry, pigs, ruminants, fish, crustaceans, companion animals (pets), and fur-bearing animals because it increases productivity and improves feed efficiency. Fish meal has been used as a feed ingredient for farm animals for well over a century. It provides a unique balance of essential amino acids, energy, vitamins, minerals, and trace elements that complement the deficiencies of other feed ingredients. Fish meal is also a good source of the amino acid taurine and the essential fatty acid arachidonic acid that are needed for cat nutrition. In addition to being a major source of energy, the residual fat in fish meal is a rich source of omega-3 fatty acids that represent over 30% of the total fatty acids present. The following table gives typical composition data for a number of different fishery products available in the global market (Table 26.1).

New equipment and processing techniques in the production of fish meal have given the industry the flexibility to produce proteins that are tailored for particular animals. Special quality fish meals are now available for ruminants, farmed fish, companion animals (pets), and early weaned pigs. Freshness of raw material is an extremely important crite-

rior for all these special meals since the profitability of feed use can vary with the freshness of the raw material used. In Denmark, a penalty payment system in which Danish fishing vessels are paid according to the quality of the raw material landed at their factory was initiated in 1986. Originally designed to reduce plant odors from poor quality fish, the system soon demonstrated a higher quality finished product with higher yields for less cost (Madsen, 1986).

However, apart from freshness, monogastric animals and ruminants have quite different requirements for feed ingredients. Some producers now make a special quality fish meal using very fresh raw material processed through cookers and dryers at temperatures 10–20°C (50–68°F) below normal processing temperatures. Trials in Norway have demonstrated that the processing temperature affects the digestibility of the fish meal when young mink are used as the test animal. In other experiments in Norway using Atlantic salmon, drying temperature affected weight gain over 18 weeks of feeding (Pike, 1990).

The fish meal market has been evolving at least since 1995, and there has been a gradual transition from land-based animals to aquaculture species. Figure 26.13 shows this transition in the fish meal market over the period 1995 projected to 2010.

### Crude fish oil

Fish oils have been used as food for a long time. The fishermen of Iceland, Greenland, Scotland, and Norway have used it for thousands of years. Cod liver oil was known to have some therapeutic value as early as 1657 when it was found that something in the oil helped alleviate the causes of night blindness. It was also reported during the Middle Ages that cod oil could be used to treat rickets. Between 1752 and 1784, Dr. Samuel Kay, a physician at Manchester Infirmary in England, conducted extensive clinical tests on the treatment of bone disease and rheumatism. In a paper given before the British Medical Society around 1770, he reported that cod liver oil was effective in treating arthritis.

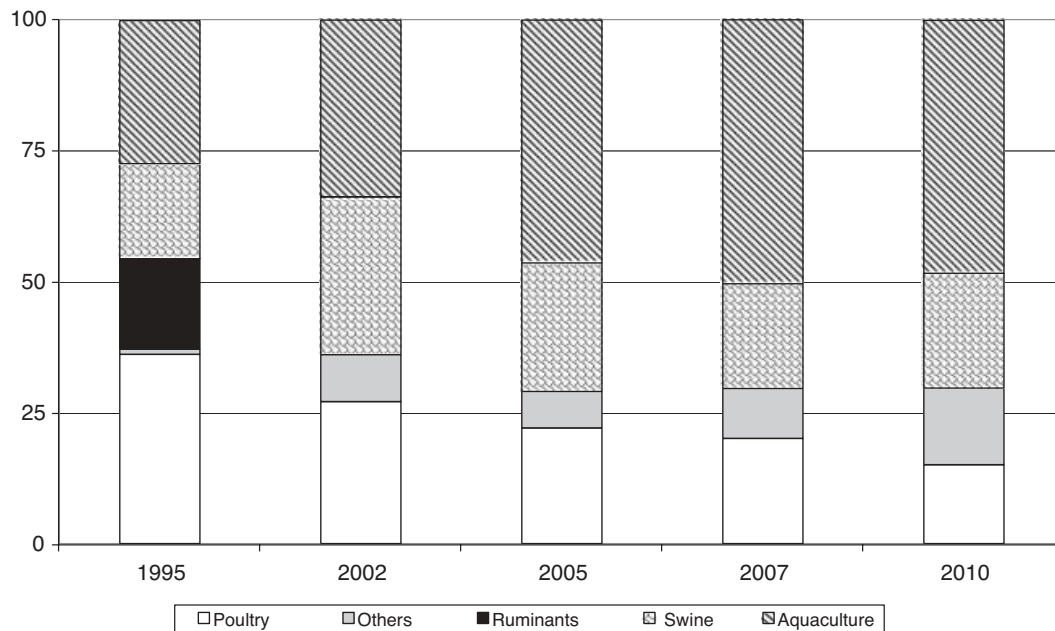
The world will produce over 176 million mt of fats and oils in the 2010–2011 crop year (Oil World Annual, 2011). About 1 million mt of fish

**Table 26.1** The average composition of various fishery products.

	Menhaden	Anchovy Peru	Anchovy Chile	Herring, Atlantic	Herring, Norway	Tuna	King crab	Blue crab	Menhaden Solubles	Alaska <sup>a</sup> whitefish meal
<b>Proximate composition (%)</b>										
Protein	62.0	65	67	72.6	75.3	59.5	39.7 <sup>b</sup>	29.4 <sup>b</sup>	31.8	69.3
Fat	10.2	10.4	5.5	9.7	6.0	7.4	7.4	2.1	8.9	7.6
Moisture	8.3	8.2	7.7	7.0	6.6	6.5	4.7	4.4	48.7	6.1
Ash	18.0	15.4	14.5	10.4	10.1	23.3	26.6	31.0	7.8	17
<b>Macro minerals (%)</b>										
Calcium	5.3	4.0	3.4	2.0	2.0	8.9	6.9	18.0	0.1	5.67
Phosphorous	3.0	2.6	2.2	1.5	1.5	4.7			0.6	3.15
Sodium	0.34	0.87	1.10	0.63	0.42	0.73	1.20	1.80	1.10	0.92
Potassium	0.72	0.65	0.89	1.12	1.20	0.73	1.20	1.80	1.10	0.36
Magnesium	0.14	0.25	0.27	0.14	0.11	0.23	3.5	1.3	0.1	0.27
<b>Micro minerals (ppm)</b>										
Iron	438	246	226	146	151	368	375	155	574	64.69
Copper	11	11	9	6	5	11	111	32	44	3.41
Zinc	151	111	100	121	120	213	251	102	18	97.9
Manganese	36	10	9	5	2	9	12	>400	5	5.11
Chromium	11	8	6	3	4	18	15	42	3	
Boron	14	14	112	6	6	16	22	25	3	
Barium	20	5	6	2	3	5	9	34	5	
Strontium	63	88	59	37	71	>200	>200	>200	4	297
Aluminum	352	77	73	35	33	150	176	430	194	
Selenium	2.2	1.4	1.4	2.0	2.8	4.6	0.25	3.8	2.03	
<b>Amino acids as percentage of sample</b>										
Lysine	4.7	4.9	5.3	5.7	5.7	3.9	1.7	1.4	1.5	4.30
Methionine	1.8	1.9	2.0	2.2	2.1	1.5	0.7	0.5	0.5	
Cystine	0.6	0.6	0.6	0.7	0.7	0.4	0.3	0.2	0.3	
Tryptophan	0.7	0.7	0.8	0.8	0.8	0.6	0.5	0.4	0.1	
Histidine	1.4	1.5	1.8	1.6	1.9	1.8	1.0	0.7	0.8	1.23
Arginine	3.8	3.7	3.9	4.2	4.4	3.4	2.4	1.8	1.3	3.65
Threonine	2.5	2.7	2.9	3.0	3.0	2.3	1.7	1.0	0.7	3.23
Valine	3.2	3.4	3.6	3.9	4.0	2.8	2.1	1.3	0.9	3.48
Isoleucine	2.7	3.0	3.2	3.3	3.4	2.4	1.6	1.0	0.6	2.68
Leucine	4.5	4.9	5.1	5.4	5.2	3.8	2.3	1.4	1.2	4.19
Tyrosine	2.0	2.2	2.3	2.4	2.3	1.8	1.6	1.0	0.7	1.46
Phenylalanine	2.5	2.8	2.9	2.9	2.8	2.2	1.6	1.1	0.3	2.05
Aspartic acid	5.7	6.1	6.3	6.6	4.4	5.0	3.8	2.2	1.6	10.12
Serine	2.3	2.3	2.5	2.7	2.6	2.2	1.7	0.9	0.7	3.35
Glutamic acid	7.9	8.3	8.6	9.2	9.2	6.4	4.6	3.0	2.6	12.29
Proline	2.9	2.6	2.7	2.8	3.1	2.9	1.9	1.3	1.4	3.28
Glycine	4.2	3.6	3.7	4.0	4.6	4.3	2.6	1.8	2.8	7.75
Alanine	3.7	4.0	4.2	4.4	6.5	3.6	1.9	1.4	1.8	5.65
M E kcal/lb	1530								922	

Sources: Miller, 1973; Smiley et al., 2003.

<sup>a</sup> Smiley et al., 2003.<sup>b</sup> Protein adjusted for chitin nitrogen.



**Figure 26.13** Evolution of the fish meal market.

oil will be produced during that same period. Most of the world's marine oil production is consumed in Europe, South America, and Japan, with countries within those areas engaged in aquaculture operations consuming the most fish oil. Up until the mid-1990s, the largest use for fish oil was in the partially hydrogenated form in Europe in the baking industry. When the *trans* fatty acid and health issue became widespread, companies began to move away from oils that required a high degree of hydrogenation and that market for fish oil has been decreasing ever since. However, with that lost market, the aquaculture feed market began to increase as the farming of salmon and other carnivorous fish species increased.

Germany, the United Kingdom, and the Netherlands represent the countries that used fish oil for hydrogenation, while Norway, Chile, Canada, and Asia use fish oil for aquaculture feeds (Figure 26.14). There is a remarkable transition.

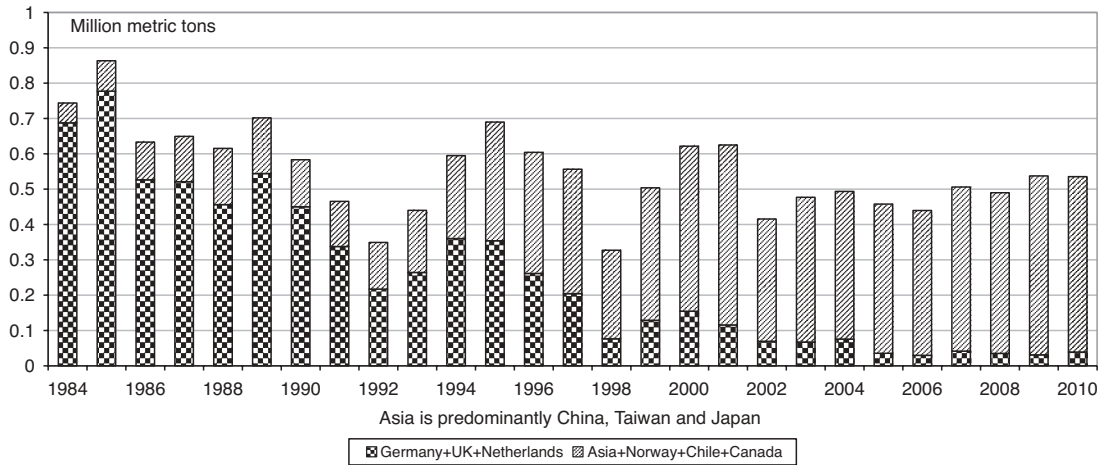
The gradual change is the fish oil market from hydrogenation to aquaculture and the slow increase in the production of nutraceutical oils (omega-3) is shown in Figure 26.15.

While the nutraceutical market for fish oil is still relatively small, only representing about 10%, it has

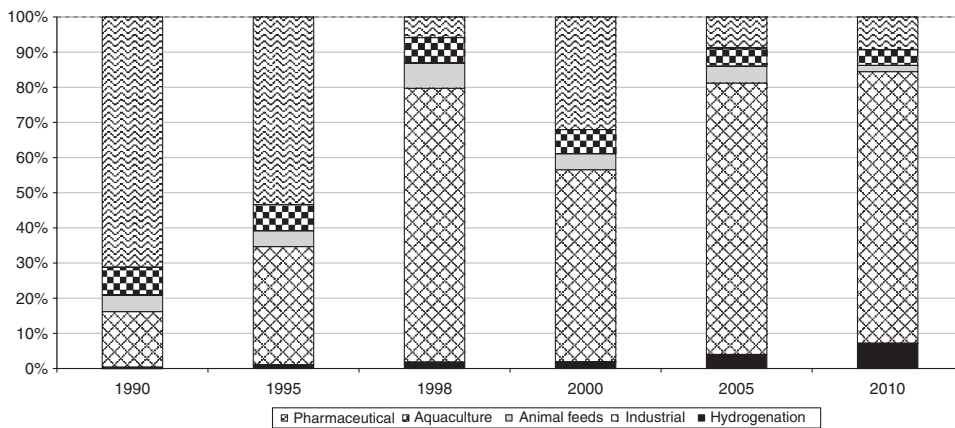
great potential as a source of revenue for the fish meal industry. This can be seen in Figure 26.16.

For many years, countries throughout the world have recognized the value of oils from marine sources for both edible and industrial purposes and specific segments of the fishing industry have been developed to provide this product. The supply of marine oils has come from several sources over these many years including whale and marine mammal oils, fish body and liver oils, and more recently krill and marine algae (Bimbo, 2007a, 2007b).

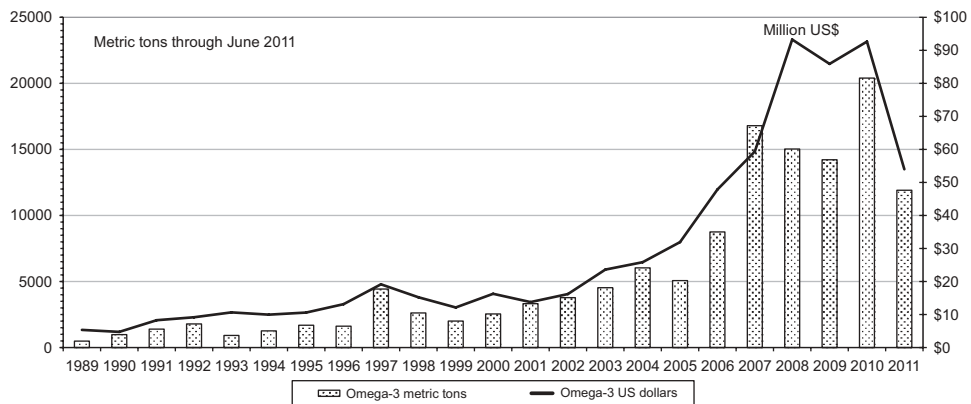
Fish oils have long been a natural constituent of the diet of man since they are a normal part of the edible portion of fish. Although food fish contain substantially less fat than land animals, they do represent a source of a different type of fat from that supplied by animals and plants. Marine fatty acids of the *n*-3 type have different impacts on our physiology than do the *n*-6 type of polyunsaturated fatty acids that are present in the grains and cereals from our continents. These two families of fatty acids appear to serve different functions in human health and disease. In recent years, much research has been conducted to evaluate the possible pharmaceutical uses of fish oils and this work has been



**Figure 26.14** Fish oil market change from hydrogenation to aquaculture (Oil World Annuals, 1980–2011–2011, 2011). Reproduced with permission.



**Figure 26.15** Evolution of the fish oil market.



**Figure 26.16** Volume and revenue of omega-3 fish oils imported into the United States (NMFS 2011a, 2011b). Reproduced with permission of the United States Bureau of the Census.



**Table 26.2** Quality guidelines for crude fish oil and their physical characteristics.

Moisture and impurities (%)	Usually basis 0.5% up to 1% maximum
Free fatty acids (% oleic)	Range 1–7% but usually 2–5%
Peroxide value (meq/kg)	3–20
Anisidine number	4–60
Totox value	10–60
Iodine value	
Capelin	95–160
Herring	115–160
Menhaden	120–200
Sardine	160–200
Anchovy	180–200
Jack Mackerel	160–190
Sand Eel	150–190
Color, gardner scale	Up to 14
Iron (ppm)	0.5–7.0
Copper (ppm)	Less than 0.3
Phosphorus (ppm)	5–100
<b>Physical characteristics</b>	
Specific heat (cal/g)	0.50–0.55
Heat of fusion (cal/g)	About 54
Caloric value (cal/g)	About 9500
Slip melting point (°C)	10–15
Flash point (°C)	
As triglycerides	About 360
As fatty acids	About 220
Boiling point (°C)	Greater than 250
Specific gravity at 15°C	About 0.92
at 30°C	About 0.91
at 45°C	About 0.90
Viscosity centipoise at 20°C	60–90
at 50°C	20–30
at 90°C	About 10

Source: Bimbo, 1998.

reviewed several times (Bimbo, 1983; Lands and Bimbo, 1983).

Table 26.2 gives some typical specifications for fish oil in general as well as some physical properties.

Table 26.3 gives a comparison of the difference in the fatty acid composition of several fish oils, vegetable oils, and animal fats.

Fish oil is a normal constituent of many animal feeds, which often contain fish meal as a protein source. Fish meal usually contains up to 12% fish oil that is metabolized and utilized as an energy

source. As a nutritive component, fish oil possesses at least three potentially beneficial properties: it is a concentrated source of calories; it contains essential fatty acids; and it provides highly unsaturated fat (Lands and Bimbo, 1983).

Fish oil is also utilized as an industrial drying oil, a source for biodiesel fuels and as such competes with linseed, soybean, and other oils. The industrial use of fish oil depends upon different chemical modifications of the oil and the resultant physical and chemical properties of the modified products. Fish oils can be chemically altered by reactions of the double bonds or by reactions involving the fatty acid end of the basic molecule in the oil. Each type of modification will produce a product with different physical and chemical properties more readily utilized than the original oil (Bimbo and Crowther, 1992). Some of the past and present industrial uses of fish oils include linoleum and oil cloth, leather tanning, printing inks, core and foundry oils, lubricants and greases, ore floatation agents, insecticidal compounds, fungicidal derivatives, fire retardants, soap manufacture, protective coatings, pneumatic tool and steam cylinder stock lubricants, rubber compounds, caulking compounds, glazing compounds, automotive gaskets, tin plating oils, rust proofing compounds, refractory compounds, cutting oils, plasticizers, presswood fiber boards, ceramic deflocculants, fermentation substrates, illuminating and fuel oils, mushroom culture, insect and animal attractants, and polyurethane foams (Bimbo, 1989).

## Global aquaculture market

Aquaculture consumes about 2.5 million mt of fish meal (42%) and about 700,000 mt of fish oil (70%) annually. So, aquaculture is the major market for both fish meal and fish oil. Aquaculture has been growing at an average rate of 15.75% since 1988. This is shown in Figure 26.17.

Fish meal and fish oil are used in the diets of both carnivorous and plant-eating fish. Table 26.4 shows the projected growth in aquaculture species over the period 2002 projected to 2012.

Lipids from wild fish particularly marine fish contain comparatively high levels of omega-3 PUFA, which they obtain in the diet by consuming plankton, algae, and other fish. Numerous investigators have demonstrated that fish are what

**Table 26.3** Fatty acid composition (percent) of marine oils compared with several vegetable oils and animal fats.

	Butter fat	Coconut	Tallow	Lard	Corn oil	Canola	Soybean oil	Herring oil	Menhaden oil	Anchovy oil	Tuna oil
C4	3.2										
C6	1.9	0.6									
C8	1.1	7.5									
C10	2.5	6.0									
C12	2.8	44.6	0.9								
C14	10.0	16.8	3.7	1.3				7.0	9.0	9.0	3.0
C16	26.0	8.2	24.9	23.8	10.6	4.3	10.5	17.0	18.0	17.0	22.0
C16:1	2.2		4.2	2.7				6.0	9.0	13.0	3.0
C18	12.0	2.8	18.9	13.5	1.8	2.1	4.4	2.0	3.0	3.0	6.0
C18:1	25.0	5.8	36.0	41.2	27.3	61.7	22.6	14.0	10.5	10.0	21.0
C18:2	2.2	1.8	3.1	10.2	53.5	19.0	51.0	1.0	1.0	1.0	1.0
C18:3	1.5		0.6	1.0	1.1	9.0	6.8	2.0	1.5	1.0	1.0
C18:4								3.0		2.0	1.0
C20:1				1.0		1.3		15.0	1.0	1.0	1.0
C20:5								6.0	14.5	22.0	6.0
C22:1								19.0		1.0	3.0
C22:5								1.0		2.0	2.0
C22:6								6.0	12.0	9.0	22.0

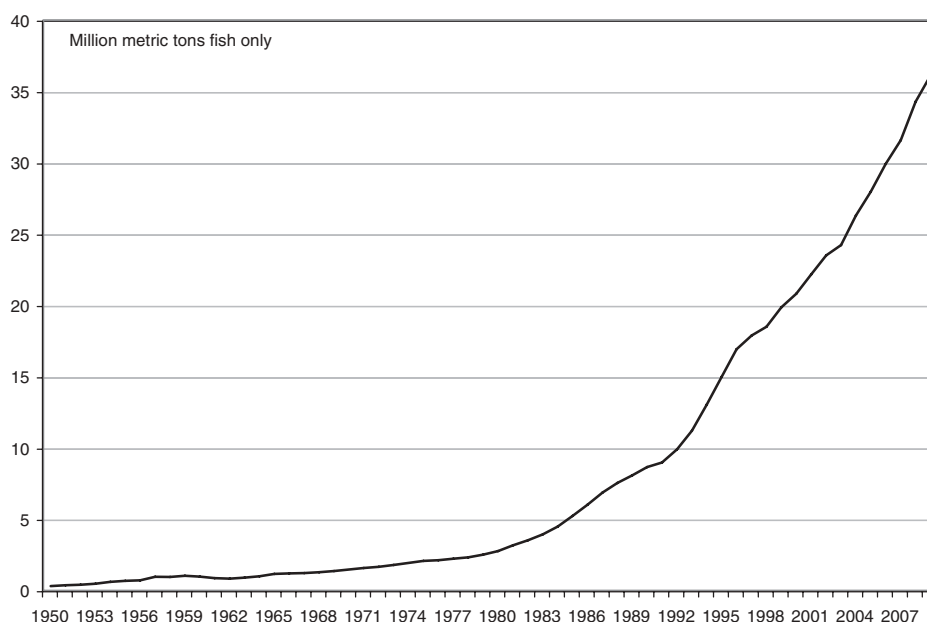
Source: USDA, 2011.

they eat. The composition and flavor of the fat in the fish can be easily adjusted by the type of fat fed.

Many farm-raised fish are low in omega-3 fatty acids because their diets are formulated primarily

from agriculture products. This deficiency can be eliminated by adding fish oil containing high levels of omega-3 to their diet.

The recent increases in the prices for fish meal and oil have created incentives for researchers to

**Figure 26.17** Global aquaculture production (FAO 2011).

**Table 26.4** Predicted global growth in farmed fish production.

Species	Growth	1000 Metric tons				
	2002–2012 (%/Yr)	2002	2003	2005	2010	2012
Shrimp	15.6	1,405	1,805	2,184	3,209	3,605
Freshwater crustaceans	11.34	652	688	802	1,091	1,392
Marine fish <sup>a</sup>	10.35	1,080	1,101	1,332	1,957	2,198
Salmon	6.1	1,213	1,259	1,388	1,771	1,953
Trout	4.75	562	554	588	750	829
Eel	1.72	232	232	237	262	272
Milkfish	5.91	528	552	597	762	840
Carp	5.98	9,881	10,179	11,222	14,323	15,791
Tilapia	12.55	1,486	1,678	2,030	2,938	3,352
Catfish	7.38	527	569	651	831	916
Totals	8.07	17,566	18,617	21,031	27,939	31,747

Source: Tacon et al., 2006. Reproduced with permission from the Food and Agriculture Organization of the United Nations.

<sup>a</sup>Bass, bream, yellowtail, grouper, jacks and mullets, flounder, turbot, halibut, sole, cod, and hake.

find substitutes for fish meal and oil in aquaculture diets. Many raw materials are being evaluated including animal and vegetable proteins as well as animal and vegetable oils. None of these products offer the important omega-3 fatty acids docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), although vegetable oils can provide alpha linolenic acid (ALA). ALA can be converted to DHA by biochemical processes; however, the conversion is not very efficient in most animals.

In any case, there will not be a shortage of fish meal for the traditional markets as the increased production of edible fish from aquaculture naturally generates more cuttings and offal that can be converted back into fish meal.

Table 26.5 shows the predicted use of fish meal in the feeds of the major aquaculture species over the period 2002–2012.

Table 26.6 shows the predicted use of fish oil in fish feeds over the period 2002–2012.

**Table 26.5** Predicted use of fish meal in fish feeds.

Species	% Fish meal inclusion in feed produced					1000 Tons of fish meal				
	2002	2003	2005	2010	2012	2002	2003	2005	2010	2012
Shrimp	24	23	20	15	13	545	670	584	736	725
Freshwater Crustaceans	20	20	18	12	11	135	139	143	131	137
Marine fish <sup>a</sup>	45				40	575	590	604	649	719
Salmon	35				20	552	573	499	425	422
Trout	30				15	168	216	127	108	99
Eel	47	45	40	30	28	179	171	145	113	112
Milkfish	8	7	5	2	2	38	36	27	13	15
Feeding carp	5	5	4	2	2	415	438	364	229	263
Tilapia	7				2	67	79	55	52	61
Catfish	2					22	24	18	22	24
Carnivorous freshwater fish	40				30	124				183
Totals						2696	2936	2666	2478	2577

Source: Tacon et al., 2006. Reproduced with permission from the Food and Agriculture Organization of the United Nations.

<sup>a</sup>Bass, bream, yellowtail, grouper, jacks and mullets, flounder, turbot, halibut, sole, cod, and hake.

**Table 26.6** Predicted use of fish oil in fish feeds.

Species	% Fish oil inclusion in feed produced					1000 Tons of fish oil				
	2002	2003	2005	2010	2012	2002	2003	2005	2010	2012
Shrimp	2	2	2	2	2	45.4	58.3	68.4	98.2	111.5
Freshwater Crustaceans	2	2	1.5	1	1	13.5	13.9	11.9	10.9	5.9
Marine fish <sup>a</sup>	8	7.5	6	6	5	112.3	110.6	100.7	149.7	143.8
Salmon	26	25	10	8	7	410	409	166	170	164
Trout	20	17.5	10	6	5	95	126	70.5	54	49.7
Eel	4	3	3	2	2	15.2	11.4	10.9	7.5	8
Milkfish	1	1	1	1	1	4.7	5.2	5.4	6.7	7.7
Feeding carp	0.5	0.5	1	1	1	41.5	43.8	90.9	114.6	131.4
Tilapia	1	1	1	1	1	13.4	15.8	18.3	26.2	30.6
Catfish	1	1	1	1	1	7.3	8	8.8	10.9	12.2
Carnivorous freshwater fish	6				7	19				43
Totals						777.3	802	551.8	648.7	707.8

Source: Tacon et al., 2006. Reproduced with permission from the Food and Agriculture Organization of the United Nations.

<sup>a</sup>Bass, bream, yellowtail, grouper, jacks and mullets, flounder, turbot, halibut, sole, cod, and hake.

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## Further reading

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# 27

## Regulations

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Roy E. Martin

This chapter explains how the US industry is regulated and by whom. The reason for a special chapter will become obvious as you move through the tangled web of federal, state, and local regulations that have been imposed on the seafood industry over the years.

### Food and Drug Administration

The Food and Drug Administration (FDA) regulates the production and marketing of most food products, including fish, under the Federal Food, Drug, and Cosmetic Act of 1938, as amended (FDC Act). FDA's authority is limited to food, intended for, or having passed through interstate commerce, but interstate commerce has been very broadly construed. FDA jurisdiction may even extend to products that are intended for intrastate use or trade if they are produced, transported, or stored by a person or company engaged in interstate commerce. It is important to understand that the US Department of Agriculture (USDA) plays no direct role in the seafood industry, a situation unlike that of the USDA with other fresh food industries.

With FDA's broad authority, there are few aspects of the seafood industry that it cannot regulate,

should it choose to do so. To be more specific, FDA has issued regulations covering every aspect of food production and marketing, including food name and ingredients, food quality, manufacturing practices, packaging, and labeling. Depending on the regulation involved, noncompliance constitutes misbranding or adulteration and subjects the food to possible seizure and condemnation.

Adulteration refers to unacceptable food quality and results from such things as contamination with filth or toxic substances, preparation under unsanitary conditions, the use of unsafe ingredients, the presence of concealed defects, the omission of a valuable ingredient, or the like.

A food is misbranded when it is the subject of a deceptive representation, such as false or misleading packaging or labeling; when it is not accompanied by a required disclosure, such as name, ingredients, quantity, and so on; or when it is misrepresented.

The FDC Act authorized the FDA to establish "a reasonable definition and standard of identity" for a food where it will "promote honesty and fair dealing in the interest of consumers." A standard of food identity is, in essence, a recipe designed to avoid confusion among consumers by assuring that a food designated by a specific name contains

certain ingredients in certain proportions and only a limited number of other ingredients. Any product that purports to be or is represented as a food for which a definition and standard of identity has been prescribed is subject to and must comply with that standard.

There are standards of identity for various fish products including:

- (1) oysters – there is a separate standard of identity for each of the 12 different varieties and sizes;
- (2) canned Pacific salmon;
- (3) canned wet pack shrimp (in transparent or non-transparent containers);
- (4) frozen raw breaded shrimp (regular or lightly breaded);
- (5) canned tuna.

A food that fails to conform to an applicable definition and standard of identity is considered to be misbranded. A product generally will be considered nonconforming if it fails to contain an ingredient that is required by the definition and standard, or if it contains any unspecified ingredients.

Many food standards allow for the use of specific optional ingredients, particularly seasonings. Some standards include provisions for the substitution or addition of any “safe and suitable” optional ingredients of a certain type, such as any safe and suitable flavorings. To be safe and suitable, an ingredient must (1) perform an appropriate function in the food; (2) be present at a level no higher than necessary to achieve its intended purpose in that food; and (3) qualify as an approved food or color additive or as a nonadditive. Any ingredient that would significantly change or degrade the basic characteristics of the food (e.g., nutritional value, taste, smell, appearance, and stability) would not be considered suitable.

Temporary Marketing Permits are an administrative mechanism developed by FDA to permit the test marketing of nonconforming products for a limited time, sometimes in limited amounts, and for the limited purpose of obtaining marketing data for use as evidence in support of a petition to amend an applicable standard. Permits are available only where the interests of consumers are adequately safeguarded, and generally only for a period not to exceed 15 months.

## Common or usual names

Foods not subject to standards of identity are nonetheless subject to certain requirements concerning names and identifying terms. Under FDA regulations, the identity of such “nonstandardized” foods must be stated as “the common or usual name of the food” that is one that accurately identifies or describes the basic nature or characteristics of the food in terms as simple and direct as possible.

If the food contains any characterizing ingredient(s) or component(s) that have a material bearing on the price or consumer acceptance of the product, the name must include a statement of their presence and amount. The name must also state the absence of such a characterizing component if that fact would have a material bearing on price or consumer acceptance.

FDA has issued numerous rulings and guides on these issues as well as regulations that specify common or usual names or other required designations for certain nonstandardized foods including a variety of fish and fish products:

- (1) Fish sticks or portions (made from minced) fish.
- (2) Pacific whiting (previously known as hake).
- (3) Bonito (cannot be called tuna).
- (4) Fried clams (made from minced) clams.
- (5) Crabmeat (identifies species) to be designated as King, anasaki, Korean variety, kegani, or Snow crabmeat.
- (6) Seafood cocktails (percentage labeled).
- (7) Nonstandardized breaded (composite shrimp units).
- (8) Greenland turbot (cannot be labeled halibut).
- (9) Crustaceans (quantity of contents).
- (10) Caviar (names given only to sturgeon roe).
- (11) Crabmeat products with added fish (cannot be labeled only as “crabmeat”).
- (12) Kipper and kipper unsplit (defines both forms).
- (13) Canned shrimp (size and count labeling).
- (14) Snapper (designates certain species).
- (15) Capelin and smelt (smelt cannot be called capelin).

A common or usual name may also be established by consumer use and understanding, rather than by regulation, for example, the court case *Mrs. Paul’s Kitchens, Inc., versus Califano* (Civ. No. 77-592) (E.D.Pa. 1978) (fish fillets).

If a food has no established common or usual name, it may be identified by “an appropriately descriptive term,” or where the nature of the food is obvious, “a fanciful name commonly used by the public for such food.” However, it must always be truthful, nonmisleading, and provide an accurate description of the basic nature of the product.

## Imitations

A food that resembles and is intended to substitute for another food and that is nutritionally inferior to that food is an imitation and must be clearly labeled as such:

- (1) A product may be an imitation of any food (standardized or nonstandardized). However, a nontraditional food (i.e., one that is manufactured with the use of modern food technology) may be marketed without being designated imitation so long as it is clearly identified as a product different from the traditional food.
- (2) Nutritional inferiority is defined as any reduction in the content of an essential nutrient that is present in a measurable amount (i.e., 2% or more of the US RDA).
- (3) *Substitution*: A question of fact based on the promotion and suggested use of the product, consumer understanding, and whether the form of the product indicates that it is intended to substitute for something else.

The act specifies numerous defects in the quality and composition of food, from missing ingredients to the presence of toxic chemicals that constitute adulteration:

- (1) *Economic adulteration*: The FDC act condemns any deception as to the quality or value of a food or its ingredients as economic adulteration. For example, a food is deemed adulterated if any valuable constituent has been omitted or any substance has been substituted in whole or in part. In addition, a food is declared to be adulterated if it has been treated in a manner that conceals damage, inferiority, or dilution, or if anything has been added to it that makes it appear bigger, better, or of greater value than it is.
  - (2) *Filthy, putrid, or decomposed substances*: Any food product that includes any “filthy, putrid, or decomposed substances”; or any food product that is “otherwise unfit for food” is adulterated. These terms subsume such things as dirt; wood splinters; insect, worm, and rodent parts; mold; and damage from water and freezing temperatures. Although the statutory prohibition is absolute and condemns even the smallest quantity of such substances in food, FDA generally will not take any enforcement action unless the contamination rises to a certain level, or violations of other requirements are also present. The FDA has informally established “Defect Action Levels” that specify the amount of foreign substance in any particular food that will trigger legal action by the FDA to remove the product from the market (see Table 27.1).
- Any food that contains an unsafe food additive is adulterated, and every food additive is deemed unsafe unless there is in effect a food additive regulation that prescribes the conditions for its use or it is used for investigational purposes only:
- (1) The definition of food additive is cast broadly to comprehend any substance whose intended use “results or may reasonably be expected to result, directly or indirectly, in its becoming a component or otherwise affecting the characteristics of any food”:
    - (a) Includes substances used not only in the production and manufacture but also in the packaging, transportation, and storage of food.
    - (b) Substances such as cleaning solutions or paint, which are used in conjunction with food handling operations in a manner not ordinarily expected to result in food contamination but that inadvertently or accidentally do so, are not considered to be food additives. However, such accidental contaminants are subject to provisions regarding poisonous and deleterious substances.
  - (2) *Generally recognized as safe (GRAS)*: By definition, the term food additive does not apply to any substance that qualified experts in food safety generally recognize as having been proven safe for its intended use. FDA has published lists of GRAS substances. Although a substance may be GRAS without specifically

**Table 27.1** FDA defect action levels.

Product	Defect action level
Fish, fresh or frozen (applies only to fish fillets weighing 3 lb or less)	Decomposition in 5% or more of the fish or fillets in the samples (but not less than 5 fish) show Class III decomposition over at least 25% of their areas; or 20% or more of the fish or fillets in the sample (but not less than 5 fish) show Class II decomposition over at least 25% of their areas; or The percentage of fish or fillets showing Class II decomposition as mentioned previously, plus four times the percentage of those showing Class III decomposition as mentioned previously equals at least 20% and there are at least five decomposed fish or fillets in the sample. Classes of decomposition are as follows: I. No odor of decomposition II. Slight odor of decomposition III. Definite odor of decomposition
Tullibees, ciscoes, innconnus, chub, whitefish	50 parasitic cysts per 100 lb (whole or fillets) and provided that 20% of the fish examined are infested.
Blue fin and other freshwater herring	60 cysts per 100 fish (fish 1 lb or less) or 100 lb of fish (fish over 1 lb) provided that 20% of the fish examined are infested.
Redfish and ocean perch	3% of the fillets examined contain 1 or more copepods accompanied by pus pockets.
Shrimp, fresh or raw, headless, peeled or breaded	Decomposed as determined by organoleptic frozen, examination. 5% Class III, or 20% Class II (see the previous-mentioned description, or, if percentage of Class II shrimp plus four times percent Class III, equals 20%).
Salmon, canned	Decomposition: a defective can is defined as one that contains Class II or Class III decomposition (see the previous-mentioned description). Two Class III defective cans, regardless of lot and container size; or 2–30 Class II and/or Class III defective cans as required by sampling plan based on lot size and container size.
Calico scallops	If 20% or more of the calico scallops are contaminated with nematodes, the scallops should be recommended for seizure. All samples should consist of ten 1 lb subsamples. Samples should not be frozen because the scallop meat will become opaque.

being recognized as such by FDA, food manufacturers often avoid the risk of challenge to their use of a substance by petitioning the FDA for a GRAS determination. A GRAS proceeding will result either in an affirmation of GRAS or a finding that the substance is a food additive. In the latter event, FDA will issue a food additive regulation prescribing conditions of use, or an interim food additive regulation providing for use of the substance pending further study, or a ban on use of the additive.

- (3) The definition of food additive also expressly excludes color additives, new animal drugs, pesticide chemicals used on or in connec-

tion with raw agricultural commodities, and prior sanctioned substances-substances used in accordance with sanctions or approvals granted by FDA prior to September 6, 1958, when the Food Additives Amendment was enacted. However, these substances are all subject to a prior approval process of one sort or another. Approval of a food additive requires a finding by FDA that use of the additive will be safe and will not promote consumer deception:

- (a) Safety, for purposes of food regulation under the act, is always determined by reference to the effects of a substance on the health of humans or animals.



- (b) If necessary to assure its safety, FDA may restrict use of an additive to certain foods or certain amounts or in other respects. In such cases, the maximum allowance is set by statute as the quantity of additive reasonably required to accomplish its intended effect. FDA's current practice is to set limitations or tolerances at 1/100 of the amount that has been used without harm to experimental animals.
- (c) In addition, there is an effectiveness requirement; tolerances may not be issued at all if the additive cannot be shown to achieve its intended purpose.
- (d) *Color additives*: A food that contains an unsafe color additive is also adulterated, and as with food additives, color additives are automatically deemed unsafe unless they have been approved for use and listed in a regulation by FDA in accordance with procedures outlined in the act, or they are used under an investigational use exemption. In addition, unless accepted by the FDA, color additives must be tested on a batch-by-batch basis to ensure compliance with the applicable listing regulation. Color additives include any dye, pigment, or other substance that is capable of imparting color (including white, black, and grays) to food. Other substances that are used solely for purposes other than coloring may be exempted by regulation from application of the color additive provisions where the color imparted "is clearly unimportant insofar as the appearance, value, marketability, or consumer acceptability is concerned."
- (e) *Pesticides*: The FDC Act specifically addresses the safe use of pesticides in connection with raw agricultural commodities, such as fresh fruits and vegetables, grains, nut, eggs, raw milk, meat, and seafood. It declares adulterated any food commodity that bears or contains an unsafe pesticide chemical. The status of pesticide residues in processed food is not clearly defined in the act. However, the statute does specify that the presence of pesticide residues will not be considered to adulterate a processed food so long as the chemical has been removed to the extent possible using good

manufacturing practices, and the chemical concentration does not exceed the tolerance prescribed for the raw product. The FDA considers a processed food to be adulterated if it contains pesticide residues for which no tolerance has been established, or if it contains residues in excess of an established food additive tolerance or pesticide chemical tolerance.

Although we would not generally think of pesticides in connection with fish, fish are often exposed to and have a tendency to retain varying levels of pesticides and industrial wastes that are deposited directly and indirectly into the water where they live. It is important to note that products containing a pesticide above a specific tolerance level are considered adulterated, as they contain an unapproved food additive notwithstanding that the substances are present in raw product and are not themselves added or changed by processing of the fish.

### Poisonous and deleterious substances

A naturally occurring poison is one that exists as an inherent natural constituent of the food rather than as a result of environmental, agricultural, industrial, or other contamination. A food that may be harmful to human health because it contains a naturally occurring poison is considered "adulterated" unless the quantity present "does not ordinarily render it injurious to health." Although the FDA is not authorized to establish tolerances for natural contaminants, an informal tolerance system exists in FDA's Defect Action Levels (Table 27.2) that specify the levels of contamination that FDA considers to warrant enforcement action.

An added poisonous or deleterious substance is any contaminant other than a naturally occurring one that may render food injurious to health. It includes substances introduced into natural foods and any substance intentionally included in a processed food product. It also includes any extraordinary amount of a natural contaminant that is caused by the mishandling or improper treatment of food.

The FDA is authorized to establish tolerances for added poisonous and deleterious substances that either are required for production or cannot be avoided by good manufacturing practice. The presence in food of an added poisonous or

**Table 27.2** FDA action levels for poisonous or deleterious substances in seafood.

Substance	Possible sources	Action levels
Aldrin	Fish and shellfish	0.3 ppm
Dieldrin	Fish and shellfish	0.3 ppm
Benzene hexachloride	Frog legs	0.5 ppm
Chlordane	Fish	0.3 ppm
DDT, DDE, TDE	Fish	5.0 ppm
Endrin	Fish and shellfish	0.3 ppm
Heptachlor	Fish and shellfish	0.3 ppm
Heptachlor epoxide	Fish and shellfish	0.3 ppm
Kepone	Crabmeat	0.4 ppm
Kepone	Fish and shellfish	0.3 ppm
Mercury (measured as methyl mercury)	Fish, shellfish, and crustaceans	1.0 ppm
Mirex	Fish	0.1 ppm
PCB	Fish	2.0 ppm
Toxaphene	Fish	5.0 ppm
Paralytic shellfish toxin	Clams	80 µg/100 g meat
Paralytic shellfish toxin	Mussels	80 µg/100 g meat
Paralytic shellfish toxin	Oysters	80 µg/100 g meat

deleterious substance in excess of or in the absence of, an applicable tolerance is unsafe and constitutes adulteration.

## Good manufacturing practices

Under the FDC Act, any food that has been prepared, packed, or held under unsanitary conditions whereby it may have become contaminated with filth or rendered injurious to health is deemed adulterated, whether or not the food actually was made harmful or unsafe.

FDA's initial efforts to enforce this provision consisted primarily of case-by-case adjudications based on ad hoc product surveillance and plant inspections. In the early 1960s, FDA developed standardized forms, inspection checklists, and formal industry guidelines in order to make its enforcement more uniform and more efficient. Ultimately, FDA invoked its general rule-making authority to promulgate regulations that include detailed requirements for food production and handling facilities and that specify what the FDA considers to be "good manufacturing practice to assure that food for human consumption is safe and has been prepared, packed, and held under sanitary conditions."

These good manufacturing practice (GMP) regulations represented a clear shift in focus at FDA from unsafe products to deficient production systems and from random post hoc detection and apprehension of defective products to a system of preventive maintenance. Certainly from FDA's point of view, this approach is advantageous, since primary responsibility for enforcement actually rests with a firm's quality assurance staff, and FDA can monitor compliance simply by conducting a paper-work audit.

FDA issued its food GMP regulations as a two-tier system: "umbrella" GMPs that apply to all food handling operations and "categorical" GMPs that contain additional requirements specifically applicable to certain types of food.

The umbrella GMPs, promulgated in 1969, consist of generally applicable specifications for personnel practices, buildings and grounds, sanitary facilities, design and care of equipment, and production and process controls, all aimed at maintaining adequate sanitary conditions in all food handling facilities and during all food handling operations. It is difficult to provide a useful summary of the regulations, in part because they range from mandatory to precatory and from very general to very specific. We discuss the issue of categorical GMPs later.

A major issue regarding GMPs is the tension between specificity and flexibility. Although the FDA's specification of operating requirements provides industry with a clear statement of what is expected, it also limits industry's ability to adopt alternative or innovative procedures that could work better in a particular plant or that may be necessitated by a change in technology. The further problem encountered is that there is no provision for exemption from the food GMPs, although it may be possible to petition for an exemption notwithstanding the absence of any specific statutory or regulatory authority for same. FDA generally takes the position that its GMP regulations constitute mandatory requirements for food handling, a violation of which automatically establishes a violation of the FDC Act. In at least one case, however, defendants in a criminal action were acquitted where their operations clearly violated GMP regulations for smoked fish but "were generally consistent with those observed at the time by other smoked fish processors," and the government failed to prove that their products "may have been rendered injurious to health."

### Revision of umbrella GMPs

FDA published a revision of its umbrella food GMPs in 1986. Although reasserting its position that the GMPs are intended to have the force and effect of law, FDA has made some effort to incorporate a more flexible approach. Thus, in certain sections, FDA has stated a general objective in mandatory terms, and has listed acceptable, but not exclusive, means of meeting that objective.

The revision retains many original GMP provisions but also includes some new requirements and procedures. One significant change requires product coding and record keeping. The product codes would identify at least the processing plant and packaging lot for each food product. The record-keeping provision requires the retention of three categories of records, including distribution records, for a period equivalent to the shelf life of the product, not to exceed 2 years. The coding and record-keeping provisions are intended to facilitate recalls.

In light of the revised GMPs, FDA has revoked categorical GMPs for smoked and smoke-flavored fish and frozen raw breaded shrimp.

### Emergency permit control

In limited circumstances, FDA may require that certain products get formal clearance before being marketed, but this requirement can be invoked only when necessary to prevent an epidemic or other health emergency. The emergency permit control system is designed to give FDA the wherewithal to prevent the outbreak of disease from food that is contaminated during processing, where that contamination is not readily detectable before the food is likely to be consumed.

FDA has issued regulations for producers and packagers of acidified foods and low-acid canned foods. The regulations require that manufacturers of these products register with FDA, submit processing information, comply with the processes described, maintain records, and comply with all applicable GMPs.

Compliance with these requirements operates, in effect, to exempt the manufacturer from the need to obtain premarketing clearance for its product on a lot-by-lot basis. However, this exemption may be revoked and a permit for shipping or selling the food may be required if FDA finds a violation of these rules.

### Labeling

A label is defined as any printed or graphic display on a food container, and labeling includes package labels as well as any written, printed, or graphic matter that accompanies a food product.

FDA administers a set of very detailed and intricate regulations that dictate not just the content of product label information, but also its layout, including location and type size. The general rule for all required product information is that it must appear on the labeling with such prominence and in such terms that it is likely to be read and understood by the ordinary consumer. Required information that appears on a product label must be visible to the consumer through any outer packaging that is used.

### General information

Every packaged food product must bear the product name and a statement of net contents by weight,

count, and so on, on the principal display panel of the package (that part of the label most likely to be displayed by the retailer). Where a food is marketed in various forms (e.g., whole and slices), the particular form is considered a necessary part of the statement of identity, and must appear on the label unless the form of the food is clearly visible through the package.

The statement of quantity is subject to very detailed regulations concerning location (within the lower 30% of principal display panel and separate from other printed matter), print size (depends on package size), and type of measure (fluid measure, gallon, quart, pint, and fluid oz for liquid foods; standard weight lb and oz for solid, semisolid, and viscous foods). A statement of the number of servings contained in the package is not required. However, if serving information is provided, it must include the serving size, expressed in common measurement or cooking terms, such as cups, tablespoons, or ounces.

The label also must state the name and place of business of the manufacturer, packager, or distributor. If the designated company is not the manufacturer, its connection with the food must be demonstrated by a qualifying phrase such as "Manufactured for \_\_\_\_\_," or "Distributed by \_\_\_\_\_." This information may appear anywhere on the label so long as it is conspicuous.

## **Ingredient information**

As a general rule, a food product made from two or more ingredients must list those ingredients on the product label in descending order of predominance by weight. Ingredients must be listed by their common and usual names, subject to a number of specific rules.

Spices, colorings, and flavorings need only be listed by those general terms. However, artificial flavoring or coloring must always be designated as such. Where a mixture of natural and artificial flavorings is used, a designation like "natural and artificial crab flavoring" is appropriate. A preservative must be designated both as "preservative" and by its common or usual name.

If an ingredient has two or more components, it must be followed immediately by a parenthetical listing of those components, for example, "onion paste (dehydrated onion, spices, and water)," unless the ingredient is a sauce of standard

composition (e.g., chili sauce and tomato sauce). Water is considered an ingredient and must be listed in its proper order (judged by the water content remaining in the product following any evaporation in the preparation process).

## **Nutrition labeling**

Nutritional labeling became mandatory under provisions of the Nutrition Labeling and Education Act of 1990 (NLEA). All seafood products are covered and must meet the following. A Nutrition Panel, usually placed on the right side of a package, shall contain the following "nutrition facts":

- Total calories
- Calories from fat
- Total fat
- Saturated fat
- Cholesterol
- Sodium
- Total carbohydrate
- Fiber
- Sugar
- Protein
- Vitamin A
- Vitamin C
- Calcium
- Iron

### *Nutrition panel-format*

All nutrients must be declared as a percent of their daily allowance (DA). The amount in grams of macronutrients (such as fat, cholesterol, sodium, carbohydrates, and protein) must be listed to the immediate right of each of the names of each of these nutrients. A column headed percent DA will appear, as will a footnote to help consumers place their individual nutrient needs with respect to the DAs used on the label.

Requiring nutrients to be declared as a percent of the DA is intended to prevent misinterpretations that arise with quantitative values. For example, a food with 140 mg of sodium could be mistaken for a high-sodium food because 140 is a relatively large number. However, in actuality, that amount represents less than 6% of the DA for sodium, which is 2400 mg.

On the other hand, a food with 5 g of saturated fat could be construed as being low in that nutrient. But in fact, that food would provide one-fourth of the total DA because 20 g is the DA for saturated fat based on a 2000-calorie diet.

### Format modifications

Variations in the format of the nutrition panel are allowed. Some are mandatory. For example, the labels of foods for children under 2 (except infant formula, which has special labeling rules under the Infant Formula Act of 1980) may not carry information about saturated fat, polyunsaturated fat, monounsaturated fat, cholesterol, calories from fat, or calories from saturated fat. The reason for this restriction is to prevent parents from wrongly assuming that infants and toddlers should restrict their fat intake, when, in fact, they should not. Fat is important during these years to ensure adequate growth and development.

Labels of foods for children under 4 may not include the percent of DAs per serving or the actual DAs for macronutrients. Only the percent of the DAs for vitamins and minerals is allowed. The reason: FDA has not established DAs for macronutrients for this age group.

Some foods may qualify for a simplified label format. This format is allowed when the food contains insignificant amounts of seven or more of the mandatory nutrients and total calories. "Insignificant" means that a declaration of zero could be made in nutrition labeling, or, for total carbohydrate, dietary fiber, and protein, the declaration states "less than 1 g."

For foods for children under 2, the simplified format may be used if the product contains insignificant amounts of six or more of the following: calories, total fat, sodium, total carbohydrate, dietary fiber, sugars, protein, vitamins A and C, calcium, and iron.

If a simplified format is used, information on total calories, total fat, total carbohydrate, protein, and sodium—even if they are present in insignificant amounts—must be listed. Other nutrients, along with calories from fat, must be shown if they are present in more than insignificant amounts. Nutrients added to the food must also be listed.

Small- and medium-size packages will be granted certain exceptions to make the nutrition labeling practical on the smaller space.

### Serving sizes

The serving size is the basis for reporting each food's nutrient content. Serving sizes will be uniform and reflect the amounts that people actually eat. They must be expressed in both common household and metric measures.

NLEA defines serving size as the amount of food customarily eaten at one time. The serving sizes that appear on food labels will be based on FDA established lists of "Reference Amounts Customarily Consumed Per Eating Occasion."

These reference amounts are broken down into 139 FDA regulated food product categories, including 11 groups of foods specially formulated or processed for infants or children under 4. They list the amounts of food customarily consumed per eating occasion for each category, based primarily on national food consumption surveys. FDA's list also gives the suggested label statement for serving size declaration. For example, the category "breads (excluding sweet quick type), rolls" has a reference amount of 50 g, and the appropriate label statement for sliced bread or roll is "\_piece(s)(\_g)" or, for unsliced bread, "2 oz (56 g/\_ inch slice)."

The serving size of products that come in discrete units, such as cookies, candy bars, and sliced products, is the number of whole units that most closely approximates the reference amount. Cookies are an example. Under the "bakery products" category, cookies have a reference amount of 30 g. The household measure closest to that amount is the number of cookies that comes closest to weighing 30 g. Thus, the serving size on the label of a package of cookies in which each cookie weighs 13 g would read "2 cookies (26 g)."

If one unit weighs more than 50% but less than 200% of the reference amount, the serving size is one unit. For example, the reference amount for bread is 50 g; therefore, the label of a loaf of bread in which each slice weighs more than 25 g would state a serving size of one slice.

Certain rules apply to food products that are packaged and sold individually. If such an individual package is less than 200% of the applicable reference amount, the item qualifies as one serving. Thus, a 360 mL (12 fluid oz) can of soda is one serving, since the reference amount for carbonated beverages is 240 mL (8 oz).

However, if the product has a reference amount of 100 g or 100 mL or more and the package contains



more than 150% but less than 200% of the reference amount, manufacturers have the option of deciding whether the product can be one or two servings.

An example is a 420 g (15 oz) can of soup. The serving size reference amount for soup is 245 g. Therefore, the manufacturer has the option to declare the can of soup as one or two servings.

### Daily value—DRVs

The label reference value, DV, comprises two sets of dietary standards: Daily Reference Values (DRVs) and Reference Daily Intakes (RDIs). Only the DV term will appear on the label, though, to make label reading less confusing.

As part of regulations, DRVs are being introduced for macronutrients that are sources of energy: fat, carbohydrate (including fiber), and protein; and for cholesterol, sodium and potassium, which do not contribute calories.

DRVs for the energy-producing nutrients are based on the number of calories consumed per day. A daily intake of 2000 calories has been established as the reference. This level was chosen because it has the greatest public health benefit for the nation.

DRVs for the energy-producing nutrients are calculated as follows:

- (1) Fat based on 30% of calories.
- (2) Saturated fat based on 10% of calories.
- (3) Carbohydrate based on 60% of calories.
- (4) Protein based on 10% of calories (The DRV for protein applies only to adults and children over 4. RDIs for protein for special groups have been established.).
- (5) Fiber based on 11.5 g of fiber per 1000 calories.

Because of current public health recommendations, DRVs for some nutrients represent the uppermost limit that is considered desirable. The DRVs for fats and sodium are as follows:

- (1) *Total fat*: less than 65 g.
- (2) *Saturated fat*: less than 20 g.
- (3) *Cholesterol*: less than 300 mg.
- (4) *Sodium*: less than 2400 mg.

### Daily intake—RDIs

The RDI replaces the term “US RDA,” which was introduced in 1973 as a label reference value for

vitamins, minerals, and protein in voluntary nutrition labeling. The name change was sought because of confusion that existed over “US RDAs,” the values determined by FDA and used on food labels, and “RDAs” (Recommended Dietary Allowances), the values determined by the National Academy of Sciences for various population groups and used by FDA to figure the US RDAs.

### Nutrient content descriptors

The regulations spell out that terms may be used to describe the level of a nutrient in a food and how they can be used. These are the core terms:

- (1) *Free*: This term means that a product contains no amount of, or only trivial or “physiologically inconsequential” amounts of, one or more of these components: fat, saturated fat, cholesterol, sodium, sugars, and calories. For example, “calorie-free” means fewer than 5 calories per serving and “sugar-free” and “fat-free” both mean less than 0.5 g per serving. Synonyms for “free” include “without,” “no,” and “zero.”
- (2) *Low*: This term could be used on foods that could be eaten frequently without exceeding dietary guidelines for one or more of these components: fat, saturated fat, cholesterol, sodium, and calories. Thus, descriptors would be defined as follows:
  - (a) *Low fat*: 3 g or less per serving.
  - (b) *Low saturated fat*: 1 g or less per serving.
  - (c) *Low sodium*: less than 140 mg per serving.
  - (d) *Very low sodium*: less than 35 mg per serving.
  - (e) *Low cholesterol*: less than 20 mg per serving.
  - (f) *Low calorie*: 40 calories or less per serving.  
Synonyms for low include “little,” “few,” and “low source of.”
- (3) *Lean and extra lean*: These terms can be used to describe the fat content of meat, poultry, seafood, and game meats:
  - (a) *Lean*: less than 10 g fat, less than 4 g saturated fat, and less than 95 mg cholesterol per serving and per 100 g.
  - (b) *Extra lean*: less than 5 g fat, less than 2 g saturated fat, and less than 95 mg cholesterol per serving and per 100 g.

- (4) *High*: This term can be used if the food contains 20% or more of the DA for a particular nutrient in a serving.
- (5) *Good source*: This term means that one serving of a food contains 10–19% of the DA for a particular nutrient.
- (6) *Reduced*: This term means that a nutritionally altered product contains 25% less of a nutrient or of calories than the regular, or reference, product. However, a reduced claim cannot be made on a product if its reference food already meets the requirement for a “low” claim.
- (7) *Less*: This term means that a food, whether altered or not, contains 25% less of a nutrient or of calories than the reference food. For example, pretzels that have 25% less fat than potato chips could carry a “less” claim. “Fewer” is an acceptable synonym.
- (8) *Light*: This descriptor can mean two things:
  - (a) First, that a nutritionally altered product contains one-third fewer calories or half the fat of the reference food. If the food derives 50% or more of its calories from fat, the reduction must be 50% of the fat.
  - (b) Second, that the sodium content of a low-calorie, low-fat food has been reduced by 50%. In addition, “light in sodium” may be used on food in which the sodium content has been reduced by at least 50%.  
The term “light” still can be used to describe such properties as texture and color, as long as the label explains the intent; for example, “light brown sugar” and “light and fluffy.”
- (9) *More*: This term means that a serving of food, whether altered or not, contains a nutrient that is at least 10% of the DA more than the reference food. The 10% of DA also would apply to “fortified,” “enriched,” and “added” claims, but in those cases, the food must be altered.

## Other definitions

The regulations also address other claims. Among them are as follows:

- (10) *Percent fat free*: A product bearing this claim must be a low-fat or a fat-free product. In addition, the claim must accurately reflect the amount of fat present in 100 g of the food. Thus,

if a food contains 2.5 g fat per 50 g, the claim must be “95% fat free.”

- (11) *Implied*: These types of claims are prohibited when they wrongfully imply that a food contains or does not contain a meaningful level of a nutrient. For example, a product claiming to be made with an ingredient known to be a source of fiber (such as “made with oat bran”) is not allowed unless the product contains enough of that ingredient (e.g., oat bran) to meet the definition for “good source” of fiber. As another example, a claim that a product contains “no tropical oils” is allowed but only on foods that are “low” in saturated fat because consumers have come to equate tropical oils with high saturated fat.
- (12) *Meals and main dishes*: Claims that a meal or main dish is “free” of a nutrient, such as sodium or cholesterol, must meet the same requirements as those for individual foods. Other claims can be used under special circumstances. For example, “low calorie” means the meal or main dish contains 120 calories or less per 100 g. “Low sodium” means the food has 140 mg or less per 100 g. “Low cholesterol” means the food contains 20 mg cholesterol or less per 100 g and no more than 2 g saturated fat. “Light” means the meal or main dish is low fat or low calorie.
- (13) *Standardized foods*: Any nutrient content claim, such as “reduced fat,” “low calorie,” and “light,” may be used in conjunction with a standardized term if the new product has been specifically formulated to meet FDA’s criteria for that claim, if the product is not nutritionally inferior to the traditional standardized food, and the new product complies with certain compositional requirements set by FDA. A new product bearing a claim also must have performance characteristics similar to the referenced traditional standardized food. If the product doesn’t, and the differences materially limit the product’s use, its label must state the differences (e.g., not recommended for baking) to inform customers.
- (14) *Healthy*: FDA also is issuing a proposal to define the term “healthy.” Under that proposal, “healthy” could be used to describe a food that is low in fat and saturated fat and contains no more than 480 mg sodium and no more than 60 mg cholesterol per serving.

## “Fresh”

Although not mandated by NLEA, FDA also issued a regulation for the term “fresh.” The agency took this step because of concern over the term’s possible misuse on some food labels.

The regulation defines the term “fresh” when it is used to suggest that a food is raw or unprocessed. In this context, “fresh” can be used only on a food that is raw, has never been frozen or heated, and contains no preservatives. (Irradiation at low levels is allowed.) “Fresh frozen,” “frozen fresh,” and “freshly frozen” can be used for foods that are quickly frozen while still fresh. Blanching (brief scalding before freezing to prevent nutrient breakdown) is allowed.

Other uses of the term “fresh,” such as in “fresh milk” or “freshly baked bread,” are not affected.

## Health claims

Claims for seven relationships between a nutrient or a food and the risk of a disease or health-related condition is allowed for the first time. They can be made in several ways: through third-party references, such as the National Cancer Institute; statements; symbols, such as a heart; and vignettes or descriptions. Whatever the case, the claim must meet the requirements for authorized health claims; for example, they cannot state the degree of risk reduction and can only use “may” or “might” in discussing the nutrient or food–disease relationship. And they must state that other factors play a role in that disease.

They also must be phrased so that the consumer can understand the relationship between the nutrient and the disease and the nutrient’s importance in relationship to a daily diet.

An example of an appropriate claim is: “While many factors affect heart disease, diets low in saturated fat and cholesterol may reduce the risk of this disease.”

The allowed nutrient–disease relationship claims and rules for their use are as follows:

- (1) *Calcium and osteoporosis*: To carry this claim, a food must contain 20% or more of the DV for calcium (200 mg) per serving, have a calcium content that equals or exceeds the food’s content of phosphorous, and contain a form of calcium that can be readily absorbed and used by the body. The claim must name the target group most in need of adequate calcium intakes (i.e., teens and young adult white and Asian women) and state the need for exercise and a healthy diet. A product that contains 40% or more of the DV for calcium must state on the label that a total dietary intake greater than 200% of the DV for calcium (i.e., 2000 mg or more) has no further known benefit.
- (2) *Fat and cancer*: To carry this claim, a food must meet the descriptor requirements for “low fat,” or, if fish and game meats, for “extra lean.”
- (3) *Saturated fat and cholesterol and coronary heart disease (CHD)*: This claim may be used if the food meets the definitions for the descriptors “low saturated fat,” “low cholesterol,” and “low fat,” or, if fish and game meats, for “extra lean.” It may mention the link between reduced risk of CHD and lower saturated fat and cholesterol intakes to lower blood cholesterol levels.
- (4) *Fiber-containing grain products, fruits and vegetables and cancer*: To carry this claim, a food must be or must contain a grain product, fruit, or vegetable and meet the descriptor requirements for “low fat,” and, without fortification, be a “good source” of dietary fiber.
- (5) *Fruits, vegetables, and grain products that contain fiber and risk of CHD*: To carry this claim, a food must be or must contain fruits, vegetables, and grain products. It also must meet the descriptor requirements for “low saturated fat,” “low cholesterol,” and “low fat” and contain, without fortification, at least 0.6 g soluble fiber per serving.
- (6) *Sodium and hypertension (high blood pressure)*: To carry this claim, a food must meet the descriptor requirements for “low sodium.”
- (7) *Fruits and vegetables and cancer*: This claim may be made for fruits and vegetables that meet the descriptor requirements for “low fat” and that, without fortification, for “good source” of at least one of the following: dietary fiber or vitamins A or C. This claim relates diets low in fat and rich in fruits and vegetables (and thus vitamins A and C and dietary fiber) to reduced cancer risk. FDA authorized this claim in place of an antioxidant vitamin and cancer claim.

## Ingredient labeling

“Standardized foods” now require full ingredient labeling. These foods were previously exempt. Ingredient declaration now has to be on all foods that have more than one ingredient.

Also, the ingredient list will include the following, when appropriate:

- (1) FDA-certified color additives, such as FD&C Blue No. 1, by name.
- (2) Sources of protein hydrolysates, which are used in many foods as flavors and flavor enhancers.
- (3) Declaration of caseinate as a milk derivative in the ingredient list of foods that claim to be non-dairy, such as coffee whiteners.

The main reason for these new requirements is that some people may be allergic to such additives and will now be better able to avoid them.

## Nutrition labeling—exemptions

Under NLEA, some foods are exempt from nutrition labeling. These include the following:

- (1) Food produced by small businesses (i.e., those with food sales of less than \$50,000 a year or total sales of less than \$500,000).
- (2) Restaurant food.
- (3) Food served for immediate consumption, such as that served in hospital cafeterias and airplanes.
- (4) Ready-to-eat food prepared primarily on site; for example, bakery, deli, and candy store items.
- (5) Food sold by food service vendors, such as mall cookie counters, sidewalk vendors, and vending machines.
- (6) Food shipped in bulk, as long as it is not for sale in that form to consumers.
- (7) Medical foods, such as those used to address the nutritional needs of patients with certain diseases.
- (8) Plain coffee and tea, some spices, and other foods that contain no significant amounts of any nutrients.

Although these foods are exempt, they are free to carry nutrition information when appropriate as long as it complies with the new regulations.

Packages with less than 12 square inches available for labeling do not have to carry nutrition information. However, they must provide an address or telephone number for consumers to obtain the required nutrition information.

## Advertising

As a general rule, advertising is the province of the Federal Trade Commission (FTC) rather than the FDA. However, certain advertising or promotional claims have a direct bearing on the nature and amount of data required to appear on product labels. For example, any food that is advertised on the basis of its nutritional value must include certain specified nutrition information on its label. Also, particular label information is required for food promoted for certain special uses (e.g., weight control and low sodium). In addition, promotional materials (labeling) that accompany food products are regulated directly by FDA, and in certain areas, FDA has restricted the kinds of claims that can be made about particular foods, for example, standardized designations for special dietary use claims and standards for promoting a food as a “significant source” of a nutrient or as “nutritionally superior” to another food.

Any promotional claim that goes beyond the mere statement of nutritional benefit to an assertion of therapeutic value (e.g., “cures . . . , prevents . . .”) is not only prohibited for food, but might even subject the product to regulation as a drug.

## Enforcement

- (1) *Inspections*: All food processing establishments are subject to FDA compliance inspections. Any such inspections are limited to the plant and “all pertinent equipment, finished and unfinished materials, containers, and labeling.”
- (2) Regulatory action letters.
- (3) Seizure.
- (4) Criminal actions.
- (5) Injunctions.
- (6) *Recall policies*: The recall of a defective or possibly harmful consumer product often is highly publicized in newspapers and on news broadcasts. This is especially true when a recall involves foods, drugs, cosmetics, medical devices, and other products regulated by

FDA. Despite this publicity, FDA's role in conducting a recall is often misunderstood, not only by consumers but also by the news media, and occasionally even by the regulated industry. The following headlines, which appeared in two major daily newspapers, are good examples of that misunderstanding: "FDA Orders Peanut Butter Recall," "FDA Orders 6500 Cases of Red-Dyed Mints Recalled." The headlines are wrong in indicating that the agency can "order" a recall. FDA has no authority under the Federal Food, Drug, and Cosmetic Act to order a recall, although it can request a firm to recall a product.

Most recalls of products regulated by FDA are carried out voluntarily by the manufacturers or distributors of the product. In some instances, a company discovers that one of its products is defective and recalls it entirely on its own. In others, FDA informs a company of findings that one of its products is defective and suggests or requests a recall. Usually, the company will comply; if it does not, FDA can seek a court order authorizing the federal government to seize the product. This cooperation between FDA and its regulated industries has proven over the years to be the quickest and most reliable method to remove potentially dangerous products from the market. This method has been successful because it is in the interest of FDA, as well as industry, to get unsafe and defective products out of consumer hands as soon as possible.

FDA has guidelines for companies to follow in recalling defective products that fall under the agency's jurisdiction. These guidelines make clear that FDA expects companies to take full responsibility for product recalls, including follow-up checks to assure the recall is successful. Under the guidelines, companies are expected to notify FDA when they start a recall, to report to FDA on a recall's progress, and to undertake recalls when asked to do so by the agency.

The guidelines also call on manufacturers and distributors to develop contingency plans for product recalls that can be put into effect if and when needed. FDA's role is to monitor company recalls and assess the adequacy of a firm's action. Once the recall is completed, FDA assures that the product is destroyed or suitably reconditioned and also investigates why the product was defective. The guidelines categorize all recalls into one of three classes based on the level of hazard involved:

- (1) Class I recalls are for dangerous or defective products that predictably could cause serious health problems or death. Food found to contain botulinal toxin, a label mix-up on a lifesaving drug, or a defective artificial heart valve are examples of products that could fall into this category.
- (2) Class II recalls are for products that might cause a temporary health problem, or pose only a slight threat of a serious nature. Examples might be a drug that is understrength and that is not used to treat life-threatening situations.
- (3) Class III recalls are for products that are unlikely to cause any adverse health reaction, but that are in violation of FDA regulations. An example might be a bottle of aspirin that contains 90 tablets instead of the 100 stated on the label.

FDA's strategy for each individual recall sets forth how extensively it will check on a company's performance in recalling the product in question. For a Class I recall, for example, FDA would check to make sure that each defective product has been recalled or reconditioned; for a Class III recall, the agency may decide that it only needs to spot-check to make sure the product is off the market.

FDA seeks publicity about a recall only when it believes the public needs to be alerted about a serious hazard. For example, if a canned food product, purchased by a consumer at a retail store, is found by FDA to contain botulinal toxin, an effort would be made to retrieve all the cans in circulation, including those in the hands of consumers. As part of this effort, the agency also would issue a public warning via the news media to alert consumers to the potential hazard.

## Mandatory seafood inspection

Previously, FDA inspections of seafood processors concentrated on the sanitation conditions and practices of the processor, as well as the quality of the product. There was also considerable emphasis on end-product testing for microbiological and other defects. Under the Hazard Analysis Critical Control Point (HACCP) program, these efforts will continue. However, the focus of the inspection will be on the adequacy of the processor's controls to prevent the occurrence of food safety hazards. In particular, the investigator will assess the adequacy of



the processor's HACCP plan, observe the degree to which the plan is implemented in the plant, and review records of Critical Control Point (CCP) monitoring and corrective action. The investigator will also review the processor's sanitation monitoring program.

On December 18, 1995, the FDA published as a final rule 21 CFR 123, "Procedures for the Safe and Sanitary Processing and Importing of Fish and Fishery Products" that requires processors of fish and fishery products to develop and implement HACCP systems for their operations. The regulation became effective December 18, 1997.

The agency also published the "Fish and Fishery Products Hazards and Controls Guide" ("the Guide") in September, 1996, to assist processors in the development of their HACCP plans, and to provide information to help them identify hazards that may be associated with their products and formulate control strategies for those hazards. The guide was developed to coincide with the issuance of the final regulation.

Those covered by these requirements include all seafood related entities in FDA's establishment inventory and all foreign processors that export to the United States. All importers are also included.

The plan requires every processor to conduct a hazard analysis to determine whether they have likely food safety hazards that they must control.

Where hazard analysis reveals need, every processor must develop a written HACCP plan. The plan must identify food safety hazards that are reasonably likely to occur.

These hazards may include the following:

- (1) Toxins
- (2) Microbials
- (3) Chemicals
- (4) Pesticides
- (5) Drug residues
- (6) Physical hazards
- (7) Decomposition
- (8) Parasites

The next step is to establish CCPs that will control the hazards that can occur both inside and outside the processing plant.

Once the CCPs have been determined, critical limits (safe operating parameters) must be established and then the monitoring of those CCPs must be developed.

The next step in the plan is determining corrective actions to be taken if the critical limits have been exceeded.

To ensure that the HACCP plan is working, verification can be established by reviewing, monitoring of corrective action records, calibration records, and end-product testing records within a reasonable time.

The only way the HACCP system will work is to keep detailed records of the aforementioned procedures. All records must be signed and dated by a senior company official.

As a sequel to the mandatory HACCP requirements FDA has combined their concerns about sanitation into eight areas.

### **FDA's eight key sanitation conditions**

- (1) Safety of the water that comes in contact with food or food-contact surfaces is used in the manufacture of ice.
- (2) Condition and cleanliness of food-contact surfaces, including utensils, gloves, and outer garments.
- (3) Prevention of cross-contamination from unsanitary objects to food, food packaging material, and other food-contact surfaces, including utensils, gloves, and other outer garments, and from raw product to cooked product.
- (4) Maintenance of hand washing and sanitizing and toilet facilities.
- (5) Protection of food, food-packaging materials, and food-contact surfaces from adulteration with lubricants, fuel, pesticides, cleaning compounds, sanitizing agents, condensate, and other chemical, physical, and biological contaminants.
- (6) Proper labeling, storage, and use of toxic compounds.
- (7) Control of employee health conditions that could result in the microbiological contamination of food, food packaging materials, and food-contact surfaces.
- (8) Exclusion of pests from the food plant.

Records must be kept regarding these sanitation areas.

### **Special requirements for importers**

Importers must verify that their overseas supplies follow HACCP by a combination of the following:

- (1) Obtaining third party certification that product is processed according to requirements.
- (2) Going overseas and inspecting facilities to ensure product is processed according to requirements.
- (3) Obtaining a copy of processor's HACCP plan and a guarantee that it is being followed.
- (4) End-product testing and obtaining a guarantee that plan is being followed.
- (5) Obtaining product specifications for safety.

### Special requirements for molluscan shellfish

Controlling the origin of molluscan shellfish (i.e., properly classified waters) is the most important preventive control for most hazards. Thus, the HACCP plans of processors of molluscan shellfish must include how this control is being performed, including how processors assure that they are only obtaining shellfish satisfying the following criteria:

- (1) From waters approved by a "shellfish control authority".
- (2) From harvesters who are in compliance with local licensure requirements.
- (3) If properly "tagged."

### Special requirements for smoked fish

Botulism is a significant likely hazard for this type of product if not sufficiently controlled. Thus, the HACCP plans of processors of smoked fish must include how they are controlling this hazard to ensure zero toxin production in the product for a time slightly beyond the shelf life of the product.

### Imports

FDA reviews entry notice or other documents to determine whether to take samples for examination. Sampling may be required depending on the nature of the product, history of problems presented by such commodity, and FDA priorities. After sampling, imports may be released or detained. In the latter event, the importer is given an opportunity for a hearing to present evidence of compliance with the FDC Act. If FDA issues refusal of admission, the importer may apply for permission to recondition the shipment to bring it into compliance by relabeling or other appropriate action. FDA has a Memorandum of Under-

standing with the Customs Service that authorizes FDA employees to take samples and issue notices, including refusals of admission, regarding imported products subject to the FDC Act.

Import Alerts are directives to FDA field offices regarding specific imported products or product hazards and an appropriate enforcement program, from specific sampling requirements to automatic detention ("Blocklisting"). Following are some examples: sampling swordfish from several countries for excessive mercury content; examination at the wharf and sampling as indicated for canned baby clams; upholding detention of shrimp from India containing salmonella based in part on FDA's broad discretion to regulate imports differently than domestic products in the absence of an opportunity to inspect foreign food processing facilities; and detaining samples of imported fresh or frozen raw shrimp when analysis of six 2–3 lb subsamples shows filth at or above the specified levels, as shown in the subsequent text:

- (1) Flies (whole or equivalent):
  - (a) Filth flies—two in a sample.
  - (b) Incidental flies—ten in a sample.
- (2) Filth fly fragments:
  - (a) Three fragments (excluding setae) in five of six subsamples. (These fragments are clearly identified as parts of a filth fly.)
  - (b) Large body parts (i.e., thorax, abdomen) one in three of six subsamples.
- (3) Cockroaches:
  - (a) One whole or equivalent in the sample.
  - (b) Excreta—one in two of six subsamples.
- (4) Hairs:
  - (a) Rat or mouse—three of any size in a sample.
  - (b) Striated but not rat or mouse—four of any size in a sample.

Examples of filth flies are houseflies (*Muscidae*), humpbacked flies (*Phoridae*), moth flies (*Psychodidae*), black scavenger flies (*Sepsidae*), small dung flies (*Sphaeroceridae*), Chloropoid flies (*Chloropidae*), Anthomyiid flies (*Anthomyiidae*), blow flies (*Calliphoridae*), and flower flies (*Syrphidae*). This is not necessarily a complete list of filth flies that might be found in shrimp.

Examples of incidental flies are dance flies (*Empidiidae*), beach flies (*Canacidae*), shore flies (*Ephydriidae*), and barchinid flies (*Tachinidae*). This is not necessarily a complete list of incidental flies that might be found in shrimp.

(*Note:* These guidelines do not include all types of filth or different combinations of filth which may be found in shrimp. Therefore, samples containing filth elements not covered by these guidelines will still have to be submitted to the Division of Regulatory Guidance for evaluation.)

## Bioterrorism

### **The Public Health Security and Bioterrorism Preparedness and Response Act of 2002 (The Bioterrorism Act)**

Prior Notice of Imported Food Shipments by FDA; information must be submitted and confirmed electronically as factually complete by FDA for review no less than 8 hours (for food arriving by water), 4 hours (for food arriving by air or land/rail), and 2 hours (for food arriving by land/road) before the food arrives at the port of arrival.

To assist importers, the rule now permits submission of prior notice no more than 15 calendar days before the anticipated date of arrival for submissions made through FDA's Prior Notice System Interface (PNSI) and no more than 30 calendar days before the anticipated date of arrival for submission made through Customs and Border Protection (CBP's) Automated Broker Interface of the Automated Commercial System (ABI/ACS).

The rule adds a definition for "manufacturer" and provides an alternative for identifying the manufacturer when the registration number is not known. In addition to the name of the manufacturer, the submitter must submit either: (a) the registration number of the facility associated with the article of food; or (b) the full address of the site-specific facility and reason why no registration number is being provided. Persons currently submitting prior notice using reason code L (unable to determine identity of the manufacturer—providing identity of manufacturer's headquarters) and code M (unable to determine identity of manufacturer or headquarters—providing invoicing firm's identity) per the current Consumer Packaged Goods (CPG) no longer will be able to do so. As noted previously, the final rule requires the identity of the site-specific manufacturer.

The rule exempts from prior notice food in diplomatic pouches based on the authority in Art. 27(3) of The Vienna Convention on Diplomatic Relations (1961), which states: "The diplomatic bag shall not be opened or detained."

When certain conditions are met, for the submission of the express consignment operator or carrier tracking number in lieu of the anticipated arrival information, Bill of Lading, or Airway Bill number and flight number.

The Prior Notice Rule describes enforcement discretion in the following areas and states FDA generally will not refuse the following foods that are imported without prior notice: noncommercial (i.e., personal shipments; gift packs with a single prior notice submission; imported food arriving from/exiting to the same country; seed for cultivation; certain US government shipments; and foreign-to-foreign mail and courier shipments to individuals.)

### **Record keeping under the Bioterrorism Act**

The regulations require "persons that manufacture, process, pack, transport, distribute, receive, hold, or import food" to establish and maintain records that identify the immediate previous source of all food received, as well as the immediate subsequent recipient of all food released. Rapid access to such information allows FDA to determine the source and cause of any credible threats. The agency also expects this rule will help it quickly notify consumers and/or facilities that might be affected.

The rule applies mostly to traditional food manufacturers and packers, but nonetheless sweeps others involved in the food supply within its gambit. For example, transporters of food are brought fully within its scope, including foreign transporters.

The rule applies to packaging material manufacturers, suppliers and contract packagers, as follows:

- (1) Manufacturers of finished containers that come in contact with food and who also put the food directly into the finished containers are required to establish and maintain records.
- (2) Manufacturers of finished containers that come in contact with food, but who do not actually put the food into the containers, are required only to make existing records available to FDA with respect to the container.
- (3) Manufacturers of food-contact materials that are not the finished container that contacts food are only required to make existing records available to FDA upon request.
- (4) Manufacturers of food packaging that bears the label but is never directly in contact with food

(such as secondary packaging) are completely exempt from the record-keeping requirements.

Records must be available for inspection and copying as soon as possible, not to exceed 24 hours from receipt of FDA's official written request. To minimize the burden on food companies, the required information may be kept in paper or electronic format.

The record retention period for human food ranges from 6 months to 2 years, depending on the shelf life of the food. Records for animal food, including pet food, must be retained for 1 year. The maximum length for retention of records by transporters for all types of food is 1 year.

### **Food retention under the Bioterrorism Act**

FDA has long been able to seize misbranded or adulterated food in domestic commerce. However, adulterated food could enter commerce and put consumers at risk during the time it takes to file a seizure action. Under the Bioterrorism Act, FDA is now authorized to detain a food product while a seizure order is being obtained.

Also, the statute permits FDA to detain food product for "a reasonable period," which cannot exceed 20 calendar days after the detention order is issued. However, FDA may detain the food for an additional ten calendar days if necessary to institute a seizure or injunction action.

FDA may specify the location and condition under which the detained product is to be held. FDA may require the detained articles to be labeled or tagged accordingly, and can prohibit movement of the food without its approval.

Finally, the rules establish an appeals process for contesting the detention. Once filed, FDA will hear the appeal within two calendar days after it is filed, and will issue a decision within five calendar days from filing date.

If FDA fails to act on the appeal within 5 days of its filing, the detention order is terminated. If the detention order is confirmed, the food will continue to be detained until the order is terminated or the detention period expires, whichever occurs first. However, confirmation of a detention order does constitute final Agency action and may then be appealed to a US district court.

FDA does not expect to use its new detention authority to any great extent, and indeed, it has

not been used since passage of the Act in May of 2002.

### **Exports**

Food that does not comply with FDC Act requirements may be produced and sold for export without being deemed adulterated or misbranded if it complies with the laws of the importing country, meets specifications of the foreign purchaser, is labeled for export, and is not offered for sale in the United States. Export exemption cannot be used to save adulterated or misbranded products in domestic commerce; it applies only to products originally intended for export.

### **Fines**

Misdemeanor fines under the Food, Drug, and Cosmetic Act have been increased so that they may now reach a maximum of \$500,000 under some circumstances. The Criminal Fine Enforcement Act of 1984 (Public Law 98-596) set new fines for federal law violations perpetrated on or after January 1, 1985. Although the act is an amendment to Title 18 of the US Code, not the Food, Drug, and Cosmetic Act, the Justice Department has advised FDA that it applies to the fines of the FDC Act, other statutes that contain provisions enforced by the FDA and, indeed, to all federal crimes in federal law.

The Criminal Fine Enforcement Act provides these fines applicable to the FDC Act for each offense:

- (1) A fine of up to \$100,000 for a misdemeanor by a corporation or individual not resulting in death.
- (2) A fine of up to \$250,000 for a misdemeanor perpetrated by an individual that results in death, or for a felony.
- (3) A fine of up to \$500,000 for a misdemeanor perpetrated by a corporation that results in death, or for a felony.

The maximum imprisonment for a misdemeanor under the FDC Act remains a year for each offense.

### **National Marine Fisheries Service**

The Department of Commerce carries out a variety of activities relating to fish and the fishing

industry, including operation of research and inspection programs through the National Marine Fisheries Service (NMFS). NMFS has the dual role of administering grade and quality standards for fish and fish products (see Table 27.3), and also of promoting the fish industry.

## Inspections

NMFS operates an inspection and certification service that is entirely voluntary and is supported primarily by industry fees (see the appendix). About 11% of the approximately  $1.8 \times 10^8$  kg (400 million lb) of fish consumed annually in the United States, and approximately 6% of fish processors undergo NMFS inspection. The cost varies depending on a number of factors, but on average is about \$.02/kg (\$.09/lb) of fish.

Anyone may apply for NMFS inspection and certification, but NMFS services may be refused for nonpayment of fees, abuse of or interference with the program, consistent refusal to respond to NMFS findings and recommendations, illegal practices, and so on. Inspection service may include evaluation of the following:

- (1) Fish identity, type, style, size, and so on.
- (2) Class, quality, condition, or wholesomeness of product includes the following:
  - (a) Compliance with various aspects of FDA regulations, that is, standards of identity and adulteration.
  - (b) NMFS grade standards.
  - (c) Compliance with company's own specifications.
- (3) Sanitation standards during fish handling, processing, packing, and storage operations (Sanitary-Inspected Food Establishment, SIFE):
  - (a) Measures compliance with GMPs and NMFS fish plant sanitation standards.
  - (b) Required for participation in government procurement programs.

## NMFS grade standards

- (1) Whole or dressed Fish:
  - (a) General
  - (b) Frozen headless dressed whiting

**Table 27.3** Minimum flesh content requirements for USDC inspected standardized and nonstandardized breaded and battered products (all species of fish and shellfish).

Products	USDC grade marks <sup>a</sup>	PUFI mark
Fish fillets		
Raw breaded	—	50%
Precooked breaded	—	50%
Precooked	—	50%
crispy/crunch		
Precooked battered fish	—	40%
Fish portions		
Raw breaded	75%	50%
Precooked breaded	65%	50%
Precooked battered	—	40%
Fish sticks		
Raw breaded	72%	50%
Precooked breaded	60%	50%
Precooked battered	—	40%
Scallops		
Raw breaded	50%	50%
Precooked breaded	50%	50%
Precooked	—	50%
crispy/crunch		
Precooked battered	—	40%
Shrimp		
Light breaded <sup>b</sup>	65%	65%
Raw breaded <sup>b</sup>	50%	50%
Precooked	—	50%
crispy/crunch		
Precooked battered	—	40%
Imitation breaded <sup>c</sup>	—	No minimum; encouraged to put % on label
Oysters		
Raw breaded <sup>d</sup>	—	50%
Precooked breaded <sup>d</sup>	—	50%
Precooked	—	50%
crispy/crunch <sup>d</sup>		
Precooked battered <sup>d</sup>	—	40%
Miscellaneous		
Fish and seafood cakes	—	35%
Extruded and breaded products	—	35%

<sup>a</sup>No USDepartment of Commerce (USDC) grading standard currently exists.

<sup>b</sup>FDA standards of identity require that any products USDC minimum of 50% shrimp flesh by weight and if labeled "lightly breaded" must contain not less than 65% shrimp flesh.

<sup>c</sup>Any product with a standard of identity that contains less flesh than the standard calls for must be labeled imitation.

<sup>d</sup>Flesh content on oyster products can only be determined on an input weight basis during production.



- (2) Fish steaks:
  - (a) Frozen halibut steaks
  - (b) Frozen salmon steaks
- (3) Fish fillets:
  - (a) General
  - (b) Cod fillets
  - (c) Flounder sole fillets
  - (d) Haddock fillets
  - (e) Ocean perch fillets
- (4) Frozen fish blocks and products made from the following:
  - (a) Frozen fish blocks
  - (b) Frozen minced fish blocks
  - (c) Frozen raw fish portions
  - (d) Frozen raw breaded fish sticks
  - (e) Frozen raw breaded fish portions
  - (f) Frozen fried fish sticks
  - (g) Frozen fried fish portions
- (5) Crustacean shellfish products:
  - (a) Shrimp
  - (b) Frozen raw breaded shrimp
- (6) Molluscan shellfish:
  - (a) Frozen raw scallops
  - (b) Frozen raw breaded scallops and frozen fried scallops
- (7) Proposed standard for minced fish meat (Surimi).

### *Enforcement*

Limited authority for dealing with violations of health, safety, or other standards. Actions to be taken include the following:

- (1) Notify FDA.
- (2) Notify states.
- (3) Quarantine-contaminated molluscan shellfish under Lacey Act.
- (4) Detain products in facilities receiving inspection services on contract basis.

### *Memorandum of understanding between FDA and NMFS*

NMFS takes the lead in inspection activities under voluntary inspection programs. NMFS inspections include verifying compliance with FDA rules regarding GMPs, additives, standards of identity, and labeling and packaging requirements, although FDA retains authority to conduct its own inspections and make its own determinations regarding violations of the FDC Act. At a minimum, FDA

keeps NMFS apprised of regulatory standards and criteria, as well as notifies NMFS of seizure actions. NMFS gives FDA a list of plants inspected by NMFS; specific information, upon request, regarding products or product lots against which FDA has taken or is considering taking enforcement action; and information regarding products placed under official retention by NMFS.

## **Lacey Act**

We draw the Lacey Act to your attention specifically because it has been seen, in some circumstances, as a disadvantage to the seafood industry. The National Fisheries Institute has worked for years to have the act better defined but to no avail. The purpose of the Lacey Act amendments of 1981 (commonly referred to as the Lacey Act) is to defer illegal trade in fish by improving civil and criminal penalties for violations of federal, state, and foreign laws. Because of the severity of these penalties, seafood dealers, importers, distributors, processors, and retailers should be familiar with the act.

It is unlawful under the Lacey Act for any person:

- (1) to "import, export, transport, sell, receive, acquire, or purchase any fish. . . taken or possessed in violation of any law, treaty, or regulation of the United States, or in violation of any Indian tribal law";
- (2) to "import, export, transport, sell, receive, acquire, or purchase in interstate or foreign commerce any fish . . . taken, possessed, transported, or sold in violation of any law or regulation of any state or in violation of any foreign law";
- (3) within the maritime and territorial jurisdiction of the United States to "possess any fish . . . taken, possessed, transported, or sold in violation of any law or regulation of any State or in violation of any foreign law or Indian tribal law";
- (4) having imported, exported, transported, sold, purchased, or received any fish imported from any foreign country or transported in interstate or foreign commerce, to "make or submit any false record, account, label, or identification thereof";
- (5) to attempt to commit any prohibited act described in paragraphs 1 through 4;

- (6) to “import, export, or transport in interstate or foreign commerce any container or package containing any fish unless the container or package has previously been plainly marked, labeled, or tagged in accordance with regulations issued jointly by the Secretaries of the Interior and Commerce.”

## Penalties

The Lacey Act imposes both civil and criminal penalties depending on the knowledge of the defendant, the type of violation, and the value of fish involved.

### Civil

For any violation of the act, except marking violations, a maximum civil penalty of \$10,000 may be assessed when there is evidence that the violator in the exercise of due care should have known that the fish was taken, possessed, transported, or sold in violation of any underlying law. If the violation involves the transportation, acquisition, or receipt of fish with a market value of less than \$350 that were taken or possessed in violation of any underlying law, the maximum civil penalty that may be assessed is the maximum penalty provided by the underlying law or \$10,000, whichever is less. For marking violations, there is a maximum strict liability civil penalty of \$250.

### Criminal

There is a maximum \$20,000 fine and/or 5 years of imprisonment for each violation of the act, except marking violations, where the violator knew that the fish had been taken, possessed, transported, or sold in violation of any underlying law and knowingly committed a violation of the act involving (1) importation or exportation, or (2) the sale or purchase, the offer of sale or purchase, or the intent to sell or purchase fish, wildlife, or plants with a market value of more than \$350. A maximum \$10,000 fine and/or 1 year imprisonment is imposed for any violation of the act knowingly committed, except marking violations, where the violator in the exercise of due care should have known that the fish was taken, possessed, transported, or sold in violation of any underlying law.

## Forfeitures

All fish involved in any violation of the act, other than marking violations, are subject to strict liability forfeiture to the United States. All vessels, vehicles, aircraft, and other equipment used to aid in the criminal violation of the act for which a felony conviction has been obtained are subject to forfeiture to the United States if (1) the owner of the vessel, vehicle, aircraft, or equipment was at the time of the alleged illegal act a consenting party or privy thereto or in the exercise of due care should have known that the property would be put to an illegal use and (2) the violation involved the sale or purchase of, the offer of sale or purchase of, or the intent to sell or purchase fish.

## Culpability standards

For the most part, there are two standards of fault under the Lacey Act: “knowingly” and “due care.”

### *Due care*

To be assessed a civil penalty under the act, a person must have failed to exercise due care. This standard of due care means that degree of care that a reasonably prudent person would exercise under the same or similar circumstances. The due care standard is applied differently to different categories of persons who have varying degrees of knowledge and responsibility. Persons such as fish dealers, aquaculturists, and others who are involved in commercial fish transactions are held to a higher degree of responsibility and knowledge than the average citizen. They are assumed to know that they are dealing with a highly regulated product at both the state and federal levels. The Departments of the Interior and Commerce take the view that in the exercise of due care commercial fish dealers are expected to take some affirmative action to ensure that their dealings are in accordance with all applicable federal and state laws. Due care requires them, when facing a particular set of circumstances, to undertake steps that a reasonable person in their business would take to ensure that the law is not being violated.

### *Knowingly violates*

To commit an act “knowingly” is to do it with knowledge or awareness of the true facts or

situation, and not because of mistake, accident, inadvertence, or some other innocent reason. However, knowledge of the Lacey Act itself is not required to be shown.

### Questions and answers concerning the Lacey Act

- (1) Can I be held liable under the Lacey Act if I ship fish into a state that prohibits their entry?  
Yes, if it can be shown by the government that you failed to exercise "due care" in finding out what the laws of that state are, or if you knew those laws and shipped the fish anyway. This provision of the law was supported by a number of states that believed a remedy was needed to deter shipment of fish products to the receiving state that are not prohibited by the law of the shipper's state. The specific example cited was of farmed white amur (grass carp) shipped from Arkansas to California in violation of California laws.
- (2) Does an interstate shipper of fish have to know the laws of all 50 states regarding fish shipments to avoid a felony prosecution under the Lacey Act?  
No, you can only be convicted of a felony if it can be shown that you had actual knowledge of a violation of the underlying law and chose to ignore it. To satisfy the "due care" standard of the lesser penalties, however, you should make a reasonable effort to determine the laws of those states to which you ship fish.
- (3) Why does the definition of "wildlife" include fish that are bred, born, and raised in captivity or on a fish farm?  
Congressional intent in passing the Lacey Act was to conserve wildlife. As there are no reliable ways to distinguish between captive-bred specimens and those specimens taken from the wild, effective implementation of the Lacey Act requires a comprehensive definition of wildlife.
- (4) Are intrastate shipments that violate an underlying state law subject to the Lacey Act?  
No.

### US Customs

The US Customs Service enforces country-of-origin labeling requirements under the Tariff Act. Seafood

importers should ensure that packaging labels comply with present regulatory standards. The general rule is that the marking of the country of origin on a seafood package must be "legible, indelible, and permanent." Markings must include the English name of the country of origin, unless another marking is specifically authorized by the Commissioner of Customs. The degree of permanence should be at least sufficient to ensure that in any reasonably foreseeable circumstance, the marking shall remain on the container until it reaches the ultimate purchaser unless it is deliberately removed. The marking must survive normal distribution and store handling. The ultimate purchaser in the US must be able to find the marking easily and read it without strain.

A special rule applies if the words "United States," or "American," the letters "USA" or any variation of such words or letters or the name of any city or locality in the US, or the name of any foreign country or locality other than the country or locality in which the article was manufactured or produced, appear on an imported article or container. In this instance, the name of the country of origin preceded by "made in," "product of," or other words of similar meaning must appear, legibly and permanently, in close proximity to such words, and in at least a comparable size. The FDA administers a set of very detailed regulations regarding the content, layout, location, and size of product label information. One of these regulations requires that the label state the name and place of business of the manufacturer, packager, or distributor. Special care should be taken to ensure that package labels required by FDA under this regulation also comply with the special country-of-origin rule administered by the US Customs Service.

### Bulk containers

When an article is imported in the container in which it will reach the ultimate purchaser, it is relatively simple to determine the sufficiency of the country-of-origin marking. However, special rules apply to so-called J-list articles (including fish and shellfish) that are imported in bulk and then repacked in the United States by the importer or a subsequent purchaser. In these cases, although the container in which the article is imported is usually marked, the container in which the article is

repacked for sale to an “ultimate purchaser” is frequently not.

The ultimate purchaser, as defined in Customs Regulations, is generally the last person in the United States who will receive the article in the form in which it was imported. It is not feasible to state who will be the ultimate purchaser in every circumstance. However, the following examples may be helpful:

- (1) If an imported article will be used in manufacture, the manufacturer may be the ultimate purchaser if he or she subjects the imported article to a process that results in a substantial transformation of the article, even though the process may not result in a new or different article.
- (2) If the manufacturing process is merely a minor one that leaves the identity of the imported article intact, the consumer or user of the article who obtains it after the processing will be regarded as the ultimate purchaser.
- (3) If an article is to be sold at retail in its imported form, the purchaser at retail is the ultimate purchaser.

To minimize the practice of not disclosing country-of-origin information on the new containers, customs has adopted a procedure requiring importers of repacked J-list articles, articles incapable of being marked, and articles intended to be repacked in retail containers (e.g., blister packs) to certify to the district director having custody of the articles that (1) if the importer repacks the article, he or she shall do so in accordance with the marking requirements, or (2) if the article is sold or transferred, the importer shall notify the subsequent purchaser or repacker, in writing, at the time of sale or transfer, that any repacking must conform to these requirements.

## Other legislation

### Magnuson Fishery Conservation and Management Act

The Magnuson Act (MFCMA) provides a national program for the conservation and management of all fishery resources, except tuna, within the US Exclusive Economic Zone (EEZ). The EEZ extends

from the seaward boundary of the coastal states to 200 nautical miles (370 km) from the shore.

The MFCMA authorizes eight Regional Fishery Management Councils made up of federal and state fishing administrators and knowledgeable citizens to prepare fishery management plans (FMPs) for their regions. Citizens are appointed by the Secretary of Commerce from a list of individuals nominated by state governors. Each council has a scientific and statistical committee consisting of fishery scientists and an advisory panel made up of people knowledgeable in each fishery under the council's jurisdiction.

### Optimum yield

All FMPs must be developed in accordance with seven national standards. These standards deal with conservation of stocks, use of the best available scientific information, scope of the management units, fair and equitable allocation of fishery resources, flexibility of management, and minimizing costs of management. For each fishery management plan, the councils determine the maximum level of harvest that can be taken without endangering the stock's ability to sustain itself. This level, commonly referred to as the maximum sustainable yield, is adjusted for relevant economic, social, or ecological reasons to obtain the optimum yield (OY). The regional councils use OY as the maximum amount of fish that may be harvested each year.

Management plans govern both foreign and domestic fishing. Each plan must contain a description of OY, a determination of that portion of the OY that will be harvested by US fishermen, a determination of that portion of the OY that can be made available to foreign fishermen, and an assessment of the extent to which US processors will utilize the US harvest. Discretionary provisions, which may be written into a management plan, include requirements for domestic permits and fees, data collection programs, designation of fishing zones and periods, limits on size of catch, limits on the number of fishermen permitted in each fishery, or assessments of the plan's impact on naturally spawning stocks of anadromous fish.

### Plan review

After allowing for public comment and input, regional councils submit the management plan to

the NMFS for approval. NMFS has 110 days to allow for additional public comment and review the plans on behalf of the Secretary of Commerce to ensure that they are consistent with the national standards, the provisions of the Magnuson Act, and other applicable law. If a management plan is needed but has not been prepared by the appropriate council, the secretary may prepare a plan.

## Regulations

Once a management plan is approved, the Secretary of Commerce issues regulations implementing the plan. The secretary also may promulgate regulations to address emergencies involving any fishery either on his or her own initiative or under the direction of a council by a unanimous vote. Emergency regulations remain in effect for no longer than 90 days and may be repromulgated for one additional 90-day period. All regulations are enforced with the help of the US Coast Guard and state officials. Civil and criminal penalties for violations include forfeiture of vessels, gear, or catch.

## Foreign agreements

The Magnuson Act allows foreign vessels to fish in the fishery conservation zone only for that portion of the OY that will not be harvested by US vessels. Foreign fishing for “surplus” fish is allowed only if (1) the nation has an existing international fishing agreement or has signed a governing international fishery agreement (GIFA) with the US; (2) the nation extends reciprocal fishing privileges to US vessels; and (3) foreign vessels have valid permits issued by the Secretary of Commerce. By signing a GIFA, a foreign nation recognizes the sovereign rights of the US in the EEZ and agrees that its citizens will obey all applicable rules and regulations. GIFAs are not required for foreigners to participate in recreational fishing in US fisheries.

## Foreign fishing

The total amount of “surplus” fish that is available to foreign vessels is called the Total Allowable Level of Foreign Fishing (TALFF) and is determined by the appropriate council. The Secretary of State, in cooperation with the Secretary of Commerce, determines how the TALFF is divided among each eligible nation. Under the so-called fish and chips

policy, foreign nations that assist the US fishing industry receive a greater allocation. In making the allocations, the Secretary of State considers the nation’s tariff and other import barriers, fisheries trade cooperation, fisheries enforcement cooperation, their domestic consumption needs, their contribution to the growth of the US fishing industry, cooperation in resolution of gear conflicts, cooperation in transferring technology, traditional fishing activities in the EEZ, cooperation in fisheries research, and other appropriate matters. Half of the allocations are withheld in the beginning of each year and released later, provided the foreign nations are complying with the fish and chips policy.

## Foreign permits

Permits are required for each foreign vessel that will catch, process, or otherwise support fishing operations in the EEZ. Foreign fishing activity is regulated through area and season closures, gear restrictions, and catch quotas as specified in each permit. The Magnuson Act requires 100% observer coverage of foreign fishing to monitor compliance with all US regulations.

## Foreign fees

Foreign vessels fishing in the EEZ pay permit registration fees, poundage fees, surcharges for vessel and gear damage claims filed by US fishermen, and surcharges for observers. Permit registration fees cover the administrative cost of processing foreign permit applications. The poundage fee is based on the number of metric tons of fish caught, and varies with each fishery. Foreign fishing vessels are also assessed a surcharge based on their total vessel fees that is deposited into the Fishing Vessel Gear Damage Compensation Fund. The observer surcharge goes into the Foreign Fishing Observer Fund to cover all costs of providing US observers on the foreign vessels concerned. The vessel registration fee and poundage fees are required to be at least equal to the total cost of carrying out all management, research, administrative, and enforcement activities required under the Magnuson Act.

## Foreign fishing vessels

Permits are also required for foreign vessels to receive fish from US vessels in the Federal Coastal Zone (FCZ). These over-the-side transfers or “joint



ventures” may only be approved if fish processors do not have the capacity, and will not use such capacity, to process all US harvested fish. If a joint venture permit is approved, the amount of US harvested fish received by a foreign vessel is limited to the portion of the OY that will not be used by US processors.

### Foreign harvesting and processing

The Magnuson Act provides a mechanism to phase out foreign fishing activities in the FCZ. In general, as the domestic harvest increases, foreign fishing allocations may be decreased. The act also addresses US fishing rights in foreign waters. Specifically, foreign nations that do not extend reciprocal fishing privileges to US fishing vessels may be subject to import prohibitions on its fish and fish products normally imported by the US.

### States

Individual state’s authority to regulate fishing in their waters (generally within 4.8 km (3 mi) of the shoreline) is unchanged by the Magnuson Act. However, if state action or inaction adversely affects the implementation of a fishery management plan for a fishery primarily within the FCZ, the Secretary of Commerce may preempt state authority and regulate the fishery within that state’s water pursuant to the management plan. The Magnuson Act also allows foreign processing vessels to operate in the internal waters of a state (waters within the baseline used to measure the territorial sea). If a nation has a GIFA or international fishing treaty, the governor may grant permission to a foreign vessel to process fish within a state’s internal waters unless he or she determines that fish processors within the state have adequate capacity, and will utilize such capacity, to process all of the US harvested fish from the fishery concerned that are landed in the state.

### Anadromous Fish Conservation Act

The Anadromous Fish Conservation Act authorizes the secretaries of Interior and Commerce to enter into cooperative agreements with states and other nonfederal agencies for the conservation and development of anadromous fish (including

salmon, shad, steelhead trout, and striped bass). It authorizes investigations, engineering and biological surveys, research, stream clearance, construction, maintenance, and operations of hatcheries and devices and structures for improving movement, feeding, and spawning conditions.

### Capital Construction Fund Act (Merchant Marine Act of 1970)

The Capital Construction Fund Act provides that any citizen of the US owning or leasing one or more “eligible vessels” (including eligible fishing vessels) may enter into an agreement with the Secretary of Commerce to establish a capital construction fund that will be used for the eventual replacement or reconstruction of the vessel or gear and equipment.

Eligible vessel is defined as any vessel constructed in the US, or if reconstructed, reconstructed in the US, documented under the laws of the US, and operated in the foreign or domestic commerce of the US with the grandfather provision that any ship built abroad but documented under US flag on April 15, 1970, or built abroad before that date for use in foreign trade pursuant to a contract entered into before that date shall be considered as though built in the US.

Section 607 provides for a deferral of federal income taxes on deposits into the fund from the following sources:

- (1) Earnings from shipping operations of agreement vessels.
- (2) Net proceeds from the sale or of the disposition of, or from insurance on, agreement vessels.
- (3) Earnings from investment or reinvestment of amounts held in the fund. This has the effect of deferring tax on ordinary income or capital gains on these deposits so long as they remain in the fund.

### Endangered Species Act

The Endangered Species Act protects endangered and threatened species and their critical habitats. It prohibits taking, importing, exporting, and interstate commerce of any endangered species with exceptions for scientific research, enhancement, economic hardship, and subsistence taking by Alaska natives.

### **Federal Aid in Fish Restoration Act (The Dingell-Johnson Act)**

Dingell-Johnson provides federal aid to states for management and restoration of fish having “material value in connection with sport or recreation in the marine and/or freshwaters of the United States.” Funds are derived from a federal excise tax on certain sportfishing equipment and apportioned to states by a formula based on each state’s area and number of sportfishing licenses issued. To participate, states must have fishery conservation laws, including a prohibition against the use of license fees paid by fishermen for any purpose other than the administration of that state’s fish and game department.

### **Federal Ship Financing Act of 1972**

The Federal Ship Financing Act amends Title XI of the Merchant Marine Act (1936) by replacing authority to insure vessel mortgages and loans with authority to guarantee loans. Fishing vessels of 5 net tons or over are one of several classes of eligible vessels. Generally, loans (owed to private lenders) eligible for guarantee must have aided in financing or refinancing the cost of constructing, reconstructing, or reconditioning vessels, facilities, or equipment pertaining to marine operations.

### **Federal Water Pollution Control Act**

The Federal Water Pollution Control Act requires permits from the EPA for the discharge of any pollutant into navigable waters. It provides for the Army Corps of Engineers to issue permits for the discharge of dredged or fill materials into the navigable waters, with oversight by the EPA. Permit applications are reviewed by the US Fish and Wildlife Service for impacts on fish and wildlife.

### **Fish and Wildlife Act of 1956**

The Fish and Wildlife Act establishes a comprehensive fish and wildlife policy. It authorizes the Secretary of the Interior to develop measures for “maximum sustainable production of fish,” make economic studies, and recommend measures to ensure the stability of domestic fisheries. It also undertakes promotional and informational activities to stimulate consumption of fishery products

and takes steps required “for the development, management, advancement, conservation, and protection of fishery resources.” Functions are related to marine commercial fisheries and sport fisheries. Great Lakes fishery research and certain other fishery related activities are assigned to the National Oceanic and Atmospheric Administration, under the Department of Commerce Act, to provide for cooperation between the secretaries of State and Interior and to provide representation at international meetings relating to fish and wildlife. The 1974 amendment stipulates that the Small Business Administration may make loans to fishermen, under certain situations, while the Fisheries Loan Fund moratorium exists.

### **Fish and Wildlife Coordination Act**

The Fish and Wildlife Coordination Act authorizes the Secretary of the Interior to assist federal, state, and other agencies in developing, protecting, rearing, and stocking fish and wildlife on federal lands. It also authorizes studies on the effects of pollution on fish and wildlife.

### **Fishermen’s Protective Act of 1967**

The Fishermen’s Protective Act authorizes the Secretary of State to reimburse damages to the owner or charter of a US fishing vessel that has been seized by a foreign country while operating on the high seas or while fishing between 4.8 and 370 km (3 and 200 mi) offshore of a foreign nation for highly migratory fish such as tuna. Payments may be paid for the cost of having the vessel released, replacement of confiscated gear, spoiled fish, and loss of income to commercial fishermen.

It also authorizes the withholding of financial aid to any country that seizes a US fishing vessel illegally. It gives the president discretionary authority to prohibit the importation of fishery products from nations that conduct fishing operations in a manner that diminishes the effectiveness of multi-lateral international fishery conservation programs in which the US participates.

### **Fishery Cooperative Act of 1934**

The formation of fishery marketing cooperatives and their administration are provided for in the

Fishery Cooperative Act. Responsibility for administering it lies with the Secretary of the Interior.

### **Marine Mammal Protection Act of 1972**

The Marine Mammal Protection Act establishes federal responsibility for the conservation of marine mammals with management under the Department of the Interior for sea otter, walrus, polar bear, dugong, and manatee, and under the Department of Commerce for all whales, porpoises, seals, and sea lions. It establishes (with certain exceptions) a moratorium on the taking and importation of marine mammals and products made from them, and it provides for the establishment of a three-member Marine Mammal Commission, supported by a nine member Committee of Scientific Advisors.

### **Marine Protection, Research, and Sanctuaries Act of 1972**

A program administered by the EPA to regulate dumping of materials into ocean waters was established under the Marine Protection, Research, and Sanctuaries Act. The Secretary of Commerce, in coordination with the Coast Guard and the EPA and in consultation with the Secretary of Interior, is directed to determine long range effects of pollution over fishing and other activities on ocean ecosystems. The Secretary of Commerce is authorized to designate and protect marine sanctuaries after consultation with the secretaries of the Interior, State, Defense, and Transportation and the administrator of the EPA. If waters within the territorial limits of any state are involved, state officials must also be consulted.

### **Merchant Marine and Shipping Act of 1916**

The Merchant Marine and Shipping Act comprises a vast body of legislation amended and supplemented many times. The Jones Act is the generic term used for various sections regulating US commercial shipping, including the fisheries. As it pertains to fishing boats, it does not allow any vessel of 5 net tons or over to participate in coastal fisheries if it was not built in the United States. Vessels over 5 net tons and engaged in commercial fishing are required to be documented. Under 5 net tons a vessel cannot be documented, but must be registered according to state regulations.

Other provisions under the Merchant Marine law concern licensing of fishing vessels, fines for trading without license, load lines for vessels, and regulation of fishing voyages. Another provision gives seamen a right of action against their employer for negligence, or for injury caused by the unseaworthiness of a vessel or its tackle.

### **Rivers and Harbors Act of 1899**

The Rivers and Harbors Act makes it unlawful for anyone to conduct any work or activity in navigable waters of the US without a federal permit. The Secretary of the Army is authorized to issue permits to construct piers, jetties, and similar structures, or to dredge and fill. The Corps of Engineers issues permits for the discharge of refuse affecting navigable waters. The Fish and Wildlife Coordination Act provides authority for the US Fish and Wildlife Service to review and comment as to the effects proposed activities would have on fish and wildlife.

### **Saltonstall-Kennedy Act of 1954**

The Saltonstall-Kennedy Act directs the Secretary of Agriculture to transfer annually to the Secretary of the Interior funds equal to 30% of receipts from customs duties on fisheries products. These funds are used for fishery research and development.

## **State regulations**

The states all have "little FDC" Acts that follow the federal law to a greater or lesser degree. In addition, state and local governments generally play an active and primary role in regulating the handling and processing of fresh fish and shellfish within their borders. They may specify what, where, when, and how fish may be caught and processed and may conduct related inspection programs. In contrast, FDA activity with respect to fresh fish and shellfish is generally concentrated on identity and labeling issues and on the surveillance of imports.

Some states also have laws applicable to fish imported into the state from other states or countries (e.g., minimum length required for salmon brought into California or country or state of origin labeling required for fish sold in Arkansas).

## Interstate Shellfish Sanitation Conference

The Interstate Shellfish Sanitation Conference (ISSC) is a voluntary cooperative framework for establishing and implementing uniform standards for the safe and sanitary harvesting, processing, and distribution of molluscan shellfish (oysters, clams, and mussels). The ISSC, a successor to the National Shellfish Sanitation Program, was formed in 1982.

Members include representatives from shellfish producing and consuming states and FDA, NMFS, and industry representatives, but only the state representatives have voting rights. In addition, several foreign governments participate as observers in ISSC activities.

The ISSC is intended to provide a forum for developing uniform and up to date guidelines, standards, and procedures for the states to use in conducting their sanitary control activities. The primary role in ISSC is played by the states that undertake to adopt the necessary laws and regulations for ensuring the safe and sanitary production of shellfish and to take the necessary steps to implement those laws, by, for example, identifying pollution sources; testing waters for possible bacteriological or other contamination; patrolling growing areas to detect and deter illegal harvesting; and inspecting processing plants for sanitary practices. In addition, the ISSC is managed and controlled by the states, unlike the NSSP that originally was run by the Public Health Service and later by FDA.

FDA's role in the ISSC is purely advisory. Under its Memorandum of Understanding with the ISSC, FDA agrees to evaluate state sanitary control programs and offer suggestions; provide technical support and training; coordinate federal activities pertaining to ISSC issues; publish a monthly list of all state certified shellfish producers and shippers; and establish agreements with foreign governments to provide for the adoption and use of sanitary controls equivalent to those used by the US. The foreign agreements currently approved are with Canada, Japan, Korea, Iceland, Mexico, England, and New Zealand.

ISSC builds on the work of the NSSP (i.e., NSSP Manual of Operations, Parts I and II, as amended has been formally adopted by ISSC and redesignated as the ISSP) and is structured to avoid some of NSSP's problems (e.g., ISSC includes a voting mechanism to avoid the NSSP problem of being unable to resolve issues on which there was no consensus).

Nonetheless, some issues persist from the voluntary nature of the organization and its activities, the absence of any legal sanctions for noncompliance, and the always delicate nature of federal/state relations.

## Federal Trade Commission

The Federal Trade Commission (FTC) has primary jurisdiction over advertising of foods under a Memorandum of Understanding with FDA. The FTC Act prohibits "unfair or deceptive acts or practices in or affecting commerce."

### False or misleading

An advertisement violates the FTC Act if it is false or misleading in any respect. An advertisement may be considered false or misleading if it has the capacity or tendency to deceive, regardless of advertiser's intent and regardless of whether anyone was actually fooled. Currently, FTC may require a showing of actual and material deception, before taking enforcement action. Advertisements are viewed as a whole and may be considered deceptive if the "net impression" is false or misleading, even though each sentence, taken individually, may be literally true. Meanings of advertisements are determined with reference to the "ordinary purchaser," including "the ignorant, the unthinking, and the credulous." Currently, FTC may apply a "reasonable consumer" standard. The advertiser is responsible for every claim perceived by consumers, expressed and implied, intended and unintended.

### Substantiation

An advertisement violates the FTC Act if the advertiser lacks substantiation for its claims. Advertiser must have proof, in the form of a "reasonable basis" for its claims before including them in an advertisement. What constitutes a reasonable basis is a question of fact depending on specificity of the claim; type of product; consequences of false claim; degree of reliance by consumers; and type and accessibility of supporting evidence.

(Note: The laws and regulations described in this chapter are not intended to be all inclusive. Other

federal and local agencies that deal with discharges, for example, EPA, or with the workplace (OSHA) also have regulations that impact the industry. In addition, governmental agencies at all levels are constantly modifying existing regulations and/or writing new ones.)

## Appendix

### NMFS Inspection Services

Inspection services available from the NMFS (US Department of Commerce) on fee basis.

### Technical Assistance and Sanitary-Inspected Fish Establishment Services

These services provide for the inspection of plants for sanitation only. No product inspection, certification, or grading is conducted. The services consist of two phases:

- (1) *Phase I Sanitary Consultative Services:* This service includes inspecting the facility to identify the strengths and weaknesses of the plant's sanitation to determine if it meets minimum Commerce Department (USDC) and FDA sanitary requirements and consulting with the firm on correction of any deficiencies. The inspector conducts inspections and provides technical advice to the plant to assist in upgrading sanitation practices. When a plant meets USDC requirements, it is eligible to contract for regular sanitation inspections under Phase II described later. Plants with sanitation deficiencies can remain in Phase I if they agree to a minimum of 4 hours of consultative services monthly at prevailing inspection rates. If there are several plants in the same area interested in inspection, mileage and inspection travel time costs can be prorated among them.
- (2) *Phase II SIFE Service:* Plants meeting all sanitary requirements receive inspection for sanitation for a minimum of 12 hours per month at the same hourly rate as Phase I. These plants are recognized as official establishments, operate under the FDA/NMFS Memorandum of Understanding, are awarded a certificate attest-

ing to their sanitation compliance, and are listed in a NMFS biannual publication available to potential seafood buyers, such as schools, food chains, government purchasing agencies, and consumers.

### Packed Under Federal Inspection Service

The "Packed Under Federal Inspection (PUFI)" mark or statement on a federally approved label signifies that the product is safe, wholesome, has good flavor or odor, and was produced under Federal inspection in an officially acceptable establishment. The product is not graded for a quality level but must meet acceptable commercial quality criteria in accordance with approved Federal standards of USDC approved processor specifications. If the company's own in plant quality control system meets the approval of, and is certified by, the NMFS Inspection Service, the number of hours necessary for the inspector to be onsite during the processing of produce bearing the PUFI mark can be reduced, thus reducing the overall cost.

### Product Grading Service

This service is available to processors participating in the PUFI program that pack products for which there are US Grade Standards. Participation in the program permits the use of US Grade marks on products meeting these standards. This service requires that a USDC inspector perform the grading. There is no additional cost for this service beyond the fee per hour for the PUFI service.

### Lot Inspection Service

Inspections are performed on specific lots of products of domestic or foreign origin. Generally, inspections are conducted to determine a product's compliance with criteria or specifications furnished by the requester. Since the USDC inspection net is nationwide, these lots can be located in processing plants, warehouses, cold storage plants, or terminal markets anywhere in the US. This service can be contracted for by a broker, buyer, or processor with a financial interest in the product. The contract can be on an individual request or continuing



basis. An official certificate documenting the quality and condition of the lot is supplied to the client upon completion of the inspection (usually within 2 days). These certificates have proven valuable in lawsuits concerning product quality and intransit damage because they are accepted as “prima facie” evidence in US courts. Master cartons of products lot inspected can be marked by the inspector as officially sampled or accepted per specification.

## Further reading

Federal Food, Drug & Cosmetic Act of 1938 as amended.  
Code of Federal Regulations, 21 USC sec. 321.

Agricultural Marketing Act of 1946. Code of Federal Regulations, 7 USC sec. 1621–1627.

Codex Alimentarius Standards. Federal Register” 1984 Vol. 49, pp. 7584–9749.

FDA Compliance Guides, section 7108.

FDA Fair Packaging & Labeling Act. Code of Federal Regulations, 21 USC sec. 343, part 101.

US Customs Regulations. Code of Federal Regulations, 44 USC.

National Marine Fisheries Service Grade Standards. Code of Federal Regulations, 50 USC, part 260.

The Lacey Act, Fish & Wildlife Service. Department of Interior Code of Federal Regulations, USC sec. 16.

National Shellfish Sanitation Program. Manual of Operations, Part I & II, 1988 Revision, Food & Drug Administration, Washington, DC.

# 28

## Smoked, Cured, and Dried Fish

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George J. Flick, Jr., and David D. Kuhn

Before refrigeration and canning techniques, humans preserved food caught in times of plenty to use in times of scarcity by taking advantage of environmental conditions, both induced and natural. In addition, they used naturally occurring preservatives such as salt and smoke. Undoubtedly, one of the first foods cooked on an open wood fire was some form of fish.

Although the origin of fish smoking is obscured by antiquity, aboriginal men and women must have developed this method of preserving their catch shortly after they discovered how to make fire (Crance, 1955; Paparella, 1979.). Experience soon told them that the barbecuing process made food keep longer and added a distinctive flavor. As time continued, these prehistoric cooks noticed that the flavor varied with the kind of wood burned, and other improvements gradually followed.

Proper timing and correct temperature, which to primitive people meant the correct position of the fish over the fire, were determined. Becoming more familiar with using salt, they found that a preliminary salting or brining further improved the flavor and the keeping qualities. Present methods of hot-smoking or barbecuing, as it is sometimes called, surely evolved from these crude beginnings.

About the time humans were learning how to barbecue fish, they discovered the possibilities of drying fish in the open air. They also found that a wood smudge burning under their hanging fish not only preserved the fish but also imparted a smoky flavor. With certain types of fish the smoke flavor was preferred, thus a smudge fire under the drying fish became an essential part of the process. Use of proper wood, regulation of the fire's heat, and the density of smoke, together with a preliminary salting or brining, completed the evolution of what is known as fish smoking.

It was not until the development of controlled smokehouses that any significant advances were made over those early preservation methods. Controlled processes for both cold- and hot-smoking based on scientific principles have just begun to come into use in fish smoking; today, smoking is being changed from an art to a science.

The primary curing ingredient is still salt, but additional curing ingredients may be used such as sugar, spices, and, in some products, sodium nitrite. The cured products may or may not be subsequently smoked, smoke-flavored, and/or partially dried. In this discussion, our emphasis is on fresh and saltwater species of fish that are both cured and

smoked or smoke-flavored. Preparation of these food products has long been a tradesman's art. Applying scientific principles to this ancient art can produce a safer and more consistent, appetizing, and wholesome product.

Development of modern refrigeration has meant that there is no longer the need for the high salt content previously required. Although less salt is now used in curing smoked fish, it still contributes to the finished product's shelf life, safety, and flavor. The modern mild-cured products, which may be cold- or hot-smoked, are made possible by adherence to good sanitation practices and proper refrigeration during processing, distribution, and storage. These products require proper refrigeration for preservation.

The smoked fish industry has achieved an excellent reputation for producing high quality, wholesome products. However, the industry has experienced some problems that have resulted in serious economic loss and, to a degree, an erosion of consumer confidence. There have been periodic food poisoning outbreaks associated with cured and cured-and-smoked fish products, some of which have resulted in fatalities. Case studies of these relatively infrequent outbreaks, which often involved *Clostridium botulinum* toxin, consistently appear related to improper processing procedures applied by inexperienced or unknowledgeable processors, inadequate sanitation, abusive product storage conditions (primarily by the consumer), and sometimes to consumers' erroneous belief that smoking negates the need for refrigeration or that the product has an unlimited shelf life. In recent years, both hot- and cold-smoked products have been recalled by either state health regulatory agencies or the US Food and Drug Administration due to the presence of *Listeria monocytogenes*. Many nations have established a zero defect action level or tolerance for the microorganism in ready-to-eat foods.

It is the processor's responsibility to adhere to manufacturing procedures that result in products that are not only appealing in appearance and flavor, but are wholesome, prepared under sanitary conditions, and are safe to eat.

## Economic importance

Today, people continue to smoke, cure, and dry seafood, not so much for preservation, modern

preservation techniques give a superior product more closely associated to fresh, but for the delightful taste and texture and because of cultural preferences. The selection of smoked fish products is extensive, and regional preferences exist for both the type of fish and the style of preparation. In some countries, salted and dried fish remain an important commercial product.

## Principles of smoking, drying, and curing

The two most common sources of spoilage in foods come from the actions of bacteria and autolytic enzymes. Although both are extremely important, the major emphasis here is on controlling the adverse effects of spoilage organisms in smoked, cured, and dried fish.

Water is the basic ingredient of all foods. Every food contains water even though the amounts may vary, and for the most part, the amount of available water in a food determines how rapidly that food will spoil. Foods with a high available water content (such as meats, seafood, and milk) spoil quickly; foods with a low available water content (such as flour, honey, and cereal grains) may last for years even at room temperature (Troller and Christian, 1978).

Bacteria and other spoilage microorganisms must have a minimum level of available water before they can carry out essential metabolic functions. If there is not sufficient available water, the bacteria die or become inactive. The amount of available water in a food is measured by the water activity (abbreviated  $a_w$ ). Do not confuse this measurement with the percentage of water in a food. Water activity is a measurement of the water available for microorganisms to use for metabolism. Salt and sugar can "tie up" water so that it is not available for microorganisms to use. Consequently, by adding enough salt to fish, the growth and destructive action of bacteria can be minimized. In addition, salt draws moisture from the tissue of the fish by osmotic pressure to make less water available.

Pure water has a water activity ( $a_w$ ) measure of 1.0. As the amount of available water decreases, so does the water activity value. Most bacteria must have a water activity of 0.95 or higher to grow. Table 28.1 lists some common foods and their water activity values.

**Table 28.1** Approximate  $a_w$  values of some foods and of sodium chloride and sucrose solutions.

$a_w$	NaCl (%)	Sucrose (%)	Foods
1.00–0.95	0–8	0–44	Fresh meat, fruit, vegetables, canned fruit in syrup, canned vegetables in brine, frankfurters, liver, sausage, margarine, butter, low-salt bacon
0.95–0.90	8–14	44–59	Processed cheese, bakery goods, high-moisture prune, raw ham, dry sausage, high-salt bacon, orange juice concentrate
0.90–0.80	14–19	59–saturation	Aged cheddar cheese, sweetened condensed milk, Hungarian salami, jams, candied peel, margarine
0.80–0.70	19–saturation		Molasses, soft dried figs, heavily salted fish
0.70–0.60			Parmesan cheese, dried fruit, corn syrup, licorice
0.60–0.50			Chocolate, confectionery, honey, noodles
0.50–0.40			Dried eggs, cocoa
0.40–0.30			Dried potato flakes, potato crisps, crackers, cake mixes, pecan halves
0.30–0.20			Dried milk, dried vegetables, chopped walnuts

Source: Troller and Christian, 1978. Copyright 1978. Reproduced with permission of Elsevier.

Note that fresh fish has a water activity close to 1.0 but after heavily salting and drying, the water activity is between 0.80 and 0.70, a level far below the threshold at which normal bacteria can grow. However, we must point out that there are some bacteria, called halophiles (meaning salt-loving), that can grow at a water activity value as low as 0.75 (see Table 28.2). Occasionally, these bacteria can cause considerable spoilage during the salting of fish. Some contain a red pigment, and fish contaminated with them are referred to as “pink” spoiled (Troller and Christian, 1978).

The preservation effects of dried and salt-cured fish are obtained by removing or displacing available water to prevent bacterial growth.

**Table 28.2** Lowest  $a_w$  values permitting spoilage-organism growth.

Group of microorganisms	Minimal $a_w$ value
Bacteria	0.91
Yeasts	0.88
Molds	0.80
Halophilic bacteria	0.75

## Smoked fish processing

Although the general operations in all smoked fish processing plants are similar, the specific processing procedures can vary considerably. This variability relates to differences in equipment, regional and ethnic consumer preferences, raw materials, and tradition.

We discuss the basic operations involved in the processing of smoked fish and the manufacturing practices necessary to minimize the hazard of Type E botulism and the risks of food-borne infections in the consumption of smoked fish. Effective sanitation considerations, including plant design, construction, water, and personal hygiene, are areas that must be carefully evaluated to minimize bacterial contamination (Crance, 1955; Dougherty and Seagran, 1967).

The unit operations involved in the processing of smoked fish can be categorized as follows:

- (1) Purchasing and receiving
- (2) Raw material storage (refrigerator and freezer)
- (3) Raw material preparation
- (4) Salting—drying and brining
- (5) Drying
- (6) Smoking

- (7) Cooling
- (8) Packaging
- (9) Finished product storage
- (10) Distribution and sale

We discuss each category briefly.

## Purchasing and receiving

A processor should be aware that various state and federal statutes exist concerning the purchase and possession of various fish species and size. It is important that a purchaser's plan incorporate these aspects into the program.

## Selecting and initial preparation

It is imperative that only fresh, properly prepared fish be used for smoking. Smoking will not mask or otherwise make a poor quality or spoiled fish acceptable. Smoking enhances the flavor and texture of fish; fish with a high oil or fat content are generally more suitable for smoking than lean fish. Some examples of high-fat fish are salmon, eels, whitefish, catfish, sturgeon, chubs, mackerel, mullet, and bluefish. Examples of low-fat fish, which do not smoke as well, are flounder and snapper.

When selecting fish for smoking, choose only those that are of high quality and free from bruises, torn skin, or other physical damage. Fish may be smoked whole, gutted, filleted, steaked, or chunked depending on the species and desired style. Large fish obviously should be filleted or cut into smaller pieces so that proper cooking temperatures can be achieved without overcooking the outside of the fish.

If the fish is intended for a cold-smoking process, product sourcing becomes a major consideration. Cold-smoking temperatures customarily do not exceed 37°C (100°F) and that temperature is insufficient to eliminate *L. monocytogenes* that may contaminate the fish. Additionally, there are a few postprocessing processes that can effectively eliminate the contamination. Product sourcing becomes a most important consideration in order to prevent product recalls and potential litigation.

## Receiving

Production of a quality finished product starts at the receiving department. This operation not only

involves physical control of incoming raw materials and supplies but is usually the first inspection point.

It is essential that all processing begin with a high-quality product. Containers and fish should be inspected on arrival at the plant. All fish must have been shipped at suitably low temperatures, and they should be free from adulteration and not have detectable off-odors or flavors. Special attention should also be given to firmness of flesh, eye condition, and gill color.

It is highly recommended that all incoming fish be divided into lots and given an identification tag that will accompany the product throughout the entire process and become part of the process records. Information on the tag would include point of product origin, date received, condition of fish (physical state as well as appropriate quality attributes), lot number (if desired), and size and type of fish.

Freshwater and saltwater finfish species represent the major tonnage of incoming materials. Depending on the species and ultimate use, fish may be received whole, gutted, or headed-and-gutted and may be fresh and iced or frozen.

Inspections at the receiving department should include other edible raw materials used in the processing of smoked or smoke-flavored fish, including salt, sugar, spices, and, in some products, smoke flavoring, artificial color sodium nitrite, vegetable oil, and other ingredients. Wood smoking materials such as chips and excelsior, packaging materials, and cleaners and sanitizers also should be examined.

## Raw material storage

All reasonable precautions should be taken to ensure that all products and raw materials are handled in a manner that will not contribute to their contamination or deterioration. Lots should be appropriately identified to assure their timely use on a first-in first-out basis whenever possible.

Fish that are not smoked immediately can be iced and/or refrigerated for a short period. Fresh fish that are not to be processed immediately should be refrigerated at a temperature near 0°C (32°F). Frozen fish should be either thawed promptly and processed or stored at a temperature that will maintain them in a frozen state. Fish that are to be kept for an extended period prior to cooking and smoking should be properly frozen and stored to



maintain desired quality. Usually, a temperature no higher than  $-18^{\circ}\text{C}$  ( $0^{\circ}\text{F}$ ) should be used, with  $-29^{\circ}\text{C}$  ( $-20^{\circ}\text{F}$ ) preferred. Proper chilling and/or freezing retards bacteria growth and enzyme activity, the major causes of spoilage in fishery products.

Dry and nonperishable food ingredients and package materials should be stored in a dry area in a manner that protects against contamination and deterioration. Cleaning and sanitation chemicals should be stored in a separate area.

Sodium nitrite requires special handling and should be stored in a locked area restricted to those few who will use this ingredient and who have been properly instructed regarding its use and potential hazard. Only quantities needed in a given brine should be permitted out of the room.

### Raw material preparation

Proper cleaning and preparation prior to smoking improves product quality. Immediately before processing begins, both fresh and thawed fish should be thoroughly washed by a vigorous water spray or a continuous water flow system with chlorinated water (25–50 ppm). This process helps increase shelf life and also removes blood and reduces bacterial populations that cause spoilage and food poisoning. Washing fish after brining is not as effective as a prewash because once the product has been brined, a water-soluble protein layer covers the fish surface, making it more difficult to remove entrapped bacteria.

Whole fish should be thoroughly washed prior to gutting and dressing to remove external debris and blood and the natural slime that encases most fish.

Generally, slime can be easily removed by washing the fish in cool water and rubbing the slime off. At times, slime can be difficult to remove, especially from heavily slimy fish like eels. To make removal easier, one of the four following methods can be used:

- (1) Soak the fish in a heavy brine solution for a few minutes. Often, this will quickly separate the slime from the fish.
- (2) Wash the fish in a chlorine solution (one tablespoon of liquid hypochlorite bleach in four gallons of water (Dudley et al., 1973)). Make sure that fish washed in chlorine solution are thoroughly rinsed in fresh clean water.
- (3) Quickly dip the fish in hot water (about  $82^{\circ}\text{C}/180^{\circ}\text{F}$ ) to coagulate the slime (Dudley et al., 1973).
- (4) Freeze the fish. When fish are thawed in preparation for smoking, the slime often is loosened and can be easily washed off.

The thawing or defrosting of frozen fish should be carried out in a sanitary manner and by methods that will not adversely affect the wholesomeness of the fish. Whole fish should not be mixed with gutted fish during thawing. Different species of fish should be thawed separately.

To maintain quality, thaw fish in air at a temperature of  $7^{\circ}\text{C}$  ( $45^{\circ}\text{F}$ ) or below so that no part of the fish exceeds  $7^{\circ}\text{C}$  ( $45^{\circ}\text{F}$ ). If the fish are thawed in water, then a continuous chilled water-overflow tank, a spray system, or any other process that provides frequent water exchange should be used. The fish should not remain in the tank longer than is needed to sufficiently thaw them for further processing, preferably no more than a half-hour after the fish are completely defrosted. Care should be taken to ensure that fish entering the thaw tank are completely free of packaging liner material. Cleaning and sanitizing the tank is essential to maintain sanitary conditions and should be conducted as often as necessary.

Fish should be eviscerated before salt curing and smoking. Whole fish should be eviscerated with a minimum disturbance of intestinal tract contents; all viscera should be completely removed. Cut the fish and thoroughly wash the cavity in fresh clean water. Be sure to remove all organs without puncturing or cutting them. The kidneys are usually lodged along the backbone and require extra effort to remove sufficiently. After evisceration, the fish (including the body cavity) are given a second thorough wash with a vigorous chlorinated water spray or a continuous water flow system. All offal should be placed in suitable covered containers and removed at least once a day or more frequently if necessary. Depending on offal refuse pickup, the offal containers may require refrigeration.

Consider the cut of fish to be smoked. Style and form depends on the size of fish, desired product, and personal preference. Small fish such as chubs, whitefish, and eels are usually smoked whole, eviscerated, and gills removed. Larger fish such as salmon, sturgeon, sablefish, and bluefish are cut into steaks, fillets, split, or butter-flied. The cuts

may be skinless. Always keep fish or cuts of fish packed in ice or properly refrigerated to retard decomposition.

### Rinsing

Both fresh and thawed fish that have been eviscerated should be rinsed thoroughly before brining. All rinsing operations should be carried out with chlorinated water, either as a vigorous spray or in a continuous water flow system. The concentration of chlorine in the rinse water should be maintained between 25 and 50 ppm.

### Salting

One of the most difficult, but most important, steps in preparing smoked fish is obtaining the desired concentration of salt or other preservatives in all parts of the product. Uniform salt concentrations are important. Depending on the concentration, salt can slow the growth of spoilage microorganisms and some food poisoning bacteria. However, the main purpose of adding salt is to impart flavor, because the amount used in modern smoked products has little effect on keeping quality. Again, we stress that the smoked fish available today are perishable and require refrigeration.

Factors contributing to salt variation in smoked fish include fish size; species; fat content; condition (fresh or frozen, skin on or skin off, state of rigor); method of salt application; brine concentration; brine temperature; brining time; brine-to-fish ratio; circulation of brine; and section of fish. (Several of these factors are discussed in more detail later in this chapter.)

In recent years, there has been a trend toward lowering the salt content in processed foods as a means of reducing dietary sodium. Smoked fish processors have been very sensitive to this issue, because they are interested in adjusting to consumer tastes without sacrificing product safety or market share.

The salt used should be of food-grade quality, low in calcium and magnesium, and essentially free of iron and copper. The application of salt to fresh or thawed fish is carried out prior to either hot- or cold-smoking by exposing the fish, or portion thereof, to dry salt or, more commonly, to salt brine. Some processors use a combination of the two procedures. Although there is no hard and fast rule that

dictates the use of one procedure over the other, salt brines are most widely used because they are easier to handle and offer better control.

With dry salting, the amount of salt, the time, and the temperature should be carefully controlled to attain desired product. The amount of salt-to-fish by weight may vary from 1:8 for light salting, 1:3 for split fish, or 1:1 for heavy salting. Dry salting should be carried out at a temperature not exceeding 3°C (38°F). (In the preparation of some Nova Scotia salmon by the dry-salting procedure, brown sugar is also sprinkled in with salt.) Because of the variations possible, only through experimentation and experience can the proper curing be ascertained.

### Brining or curing

Brining serves three purposes: (1) it firms the texture of the fish, (2) it provides seasoning or flavor, and (3) it acts as a preservative in some types and styles of smoked fish. But brining must be carried out under the most careful conditions to prevent making an unpalatable salty product.

Liquid salt solutions, or brines, are an important step in processing smoked fish and require some precision and vigilance on the part of the preparer. A saturated brine is made from good-quality bulk or bagged salt in equipment available from the major salt companies. Salt storage and brine making can be confined to one location and the brine pumped to the points of use. A brief explanation of the arithmetic of salt solutions is appropriate. Quantity of salt is usually stated in pounds. One gallon of fully saturated brine at 15°C (60°F) contains exactly 2.987 lb of salt and tests 100°S (100° Salometer). In making brine, the concentration of the solution must be measured reasonably accurately (within 5°S) to predict the proper amount of time to soak the fish. The best and most common way to measure brine concentration is with a salometer, which is a floating scale that measures the density of the brine according to its buoyancy when placed in the brine. The denser the solution, the more buoyant the salometer will be. The scale gives readings in salometer degrees from 0°S to 100°S (corresponding from 0% to 100% saturation, 0°S for pure water, and 100°S for fully saturated brine. For example, 40°S is 40% saturated). When using a salometer, it is important that the brine temperature be considered. Ordinarily, salometers are scaled for reading at a temperature of 15°C (60°F).

**Table 28.3** Brine conversion tables (60°F).

Salometer (degrees)	Sodium chloride by weight (%)	Salt per gallon of water (lb)
0	0.000	0.000
2	0.528	0.044
4	1.056	0.089
6	1.586	0.134
8	2.112	0.179
10	2.640	0.226
12	3.16	0.273
14	3.695	0.320
16	4.223	0.367
18	4.751	0.415
20	5.279	0.464
22	5.807	0.512
24	6.335	0.563
26	6.863	0.614
28	7.391	0.665
30	7.919	0.716
32	8.446	0.768
34	8.974	0.821
36	9.502	0.875
38	10.030	0.928
40	10.558	0.983
42	11.086	1.039
44	11.614	1.094
46	12.142	1.151
48	12.198	1.208
50	12.670	1.266
52	12.725	1.325
54	14.253	1.385
56	14.781	1.444
58	15.309	1.505
60	15.837	1.568
62	16.365	1.629
64	16.893	1.692
66	17.421	1.756
68	17.949	1.882
70	18.477	1.888
72	19.004	1.954
74	19.532	2.022
76	20.060	2.091
78	20.588	2.159
80	21.116	2.229
82	21.644	2.300
84	22.172	2.372
86	22.700	2.446
88	23.338	2.520
90	23.755	2.594
92	24.283	2.670
94	24.811	2.745
96	25.339	2.827
98	25.86	2.906
100	26.395	2.98

Table 28.3 gives an accurate conversion of salometer degrees to salt concentration when the brine is 15°C (60°F). However, if the temperature is below or above 15°C (60°F), the reading will not be correct and adjustments must be made. Adjustments are made by adding or subtracting **one** salometer degree for each 5.6°C (each 10°F) that the brine temperature deviates from 15°C (60°F). For example, if the temperature of the brine is 27°C (80°F), you would **add** 2°S to the reading on the chart. If the temperature of the brine is 7°C (45°F), you would **subtract** 1.5°S (Bankston, 1973; Hilderbrand, 1980).

The typical brine used to soak fish for smoking varies from 30°S to 50°S although higher concentrations can be used. Refer to Table 28.3 to determine the pounds of salt per gallon of water to be dissolved for a particular salometer degree brine. For example, if you need an 80°S mixture, this would be a 21.116% sodium chloride solution requiring 1.012 kg (2.229 lb) of salt to 3.785 L (1 gal) of water. Obviously, if you are making up 100 gallons of solution, you would add 222.9 lb ( $2.229 \times 100$ ) of salt to 100 gal of water. The resulting solutions would give a total volume of more than 100 gal because water would be displaced by the dissolved salt.

Diluted brine solutions are commonly made in the smoked fish industry by volumetric dilution of fully saturated brine (100°S). To make 100 gal of a 40°S brine requires 40 gal of fully saturated brine and 60 gal of water. Adjustments for temperature may be required. Diluted brines should be checked for the salometer reading.

If a diluted brine is to be prepared from dry salt and water, use a brine table to establish the amounts of salt and water necessary to make the volume of diluted brine required. The salt should be completely dissolved before using the brine.

When making brine, several principles should be kept in mind:

- (1) To achieve a rapid and predictable salt penetration, use as pure a salt (NaCl) as possible. For example, calcium and magnesium, which are common salt impurities, hinder the proper penetration of salt into the fish tissues. Improper or delayed salt penetration can cause spoilage. In addition, these impurities may cause a chalky, bleached-out, unappetizing, or unnatural color that will detract from the product's appearance. Consequently, avoid using sea salts or other salts with known impurities.

- (2) Salt used for brining should be fine textured so that it will dissolve quickly. Table salt has a suitable texture, but rock salt may take an inordinate amount of time to dissolve. For consistency, it is important that an accurate measurement of salt be added to the water and that it be completely dissolved prior to use as a brine. When salt is initially added to water, it begins to dissolve quickly but the rate maybe slow considerably as the brine strength increases.
- (3) Stirring or agitating the brine will increase the rate at which the salt dissolves. Mechanical agitation by a pump, sparge, or propeller is highly recommended, but manual agitation with a paddle or a stirrer could also be employed. Agitation helps dissolve the salt and also is useful during the brining process to maintain consistent absorption. We discuss this process in more detail later.
- (4) As the water's temperature is increased, so is the rate at which the salt dissolves. Dissolving all the salt in nonchilled water and then chilling the solution to the proper brining temperature may save some effort. Prior to adding fish, it is important that the brine solution be chilled to at least 4.5°C (40°F), which maintains the quality of the fish during the procedure. Although the rate of salt penetration is retarded by chilled brine, fish quality should never be sacrificed in order to speed the process.

During the brining procedure, several phenomena occur:

- (1) Water migrates from the fish tissues because of osmotic pressure. This water loss causes some weight loss but will favorably affect the texture of the fish.
  - (2) The salt concentration in the tissue increases with soaking time. Consequently, if the fish are brined for longer than the recommended time, the final product may be unpalatable because of the high salt content.
  - (3) Salt from the brine is absorbed by the fish, and water from the fish is expelled into the brine. The end result is diluted brine. Since brine is generally changed between batches of fish, this probably has little impact on brine quality.
- As mentioned earlier, numerous factors influence the rate that fish absorb salt (Burgess et al., 1967). Among them, the most significant are as follows:
- (1) *Exposed flesh*: Salt penetrates skinless and/or filleted areas much more rapidly than areas protected by skin.
  - (2) *Fat content*: As the percentage of fat increases, the rate at which the salt penetrates the fish flesh decreases. Consequently, fat content and the species of fish brined have a significant impact on brine concentration and brining time.
  - (3) *Size and shape of fish or pieces of fish*: All other factors being equal, the thinner the fish portions, the faster the salt penetration. Fish of reasonably uniform size should be brined together. Fish of different species should not be mixed in the same tank.
  - (4) *Agitation*: Stirring the brine should give more even penetration of salt. Pockets of diluted or concentrated brine are blended to give an overall even concentration.
  - (5) *Strength of brine*: Brine strength is important to ensure a uniform and standard product from batch to batch. For example, if one vat of brine has an 80°S value and another vat for the same product has a 45°S value because of a careless worker, then the final products will not be the same. As a general rule, the stronger the brine, the shorter the brining time. Typically, brine concentrations of between 30°S and 50°S are used (Bannerman, 1980).
  - (6) *Submerge*: For a fish to brine properly and uniformly, it must be completely submerged in the brine. Floating fish or too many fish (which prevents complete coverage) causes uneven salt penetration and a substandard product.
  - (7) *Weight ratio*: As the brine-to-fish ratios increase, the amount of salt per unit weight of fish increases. A longer refrigerated brining time (18–36 hours) with a more dilute brine (20°S–45°S) often results in a more uniform salt concentration than a short brining time (2–6 hours) in a more concentrated brine (over 45°S). However, either brining procedure is acceptable.
  - (8) *Temperature control*: The brining process should be performed so that the temperature of the fish and brine does not exceed 15°C (60°F) at the start of brining. If the fish are between 3°C (38°F) and 10°C (50°F) at the start of brining, the temperature should be continuously lowered to 3°C (38°F) or below within 12 hours. If

the temperature is between 10°C and 15°C (50°F and 60°F) at the start of the brining process, the temperature should be continuously lowered to 10°C (50°F) or below within 2 hours and to 3°C (38°F) or below within the following 10 hours. Once the brining process reaches 3°C (38°F), the temperature should be constantly maintained during the entire operation.

### Water-phase salt content

Salt content in the finished smoked fish product is typically determined on the loin muscle of the fish and is expressed as percentage of salt in the water phase. To determine the salt content in the water phase of the muscle, it is necessary to remove and analyze the loin muscle for both moisture content and salt content:

$$\% \text{Salt in water phase} = \frac{\% \text{Salt}}{\% \text{Moisture} + \% \text{Salt}} \times 100 \quad (28.1)$$

A dry salting or brining process is established to attain no less than a minimum water-phase salt content appropriate for the product. There has been considerable debate over what constitutes an appropriate minimum water-phase salt content. The minimum water-phase salt content considered appropriate for smoked fish products can vary, based on use of sodium nitrite, heat processing, type of packaging, intended shelf life, and expected storage conditions.

Typically, the rate or amount of salt uptake increases with increased brine concentration, higher brine temperature, greater brine-to-fish ratio, smaller fish, longer brining period, a soft (postrigor) condition, aged fish, and prefrozen fish. Although some factors increase the salt uptake, this should not be construed as optimum brining conditions. Brining conditions are selected to produce a uniform and high-quality product within a reasonable production schedule.

Brine tanks should be cleaned and made sanitary before each use. Brine should be prepared fresh for use from food-grade salt. Brines should not be reused unless there is a suitable procedure such as ultrafiltration to return the brine to an acceptable microbiological level.

Although some organisms grow in saltwater, most spoilage organisms are severely restricted by

brine concentrations above 7% salt (approximately 27°S).

Before the fish are removed from the brining process they are generally evaluated by a chemical and sensory analysis. If the fish do not have an acceptable salt level, brining time is extended. If too salty, the product is rinsed in water to remove some of the salt.

Both of these processes must be carefully monitored to ensure that the fish are removed at the correct time. The actual required brining time can vary depending on the factors mentioned but it may be quite rapid (Childs et al., 1976). It is common practice to rinse fish after brining to remove surface salt. This operation must be done cautiously to avoid leaching excessive salt from the product.

### Ingredients

Other ingredients, such as sugar, other flavor ingredients, coloring agents, and sodium nitrite can be added during the brining process. Special brining formulas are proprietary to each smoked fish processor. All ingredients must be generally recognized as safe and approved. The use of sweeteners, liquid smoke, and coloring agents is at the discretion of the processor and should be used in accordance with good commercial practice by procedures determined appropriate for the product in preparation. Finished products should be labeled in accordance with regulatory requirements to reflect the presence of all ingredients.

Some fish are placed into a tank or tub of coloring agent to achieve a desired color or the dye may be added to the brine, combining the two operations in one. The concentration of dye used in dipping is greater than when it is incorporated into the brining solution. In some cases, dye may be injected into the fish. For coloring consistency, some types of smoked fish are dipped after preslicing. Dye solution, approved by FDA, is made up in strengths dictated by the experience of the individual curer, and it is not possible to establish exact rules that will apply universally. Processors must determine requirements by experimentation and according to the desires of their customers. The use of dyes in smoked fish and the labeling required for such processes are subject to specific state and federal regulations.

Sodium nitrite is a curing agent, preservative, and color fixative but is only permitted for use



in smoked chub; smoked, cured salmon; smoked, cured sablefish; smoked, cured shad; and smoked, cured hena. Sodium nitrite enhances the inhibitory effectiveness of salt against the outgrowth of *C. botulinum* Type E spores. The use level in brines, either in the premix or pure form, is adjusted to attain in the finished smoked chub not less than 100 ppm and not greater than 200 ppm in the loin muscle. In finished smoked sablefish, salmon, or shad, the level should not exceed 200 ppm. A rule of thumb is to add twice as much sodium nitrite to the brine as desired in the final product. For example, to obtain 200 ppm in the final product, add 400 ppm to the brine. In a 35°S brine at 15°C (60°F), the amount of sodium nitrite (400 ppm) per 189.3 l (50 gal) of brine would be approximately 78 g (2<sup>3</sup>/<sub>4</sub> oz). The actual amount required should be established by controlled experimentation. In practice, it should be thoroughly dissolved in the brine before the fish are added.

Sodium nitrite can be broken down by bacteria present on smoked fish, and its inhibitory effect is diminished. To retain its maximum effectiveness, good sanitation procedures must prevail, and the product should be stored at 0–2°C (32–34°F). It is strongly recommended that a processor obtain the services of a reputable supplier or qualified consultant for the development of safe and effective brining mixtures and their applications.

## Drying fish

After brining, fish are hung or laid on racks for drying, smoking, and heat processing. If these processes cannot be conducted within 2 hours after removal from the brine, fish should be stored in a refrigerator at 3°C (38°F) or below. Drying allows for good color formation, forms a “skin” that holds in juices, and gives the strength needed to keep fish from falling from hooks, rods, or other holding devices.

## Positioning fish for drying and smoking

Fish are usually dried in the same position in which they will be smoked, and obviously fish should be smoked with as much surface area exposed as possible. For example, a split fish should be hung or presented in such a way that split halves are open. Depending on the size and cut of fish, there are

three common methods for hanging or holding fish for drying and smoking:

- (1) Rods may be used to thread fish through the head, gills, or mouth. This method is good for smaller fish and for some fish that have been headed and split. Fish normally hang tails down when placed on a rod.
- (2) Hooks or nails allow the fish to be hung in any position, although usually they are hooked through the head. If they are hooked through the fleshy part of the body, the hooks leave an undesirable mark. In hanging fish, sufficient space should be between the fish to prevent faulty processing. Overcrowding or overloading the smokehouse could result in an inferior product and should be avoided.
- (3) Racks are useful for pieces of large fish such as chunks, steaks, blocks, sides, or fillets that do not have skin or skeletal structure to support hanging. Racks should be made of large mesh screens or other materials that allow good exposure to smoke and air circulation (Dudley et al., 1973).

Mesh bottom trays, made of half-inch mesh, may be used for some products, such as fillets and steaks. The trays are sometimes coated with edible oil to prevent pieces of fish from sticking. Pieces in the tray should be close to the same size and should not touch each other. Remove as much free liquid as possible because pools of brine lying in depressions in the fish will be slow to dry, and these damp areas may spoil rapidly during subsequent refrigerated storage. The trays may be placed directly on fixed racks in the smokehouse, or they may be conveyed into a cage that is placed into the smokehouse after it has been filled.

During hanging, dissolved proteins in the brine solution dry on the fish surface and produce the familiar glossy skin that is one of the commercial criteria for quality. When properly dried, this “pellicle” will form and the outer surface will be smooth, dry, and glossy (Crance, 1955). Without proper brining and drying, a glossy pellicle will not form. A properly formed pellicle helps give the finished product an attractive appearance because smoke readily adheres to it. A poorly formed pellicle allows the outer surface of the fish to burst or erupt, emitting coagulated body fluids, resulting in an unattractive appearance.

After hanging, the product is dried. Drying is an important step that must be controlled to produce a high-quality product. In almost all instances, fish must first be dried by removing surface moisture to a certain degree, prior to heating or smoking. When properly done, drying will make the flesh firmer and prepare it for further cooking and smoking.

Forced drying—raising the temperature and drawing a current of air through the smokehouse—reduces the time required for the smoking process. Drying time depends on such factors as air circulation, temperature, and the relative humidity of the air. Normally, it takes several hours. Generally, it is recommended that fish be dried in a cool place with circulating air created by a blower or fan, especially when home smoking fish. Some commercial processors dry fish in the smoking chamber at an elevated temperature. However, the processor must be sure that all air vents and doors are open to provide a good circulation of air and that the temperatures are carefully controlled so that the fish are not cooked.

If too much humidity builds up during this step, or if processing takes too long and the meat and bone are exposed to heat before drying, the product will fall apart. To prevent this, the protein must be set or denatured with low temperature drying **before** applying higher temperatures. If the air is too hot and moving too quickly, the surface of the fish will be damaged and will not dry properly. Fish flesh, like that of other animals, is primarily composed of protein. When proteins are dried too fast, they harden, or “denature” and the skin forms a hard case. When this happens, water cannot escape from the core of the fish and the outside forms a crust. Consequently, the oven must dry the fish slowly enough to prevent this process, called **case hardening**, but fast enough to avoid deterioration caused by bacterial and enzymatic activities. If the surface of the fish is overdried, it will crumble later and smoke color formation will be poor because of inadequate smoke absorption.

If the fish are not properly dried and the fish smoked while too moist, the smoke will not be evenly absorbed, resulting in a “streaky” product. Time is also an important factor in drying. The longer the drying process, the greater the protein degradation.

Smokehouses vary in design and many variables must be taken into consideration. Some of the

important factors are as follows:

- (1) *Air circulation*: The air inside a processing chamber must have a certain velocity and volume to achieve efficient, even processing. The volume of air can determine the distribution of heat and moisture. If the air velocity is too much or too little, the resultant product may be defective. In addition, the air must flow evenly through the product zone. Driving the air for too great a distance will result in uneven processing.
- (2) *Heating and cooling*: An efficient way to heat chamber air must be designed into the system. Optimum design places the heating element directly into the chamber, eliminating heat loss during transfer and using all the heat for processing. The shorter the air flow distance from heating element to processing area, the more efficient the system. Air used in processing must be clean and its heat and moisture content controllable. This can be assured only if the beginning air is free of impurities and by-products of fish cooking.
- (3) *Humidity*: Humidity control is an important but often misunderstood factor in producing smoked fish. Humidity is the water content of air. Relative humidity is expressed as a percentage and measures the water content of air at a particular temperature compared with the maximum amount of water air could hold at that temperature.

The higher the temperature, the more water the air can hold. To have meaning, relative humidity must be expressed as a percentage at a given temperature. To determine wet bulb temperature, take the air temperature with a wet sock placed over the bulb end of the thermometer. The water evaporates off the sock, cools the thermometer, and results in a temperature reading lower than actual air temperature. The drier the air, the faster the evaporation, the quicker the thermometer cools, and the lower the reading. Comparing the difference between the air temperature (dry bulb) and the evaporation temperature (wet bulb) on a prepared scale gives relative humidity. Air must blow at and around the wet bulb at a specific rate (approximately 244 m (800 ft) per minute) to give a correct reading. Also, the wet wick should be kept free of contamination (cleaning chemicals, smoke particles, tar, creosote, or organic vapors) which may retard water evaporation. If the

velocity is too low, there is not enough evaporation and the wet bulb temperature will be too high. If the air velocity is too great, the evaporation will be too fast and the temperature reading too low. Either way, the moisture reading is incorrect.

This discussion brings us back to the importance of air velocity. The product is saturated with water and acts much like the wet bulb thermometer at a specific temperature and air velocity. The location of the wet bulb thermometer during the reading is crucial. If the reading is taken near the supply ducts, it will measure the humidity of the air before it picks up or gives off moisture to the product. If a reading is taken at the exhaust duct, it will measure the humidity of the air after processing has taken place. Every point in the chambers will have a different reading because of evaporation or condensation. Depending on circumstances however, readings eventually equalize.

Because fish products contain a high percentage of water, the effect of the product on the air is as important as the effect of the air on the product. The product gives off or absorbs moisture at a rate dependent on its own temperature and pressure differential. As the product absorbs or gives off heat or dries, that rate changes, even if processing air values stay the same. Thus, the relative humidity, or wet bulb reading, becomes only a guide to the type of air to use. There may be times when it is desirable to reach or even exceed the saturation point of air, called steaming. Moisture condenses on the product, passing its energy content to the product.

Sometimes, dehumidification at a specific point is more important than humidification. It is also possible that a slowly rising or falling humidity over a certain time interval is more important than maintaining a constant humidity. To get this effect, humidity must be removed or added on a time interval rather than at a constant rate. When excess humidity occurs, a dehumidification cycle is automatically initiated to reduce the moisture content of the air in the processing chamber. This dehumidification can be accomplished in a number of ways. The simplest, fastest, and most economical method is to introduce fresh, ambient air into the oven while removing some of the moist air, until the humidity drops to the desired set point. It is important that your system be properly engineered because smoke or air pollution may occur. If the community has stringent air pollution requirements, a small afterburner, electric precipitator, or water scrubber

can be used to further reduce the pollution in the exhaust air.

Another way to dehumidify is with a semiclosed system with water spray dehumidification. A fine spray of water is introduced into a chamber through which the air is recirculated during the dehumidification cycle. The water cools the air, forcing out moisture. There are numerous disadvantages in this system, however. First, the water must be colder than the air at all times, resulting in high water use even if recirculating pumps are used. Second, the smoke is removed by the water spray, causing a reduction in smoke concentration and an increase in water pollution. Third, maintenance requirements are greatly increased because of its costs and limitations.

When temperatures exceed 100°C (212°F), relative humidity readings are not possible. However, air moisture content can still be controlled by adding moisture to the air, and the easiest way to add moisture is steam. Using water droplets or fog can cause water droplets to form on the product. Even when using steam, care must be taken. If the steam is too hot (at pressures over 7 psi), the air will be overheated and unwanted excess condensation will occur, causing spotting, burning, and separation. The air must have time to absorb the moisture introduced. Thus, injections of moisture that are small and fast are preferred over one continuous injection.

## Smoking

Smoking fish, like salting, dates back to early times. Probably smoking was an ancillary benefit in the drying of salt-cured fish over open fires. The smoke contributed a pleasing flavor as well as facilitating preservation. Although many refinements have been made in smoking fish, the overall process retains many of the original attributes. Methods for smoking fish vary greatly, depending on such factors as the type of fish, desired flavor, desired texture, cooking method employed, cultural preferences, and so on.

Today, we make distinctions between smoked and smoke-flavored fish, between hot- and cold-smoked fish, and between the various methods of applying the smoke constituents.

Traditionally, smoke applied to fish came from burning hardwoods such as maple, oak, alder,

hickory, birch, and fruitwoods. Within recent times, apple and cherry wood has been used for imparting fruity flavors; however, there has been only limited information supporting this belief. The best temperatures for the wood are in the range of 250–350°C (482–662°F). Temperatures greater than 400°C (752°F) are to be avoided because of the development of undesirable components in the smoke.

Liquid smoke was prepared as early as the late 1800s, but only within the last 10–15 years has it been commercially used in the smoked fish industry. Even today, smoke-flavored fish represents a small percentage of the total industry output.

The three kinds of smoke-flavor additives are natural smoke extracts, synthetic smoke flavors, and substances unconnected with smoke, such as yeast derivatives, that have a smoky flavor and smell. Smoke-flavored fish, processed using liquid smoke, can be prepared by including liquid smoke in the brine, or applying it as a dip after brining, or as an atomized spray within a modern automatic smokehouse. There is no single recommended method of application; its use depends on the processor's objectives, ingenuity, and facilities. However, recent research suggests that spraying is preferable to dipping as a means of accurately controlling flavor and acceptability. It may be necessary to dry some products after the flavor has been added in order to obtain a texture comparable with traditional products. During spray application, there are several positive results if air is circulated at a low velocity, if air temperature is raised by 5.6–7.2°C (10°–15°F), and if the liquid is injected in short bursts as a fine fog. This method provides improved flavor; a better, more even color throughout the load; faster processing; and less liquid smoke is used, lowering costs.

In general, smoking of fish is carried out as a cold-smoking process or as a hot-smoking process, and the equipment used in either process can be a traditional gravity oven or a modern electric oven.

### Cold-smoking

Cold-smoking is exactly that. The fish are not cooked because the temperature during smoking generally does not exceed 43°C (110°F) and is customarily performed below 30°C (86°F). If the temperature is allowed to rise, the muscle texture could be adversely affected. To maintain the proper tem-

perature during smoking and to ensure uniform drying and desired color, it is necessary to use an indirect source of heat and smoke. Proper cold-smoking often takes less than 24 hours. During cold-smoking, the relative humidity should at first be maintained at about 90% to facilitate smoke absorption but subsequently dropped to about 70% to achieve the required amount of drying. If it is much higher than 70% during the drying period, the drying will be too slow; if considerably lower, the fish will dry too quickly resulting in case hardening and poor smoke absorption. The cold-smoking process is primarily used for salmon. Other traditional cold-smoked items include black cod (sablefish), trout, eel, herring, haddock, and cod.

The curing process may differ slightly since both liquid and dry cures are used. Sugar and salt may be added to the cure mixture. Achieving quality results in cold-smoking is somewhat more difficult than in hot-smoking. Drying, an important part of the process, must be slow and the humidity carefully controlled to attain the desired surface hardening. The drying and cold-smoking process typically requires 18–24 hours.

With traditional gravity ovens it is particularly difficult, if not impossible, to carry out cold-smoking on warm and humid days unless the system is specially modified to cool and dehumidify. Often, heat and smoke are produced separately and then carried to the fish by fan or pipe. Careful temperature controls with thermometers, ventilators, dampers, and fire controls are necessary to achieve a good finished product. Because of the flexibility of control in modern automatic ovens, they are adaptable to cold-smoking. Again, equipment installation is a factor. In most processing plants a number of ovens are required to simultaneously process different items, and equipment cost must be considered.

The temperatures and times used in processing cold-smoked fish are very favorable for the proliferation of food spoilage and food poisoning types of microorganisms. Therefore, particular attention to sanitation, proper brining, limitation of the process to specific product types, careful handling, process control, and prompt refrigeration after smoking are essential. Although the finished product has not been cooked, it has excellent keeping properties because it has been dehydrated sufficiently to retard most bacterial growth. Sliced salmon usually has a shelf life of 21–36 days.

It has been recommended by some health regulatory agencies that cold-smoked products should have a minimum water phase salt concentration of 3.4% to assist in preventing the growth of *C. botulinum*. Following smoking, the product should be either frozen or stored at, or below, 3°C (38°F). Typical weight losses range from 40% to 45%.

Some of the problems in cold-smoked fish are variations in appearance due to biological differences and aquaculture practices, gaping of the fillets, and variations in textural characteristics (Birkeland et al., 2003). The quality of smoked salmon may be improved by freezing the fish before smoking, which results in an increase in product yield and water content, but imparts a softer texture. In cold-smoked salmon, some degradation of texture has been reported as a result of favorable temperature that enhances muscle proteases.

### Hot-smoking

Hot-smoking is the process used in the majority of smoked fish products. A hot-smoked product has been fully cooked and may reach temperatures as high as 82°C (180°F). Because of the higher temperature, hot-smoking takes only a short time, depending on the internal temperature of the product. Different species of fish tolerate heat differently; consequently, the hot-smoke process is not the same for all products. The process must be tailored to the species, the processing equipment used, market demand, distribution considerations, and regulatory requirements. Hot-smoked fish are moist and juicy when properly finished. Because of this, they have a relatively short shelf life and must be refrigerated.

In processing, the intention is to cook the fish as well as smoke it. Processing temperatures used in the industry vary significantly, but like for cold-smoked fish, it is necessary to maintain careful temperature controls and to always use a thermometer to monitor the coldest part of the fish (Dudley et al., 1973; Hilderbrand, 1980). Because elevated temperatures are used in hot-smoking, fish are generally close to the heat source.

The minimum internal temperature for adequate processing of hot-smoked fish has been a major topic of concern for years. Generally, the main considerations when determining process times and temperature are water-phase salt content, use of sodium nitrite, and the use of vacuum packaging.

Proper heating helps to eliminate food poisoning bacteria and to extend the shelf life. Both state and federal regulations that are currently in effect will dictate actual hot-smoked process minimum temperatures. Processors should always consult appropriate regulatory and health sources before the establishment of process times and temperatures. Current guidance from health regulatory agencies recommend a minimum internal temperature of 85°C (185°F) for 30 minutes. Following smoking, the product should be stored at, or below, 3°C (38°F). The product should also contain a minimum water-phase salt concentration of 2.5% if aerobically packaged and 3.5% salt if anaerobically packaged. An aerobic package is one that permits an oxygen transfer rate (OTR) of 10,000 cc of oxygen per square meter at standard temperature and pressure (STP). This can be compared to an oxygen-impermeable package that might have an oxygen transmission rate as low as 100 cc of oxygen per square meter at (STP) (e.g., 2-mL polyester). The most used STP standards are those of the International Union of Pure and Applied Chemistry (IUPAC) and the National Institute of Standards and Technology (NIST) but are far from being universally accepted standards. Other organizations have established a variety of alternative definitions for their standard reference conditions. The current version of IUPAC's standard is a temperature of 0°C (273.15K, 32°F) and an atmospheric pressure of 100 kPa (14.504 psi, 0.986 atm, while NIST's version is a temperature of 20°C (293.15K, 68°F) and an atmospheric pressure of 101.325 kPa (14.696 psi, 1 atm). Typical weight loss during hot-smoking range from 25% to 30%.

In traditional gravity ovens, heat may be produced by charcoal briquettes supplemented with gas burners. The rate of heat application, the type of fuel, and the sequence of its use are variables adjusted by the skilled smoker. Experienced smokers can usually produce acceptable results with these ovens.

Modern smoke ovens, available in many designs and sizes, can be equipped with as much automation as a processor is willing to pay for. Heat is generated by electricity, gas, or oil. The choice is dictated largely by convenience and cost. Heat transferred to the oven is usually in the form of steam and controlled air flow. The ovens can be automatically programmed to conduct a series of sequenced operations to accomplish the necessary drying,



smoking, heating, and cooling. Humidity control and air flow rates during the sequenced operations can also be programmed.

The basic processing cycle includes drying, smoking, and heating. If the fish is dried a little more in the beginning and the humidity is raised a bit in the smoking step, the need for smoke venting to reduce the humidity within the smoke can be eliminated. During cooking, the moisture in the air can be increased to raise the temperature inside the fish. At the end of the cycle, smoke can be vented up the chimney slowly to minimize air pollution problems. You should have the ability to program these functions into your unit.

Electronic advances in modern smokehouses permit exact control of the operation. It requires a skilled smoker and assistance from the equipment manufacturer to carry out the controlled testing necessary to attain the desired program for processing various products. The processing still requires judgment from the smoker because other factors such as brining and fish size must be considered. Because of the control advantages of this equipment, the industry trend is certainly toward greater use of this processing method. Wood is no longer used as a heat source because it is too expensive and makes the moisture content of the air too difficult to control. Most modern machines use steam generated by electricity, oil, or gas, but selecting a heat source is largely a matter of convenience.

### *Smoke generation*

Today's smoke generators are often separate from the processing unit.

The primary function of smoke components is to provide the desirable color, aroma, and flavor of smoked products and to contribute to product preservation by acting as an effective bactericide and antioxidant agent. The kinds and quantities of chemicals present in smoke depend on the type of wood, its water content, the temperature to which it is heated, and the precise manner in which it is heated. For example, there is a difference between smoke produced from slowly smoldering sawdust and from the same sawdust heated to a high temperature by blowing a strong current of air over it.

The different volatile chemical compounds in wood smoke are known to have varying levels of bacteriostatic and bactericidal effects. The effect of smoke on microorganisms is heightened by increas-

ing its concentration and temperature. It also varies with the kind of wood used. It has been reported that the residual effect of smoke is greater against bacteria than against molds. However, the preservative properties are not nearly as important as strict hygienic requirements, modern packaging, and continuous refrigeration.

Aroma and flavor are a blend of smoke components. The influence of wood variety on smoke flavor is caused by the basic pattern of smoke compounds formed during thermal degradation of the wood. Each type of wood gives a different quality or taste and some even make the product inedible. Softwoods may cause flavor problems and are not generally used. Hardwoods are usually used and many times are legally required. Hardwoods result in both good color and good flavor but the process takes longer than when softwoods are used, all other processing factors being equal. The type of wood chosen depends on the product desired and market preference. It is generally considered that phenol compounds and other components soluble in water are the most important factors imparting acceptable flavor in smoked products.

The amount and chemical composition of curing smoke is strongly influenced by the temperature of smoke generation and by smoking technology. The composition of liquid smoke shows an extremely wide variation. During the normal smoking process, the smoke compounds penetrate into the product only a fraction of an inch (a few millimeters), but if liquid smoke preparations or other smoked ingredients are added to the curing mixture, these compounds are found in the center of the product.

Keeping the product at the proper temperature and moisture and carefully controlling the smoke addition are critical points and usually are best controlled by an automatic system that consistently monitors and records these factors. Smoke is acidic and will dry the product and if added at a certain temperature, will denature the product. A high smoke temperature can impart a burned odor and flavor to the product. The concentration of smoke per cubic foot of air has a direct effect on the process; the higher the concentration, the quicker the deposition. It is important that the current of air passing into burning wood or sawdust is not so fast that it carries burned particles (ash) into the smokehouse. Ash should not be allowed to accumulate in large amounts in the boxes where smoke is generated.

### *Composition of smoke*

The deposit of smoke on fish is responsible for the golden color and delightful flavor of the finished product. The color is due to the interaction of carbonyls and phenols with amino components (in particular with lysine, arginine, methionine, and other sulphur-containing amino acids) on the flesh surface. There has been much discussion and much is written about the composition of smoke and the possible side effects on consumers of smoked food products. The physical state of smoke is composed of gases and droplets. Two chemical compounds of special concern are polycyclic aromatic hydrocarbons (PAH) and nitrosamines. Both are considered carcinogenic (cancer causing), the most prominent one is benzopyrene (3,4-benzopyrene has been detected at levels between 0.05 and 0.62 µg/kg), which, nevertheless, may decrease during storage. Eight to nine times 3,4-benzopyrene are absorbed during hot-smoking than during cold-smoking, and PAH levels, as a whole are highest in hot-smoked and extensively cold-smoked products. By using certain techniques (lower temperatures during smoking, and the use of an electrostatic filter, or the use of liquid smoke in place of actual smoking), it has been shown that the polycyclic aromatic hydrocarbons can be reduced.

### Cooling

After the smoking operation, whether cold-smoking or hot-smoking, the product must be promptly cooled. Proper cooling is essential in hot-smoked fish (Eklund, 1982). Hot-smoked products require more cooling, so it is expected that the cold-smoked product will be cooled at least as efficiently.

The finished product should be cooled to a temperature of 10°C (50°F) or below within 3 hours after cooking and further cooled to a temperature of 3°C (38°F) or below within 12 hours. This temperature should be maintained during all subsequent storage and distribution. Smoked fish should never be packaged hot because excessive condensation may form inside the package.

### Packaging

Shipping containers, retail packages, and shipping records should indicate by appropriate labeling the

perishable nature of the product and should specify that the product be shipped, stored, and held for sale at 3°C (38°F) or below until consumed. Permanently legible code marks should be placed on both the outer layer of every finished product package and on the master carton. Such marks should identify, at least, the plant where packed, the date of packing, and the oven load. Records must be maintained as to positive identification of the process, procedures used, and of the finished product's distribution.

It cannot be overemphasized that most smoked fish products, unless canned and sterilized by retorting, have about the same or just slightly longer shelf life than fresh fish. Consequently, smoked fish should be handled, packaged, and stored much like fresh fish. It should be kept frozen or under refrigeration just above freezing temperatures. Vacuum-packed smoked fish makes a beautiful package, but potentially it can be hazardous because the organisms that normally provide visual and odor indications of spoilage are retarded in growth, and certain food poisoning organisms, if present, are favored in outgrowth.

Currently, scientists recommend that vacuum packaging be restricted to cured salmon (lox), cold-smoked salmon (nova), hot-smoked salmon (kippered salmon), and sablefish. These products should be processed with nitrite, have the required water-phase salt content, and meet all prevailing regulations pertaining to heating and cooling. Products should be cooled to 3°C (38°F) before packaging, and packaged products stored at 3°C (38°F) or below, or frozen. The immediate package should be prominently marked with a use-by date.

Noncommercial smoked fish products are popular and are commonly made at home (Crance, 1955; Waters and Bond, 1960; Berg, 1965; Bradley et al., 1977; Richards and Price, 1979); however, the same requirements and safety precautions taken by commercial producers should be observed by home producers.

There are a number of conditions that can result in the creation of a reduced oxygen packaging environment. They include the following:

- (1) Vacuum packaging or modified or controlled atmosphere packaging. These methods directly reduce the amount of oxygen in the package.
- (2) Packaging in hermetically sealed containers or packaging in deep containers from which the

air is expressed or packaging in oil. These and similar processing/packaging techniques prevent the entry of oxygen into the container. Any oxygen present at the time of packaging may be rapidly depleted by the activity of bacterial spoilage, resulting in the formation of a reduced oxygen environment.

An oxygen permeable package should provide sufficient exchange of oxygen to allow aerobic spoilage organisms to grow and spoil the product before toxin is produced under moderate abuse temperatures.

#### *Low-temperature smoking*

Variations in smoked fish products and processing have made it possible to offer smoked-flavored fish that have many of the characteristics of hot-smoked fish with less smoking time and lower processing temperatures (Otwell et al., 1980). *Low-temperature smoking* products require additional cooking before consumption.

#### *Storage, distribution, and sale*

The need for proper refrigeration cannot be overemphasized. The finished product should not be distributed until it has been properly cooled to 3°C (38°F) or below. Furthermore, because of smoked fish's perishable nature, it is imperative that the finished product be maintained in a refrigerated condition at 3°C (38°F) or below until consumed. Most food poisoning outbreaks related to smoked fish have been related to abusive storage temperature conditions.

### **Spoilage and contamination of smoked fish**

Smoked fish is a perishable food, so to maintain its good quality and to prevent food-borne illness, it must be preserved after smoking by processing techniques. Bacteria, yeasts, and molds are microorganisms associated with smoked fish. Organisms of concern that cause infections are *Salmonella* spp. and organisms of concern causing intoxication are *Staphylococcus aureus* and *C. botulinum*. Also of microbiological concern are two parasites, *Anisakis* spp. and *Diphyllbothrium* spp., which can result in intestinal discomfort and other more severe

symptoms. These parasites have been detected in cold-smoked salmon that have not been previously frozen. Freezing fish to -23°C (-9.4°F) or below for 60 hr is sufficient to destroy the parasite; however, other frozen temperatures and times will also result in destruction of the parasites. The most common and obvious causes of smoked fish spoilage are mold growth, with *Penicillium* spp. and *Aspergillus* spp., being most prevalent. These molds grow well at refrigeration temperatures, especially if the moisture content is above 50%. The most common source of mold contamination in smoked fish is the sawdust.

*C. botulinum* is a spore-forming bacterium that has eight toxigenic types based on serological differentiation. Because it forms heat-resistant spores, it is not destroyed by heat as easily as other nonspore-forming bacteria. In addition, *C. botulinum*, Type E, has been shown to grow and produce toxin at temperatures as low as 3°C (38°F). Type E is heat resistant and is nonproteolytic, so its presence in smoked foods is often undetected. In the United States, sodium nitrate plus sodium nitrite at 500 and 200 ppm, respectively, are permitted as a general preservative in smoked salmon, sablefish, and shad to help control *C. botulinum*. As well, sodium nitrite in the range of 100–200 ppm in combination with 3.5% NaCl with a processing temperature of 57°C (134.6°F) for 30 minutes is permitted in smoked chub. Consequently, it is important that proper processing techniques are strictly followed to prevent the rare but potentially dangerous growth of *C. botulinum* in smoked fish.

One of the major bacterium affecting the safety of smoked fish products is *L. monocytogenes*. The organism is not destroyed by cold-smoking operations and hot-smoked fish is contaminated through postprocessing procedures. The major sources of postprocessing contamination are food-contact surfaces, equipment (slicing machines, recirculating injected brine device), and unsanitary practices of plant personnel. Various strains of *L. monocytogenes* are able to grow during vacuum-packed storage at 3°C (38°F). As growth of this organism is capable at low refrigerated temperatures, there may be an increasing infection risk for the consumer if fish are stored for an extended time period. It has been noted that the organism can increase by 4 logs over a 30-day storage period. Combining brining and liquid smoke with a drying (25°C/77°F) step reduced *L. monocytogenes* 10–100-fold over a 24-hour period

in cold-smoked fish. High phenol concentrations are a likely cause of this growth inhibition.

*Vibrio parahaemolyticus* was isolated from cold-smoked mullet and oil sardines. The fish showed relatively high levels of the bacterium suggesting that a small population of naturally occurring organisms could multiply to significant levels during the smoking process or during subsequent storage. Other microflora isolated from smoked fish include *Lactobacillus curvatus*, *Lactobacillus sake*, *Lactobacillus plantarum*, *Carnobacterium* spp., *Leuconostoc* spp., *Serratia liquefaciens*, *Serratia grimesii*, *Enterobacter agglomerans*, *Hafnia alvei*, *Photobacterium phosphoreum*, *Brochothrix thermosphacta*, *Aeromonas* spp., *Micrococcus luteus*, *Pseudomonas* spp., *Alcaligenes* spp., *Staphylococcus sciuri*, *Staphylococcus xylosum*, *Bacillus cereus*, *Raoultella ornithinolytica*, *Bacillus thuringiensis*, *Citrobacter freundii*, *Klebsiella pneumoniae*, *Enterobacter aerogenes*, *Enterobacter cloacae*, *Psychrobacter immobilis*, and *Shewanella putrefaciens* (Lakshmanan et al., 2002; Bjorkevoll et al., 2003; Hsu et al., 2009).

In general, bacteriocins (peptides or proteins produced and excreted by bacteria that exhibit bactericidal activity) of lactic acid bacteria exhibit strong antimicrobial activity against several smoked fish pathogenic bacteria including, *L. monocytogenes*, *S. aureus* and *C. botulinum*. The inhibitory effect is generally restricted to Gram-positive bacteria. Research has shown that by using a combination of lactate and nisin (a bacteriocin) it may be possible to produce more safe cold-smoked fish products with respect to *L. monocytogenes*. Bacteriocin produced by *Carnobacterium maltaromaticum* has been used to eliminate and prevent growth of *L. monocytogenes* in cold-smoked salmon (Nykanen et al., 2000). However, it has been shown that some strains of *L. monocytogenes* have developed resistance to bacteriocins.

### Effect of smoking on composition

The effect of hot-smoking on mackerel (*Scomber scombrus*) did not significantly affect the stability of lipids and polyunsaturated fatty acids. After smoking, there was an increase in thiobarbituric acid value and peroxide value, but the values were still indicative of acceptable quality. The percentages of triglycerides and phospholipids did not change significantly, and free fatty acids could barely be detected. The overall fatty acid composi-

tion remained virtually unchanged after the smoking process. This included the longer chain C<sub>20</sub> and C<sub>22</sub> n-3 fatty acids, now regarded as potentially essential fatty acids for humans. The hot-smoking process caused a significant decrease in protein efficiency ration in male rats when compared to the nonsmoked fish. The change in protein quality was related to the loss of essential amino acids such as lysine and tryptophan. A determination in three layers of the fillet showed that the maximum loss of the amino acids was in the outermost layer.

### Equipment

The smoked fish industry has realized the need for modernization of its physical facilities. Although this industry has been, and continues to be, quite labor intensive, improvements have been made in material handling, processing, and packaging. Among the most evident changes are the expansion and improvements in refrigeration and the transition to sophisticated, programmed, and environmentally controlled smoking ovens. However, gravity ovens are still the traditional means of processing smoked fish in the industry today.

With refrigeration, each freezer and cold storage compartment used to store food should be fitted with an indicating thermometer and should have a temperature recording device installed to show the temperature accurately within the compartment. It also should be fitted with automatic controls for regulating temperature or with an automatic alarm system to indicate a significant temperature change in a manual operation. Thermometers and other temperature measuring devices must have an accuracy of  $\pm 1.1^{\circ}\text{C}$  ( $2^{\circ}\text{F}$ ).

Generally, smoked fish have been processed in a traditional smokehouse or in the more consistent mechanical smoking chamber. Many disadvantages are associated with the traditional smokehouse, which is basically a room with a large chimney to vent the smoke and heat, making uniform temperature and smoke control a problem. Cold spots or hot spots occur, making it difficult to produce a consistent batch. In fact, fish sometimes must be shifted to get an even cook and smoke. In addition, traditional smokehouses depend heavily on climatic conditions, so that a product smoked on a cool dry day will not be the same as a product smoked on a warm humid day. Significant adjustments in cooking time and temperature must be made to



compensate for weather changes. These gravity smoke ovens, a tradition for more than a century, are being replaced by progressively more sophisticated systems.

Modern smoke ovens vary in size, design, sophistication, and, accordingly, cost. They can be used for both cold- and hot-smoking and can be programmed to control temperature, time, humidity, air circulation, cooking rates, cooling rates, and smoke density in an infinite number of combinations and sequences and can clean themselves when they are emptied. In addition, mechanical smoking usually has a separate smoke generator and, consequently, can introduce the correct amount of smoke evenly over the fish. Many times, mechanical smoking can take advantage of electrostatic filters to remove unwanted components in the smoke.

All equipment and utensils used in smoked fish processing plants should be constructed of suitable materials and be designed for adequate cleaning and proper maintenance.

## Dried salted fish

Salt curing is one of the most popular methods of preserving fish that are not stored chilled. Although not a common commercial seafood product in this country, the process has been described as follows (Burgess et al., 1967): lean fish, such as cod, are normally used for dry salting. The first step involves splitting the beheaded fish, usually from head to tail along the backbone, and removing the backbone. By splitting the fish, salt penetration is more easily controlled. Salting is done by stacking the fish in layers, alternating each layer with a layer of salt. The pile should be restacked and resalted periodically, to assure a consistent cure. After the fish have cured this way, they are in the “green cure” state, at which point the water content has been reduced to two-thirds of its original amount and the salt has penetrated throughout the fish and has saturated the remaining fluids. These green cured fish must now be dried to get the final water content down to 25%–38%. The fish are hung to dry either in the sun or in the breeze, or more likely, by artificial means such as warm air circulating within an indoor drying chamber. The final salt content may be as much as one-third the weight of the finished product.

Burgess et al. (1967) give the following description of cured fish. Fatty fish such as herring, mack-

erel, or anchovies are best suited for brining or curing. First, the guts and gills are removed, then the remaining whole fish is packed into barrels or casks, again alternating a layer of fish with a layer of salt. The salt removes water from the fish by osmotic pressure and forms a brine. Removing water from the fish causes the fish to shrink considerably. Consequently, after about 10 days of curing, the barrel must be repacked by first draining off excess brine and then adding additional cured fish to make up for the shrinkage. Additional brine may have to be added to displace air introduced as a result of disturbing the barrel. The barrel is tightly capped and sealed. At this point, the fish have been stabilized and are suitable for storage.

Prasad and Rao (1994) showed that spoilage of salt-cured fish is mainly due to red discoloration (55%) caused by halophilic cocci. The most commonly occurring bacterium in salt-cured fish with red discoloration is *Salinicoccus roseus* (Prasad and Seenayya, 2008). However, the bacterium could be controlled in both crystalline and semiground salt if the salt was heat-treated at 80°C (176°F) for 30 minutes prior to use.

Gram-positive cocci have been isolated in high numbers from salted cod during processing. They were found to be the main bacterial type in fully cured and dried salt cod (Vilhelmsson et al., 1997). Based on sequencing of 16S rDNA and comparison of 700 bases, it was concluded that they should be assigned to the species *S. xylosus*. They were found to be extremely halotolerant, even growing at 4.5 M NaCl. Likewise they grew over a wide temperature range from 8°C to 45°C.

## Dried fish

Scombroid fish such as tuna, mackerel, bonito, and saury that contain high levels of histamine in their muscle are often implicated in scombroid poisoning incidents. However, several species of nonscombroid fish such as mahi mahi, bluefish, herring, and sardine have often been implicated in scombroid poisoning. In the Orient, scombroid poisoning occurs occasionally and the implicated fish are tuna, mackerel, and black marlin. Recently, sailfish and marlin fillets have become the most frequently implicated species in scombroid outbreaks. Dried milkfish (*Chanos chanos*) were examined for the presence of biogenic amines (Hsu et al., 2009).



Except for histamine and cadaverine, the average content of various biogenic amines was less than 8.5 mg/100 g. Most of the tested dried milkfish products (78.1%) had histamine levels greater than the FDA guideline of 5 mg/100 g with some containing >50 mg/100 g.

The incidence of halophilic amine forming bacteria in fresh sardines (*Sardinella gibbosa*) was around 20%, which on salting reached a maximum level of 84% and finally decreased during the drying process (Lakshmanan et al., 2002). No amine-forming bacteria were detected in salt-dried sardines after final drying. *M. luteus* dominated during the salting process, while *Pseudomonas* and *Alcaligenes* species were the major amine forming bacteria during the drying stage. The amine forming bacterial were only able to produce cadaverine and putrescine.

Salt-cured and dried salt-cured cod (*Gadus morhua*) customarily have a short shelf life at 4°C (40°F) due to high bacterial counts. The microbiota develops off-odors that can be described partly as musty, causing rejection within 7–10 days of chilled storage (Bjorkevoll et al., 2003). The dominating bacterium, representing at least 90% of the total viable count in all products studied, was identified as *P. immobilis*. The bacterium was also isolated from cod skin mucus immediately postharvest. The bacterium survived NaCl concentrations up to 25% (w/v) proving its ability to survive the salt-curing processes.

## Pickled fish

Pickled fish rely on salt and the action of acetic acid in vinegar for preserving. Prior to shipping to a packing plant, herring, the most popular pickled fish, are normally cured several days in a 80–90°C brine with 2.5% 120-grain distilled vinegar. They are shipped to the packing plant in barrels with a 70°C brine. The herring may be cut into the desired shape and freshened overnight in water. Prior to packing, the pieces are generally cured 3 days in a solution containing 3% white distilled vinegar and 6% salt. The last step is the final cutting and packing into jars with the desired curing solution.

## Government regulations

Obviously, commercially smoking fish requires that a processor meets all state and federal regulations

applicable to the general food processing industry. The manufacturing of smoked fish products in the United States is subject to the same general governmental regulations as other foods. If the processor's operation is solely intrastate (within a state), then that state's laws apply; if, on the other hand, the enterprise involves interstate (between states) commerce, compliance with both state and federal law is required.

A brief introduction to the regulatory aspects of manufacturing food, and smoked fish in particular, is considered a prerequisite. It is the manufacturer's responsibility to be familiar with the regulations. The laws and regulations governing the seafood industry are discussed in detail in Title 21, Code of Federal Regulations.

In 1969, the FDA promulgated regulations to establish criteria for current good manufacturing practice (sanitation) in manufacture, processing, packing, or holding human foods (21 CFR 128). This regulation soon became known as the Food GMP. Later that same year, the FDA promulgated a food additive regulation entitled "Sodium nitrite used in processing smoked chub." The regulation not only specifies the limits of use of sodium nitrite in smoked chub (100 to 200 ppm in the loin muscle) but specifies other processing requirements for brining, cooking, and cooling that must be followed if sodium nitrite is used in the product.

In June 1986, the "Food GMP," or "Umbrella GMP," as it was known, was revised. This regulation should be familiar to all those currently in the industry or contemplating being in the smoked fish industry. (Note: The FDA has revoked the smoked fish GMP based on a US Court of Appeals decision.)

## Personnel

Compliance with good manufacturing procedures in any food establishment is only as good as that demanded by plant management and supervisory personnel. Food handlers and supervisors should receive appropriate training in proper handling techniques and food protection principles and should be informed of the danger of poor personal hygiene and unsanitary practices. Any person who is ill or has open sores, such as boils or infected wounds, or who might reasonably contaminate food, food-contact surfaces, or food packaging

should be excluded from such operations until the condition is corrected.

All persons working in direct contact with food, food-contact surfaces, and food packaging are expected to conform with hygienic practices necessary to protect the food from contamination. Some of these guidelines are as follows:

- (1) Wear outer garments suitable to the operation.
- (2) Maintain personal cleanliness.
- (3) Wash and sanitize hands before starting work and after each absence from the work station.
- (4) Remove all insecure jewelry and other objects that might fall into the food during preparation.
- (5) Wear impermeable gloves as appropriate and maintain them in an intact, clean, and sanitary condition.
- (6) Do not store clothing or other personal belongings in areas where food is exposed or where equipment or utensils are washed.
- (7) Refrain from eating food, chewing gum, drinking beverages, or using tobacco where food may be exposed or where equipment and utensils are washed.
- (8) Take any other precautions to avoid contamination of foods, food-contact surfaces, and food packaging.

The National Fisheries Institute has produced a videotape on personal hygiene that should be used for training plant workers.

### **Building and facilities**

Although no two smoked fish processing plants are the same, they share a number of characteristics. The buildings and facilities of smoked fish processing plants, like all food processing plants, should meet Good Manufacturing Practice (GMP) regulations. In the GMP, consideration is given to outside grounds, plant construction and design, general maintenance, substances used in cleaning and sanitizing, storage of toxic materials, pest control, sanitation of food-contact surfaces, and the storage and handling of cleaned equipment and utensils. These regulations also extend to sanitary facilities and controls that include water supply, plumbing, sewage disposal, toilet facilities, hand-washing facilities, and rubbish and offal disposal.

### **Plants and ground**

Unloading platforms should be made of readily cleanable materials and equipped with drainage facilities to accommodate all seepage and wash water. In order to prevent cross contamination between raw and finished products, the following processes should be carried out in separate rooms or facilities:

- (1) Receiving or shipping
- (2) Storage of raw fish
- (3) Presmoking operations, including processes such as thawing, dressing, and brining
- (4) Drying and smoking

Cooling and packaging processes must be carried out in a separate room or facility from the storage of the final product. The product should be processed to prevent contamination by exposure to areas, equipment, or utensils involved in earlier processing, or to refuse or other objectionable areas.

### **Sanitary facilities**

Adequate hand-washing and sanitizing facilities should be located in the processing room(s) or in one area easily accessible from the processing room(s). Readily understandable signs directing employees to wash and sanitize their hands must be posted conspicuously in the processing room(s) and other appropriate areas. Debris or refuse should not be allowed to accumulate and should be placed in suitable covered containers for removal at least once a day or more frequently if necessary.

### **Sanitary operations**

Before beginning the day's operation, all utensils and product-contact surfaces of equipment must be rinsed and sanitized. Containers used to convey or store fish should not be nested while they contain fish or otherwise handled during processing or storage whereby their contents may become contaminated. Cleaning and sanitizing utensils and equipment should be conducted in an area designated for these purposes and performed in a manner to prevent contamination of the fish or fish products.

## Quality control

A meaningful quality control program should be in effect in every smoked fish processing operation. The program should be under the supervision of knowledgeable management personnel and should encompass all phases of operation from receiving inspection to finished product quality. Appropriate records should be maintained to document incoming raw material, brining procedures, cold-smoking and hot-smoking procedures used with each fish lot, storage temperature monitoring, and quality control or quality assurance testing. Testing should include both microbiological and chemical examination.

Microbiological examination of in-line and finished product samples should be conducted with sufficient frequency to assure that processing steps and sanitary procedures are adequate. Microbial evaluation should include total aerobic plate count, *Salmonella* count, and coliform count. The finished product should be chemically analyzed often enough to assure that the fish has the proper salinity content and that sodium nitrite, if used, is present at authorized levels.

As the seafood processing industry embraces the Hazard Analyses Critical Control Point (HACCP) concept as the primary method of achieving processing, sanitation, and quality standards, it is evident that this concept will play a major role in the smoked fish industry. HACCP offers a means of assuring consistently produced product that will minimize the microbiological hazards associated with smoked fish through the following.

- (1) Sources of Information on Smoking
- (2) Seafood Network Information Center
- (3) <http://seafood.ucdavis.edu/HACCP/compendium/chapt07.htm>
- (4) Codex Alimentarius Commission
- (5) Recommended International Code of Practice for Smoked Fish

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# 29 **Transportation, Distribution, Warehousing, and Food Security**

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Roy E. Martin

Through the efforts of everyone associated with it, the American food supply has become the best, safest, and cleanest in the world. The public has come to expect such high standards. It thus becomes the everyday responsibility of people in many diverse industries to see that our food is produced, processed, and packed under clean conditions and that it is kept that way throughout the distribution chain. The public health ramifications of handling shipments of food and related products demand that each and every employee accept these as very special categories of commodities and learn to handle them as such.

## **Transportation**

As shippers and receivers, the industry uses truck, rail, and air to move shipments of seafood. The FDA states under its Good Transportation Practices Model Code that establishments engaged in the processing, packing, and storage of human food are subject to comprehensive government regulations which require that the food be prepared, packed, and held under sanitary conditions. With few exceptions, persons engaged in transporting

food are only indirectly subject to these controls. Compliance with the regulations described here should assist those of you in the transportation industry in assuring that foods for human consumption are handled and shipped under conditions that (1) prevent contamination, (2) protect against product deterioration and container damage, and (3) assure that conveyances intended, offered, or used for transporting food are suitable for that purpose.

The criteria in these regulations apply in determining whether conveyances, appurtenances, storage facilities, methods, practices, and controls used in transporting food are in conformance with, or are operated or administered in conformity with, good transportation practices. These regulations apply to all persons engaged in the transportation of human foods, including manufacturers, processors, distributors, common carriers, contract haulers, and private individuals. Conveyances when used solely for the purpose of transporting raw agricultural commodities from the field to a point of initial storage and/or processing are excluded from the requirements of these regulations, provided that special regulations covering these exclusions may be adopted whenever necessary to protect the public health.



FDA defines the following transportable classes of food: (1) "Perishable food" is food which includes, but is not limited to, fresh fruits, fresh fish, fresh vegetables, and other products which need protection from extremes of temperatures in order to avoid decomposition by microbial growth or otherwise; (2) "Readily perishable food" is food or a food ingredient consisting in whole or part of milk, milk products, eggs, meat, fish, poultry, or other food or food ingredient which is capable of supporting rapid and progressive growth of infectious or toxigenic microorganisms; and (3) "Frozen food" is food which is processed and preserved by freezing in accordance with good commercial practices and which is intended to be sold in the frozen state.

Other definitions used in the code include the following:

- *Delivery equipment*: It means any truck, railcar, ship, barge, aircraft, or other conveyance together with its appurtenances, used or offered for the transportation of food.
- *Special purpose delivery equipment*: It means those conveyances that are not designed for general purpose transportation but are built specifically for the handling of foodstuffs and which in themselves may be immediate containers.
- *Storage facility*: It means any warehouse, freight terminal, or other storage facility, including all loading docks and other appurtenances associated with and used in the storage of food during transportation.
- *Carrier*: It is any person who owns, operates, or controls delivery equipment or storage facilities.
- *Shipper*: It is any person of record who initiates the transportation of food from one place to another.
- *Carrier controlled equipment*: It means any delivery equipment, the movement of which is controlled exclusively by a common carrier or contract hauler.
- *Shipper controlled equipment*: It means any delivery equipment which the carrier has assigned to a shipper for his exclusive use.
- *Sanitize*: It means adequate treatment of surfaces by a process that effectively destroys cells of pathogenic microorganisms and substantially reduces other microorganisms. Such treatment

shall not adversely affect the product and shall be safe for the consumer.

- *Adequate*: It means that which is needed to accomplish the intended purpose in keeping with good public health practice.

## Delivery equipment design and construction

All delivery equipment shall be constructed of material that will withstand repeated cleaning and shall be designed to be easily cleaned and to protect the food being handled from dust, dirt, and other contaminating materials. In addition, delivery equipment used or intended for handling perishable food shall be constructed to protect such food from temperatures which may cause or permit damage.

Special purpose delivery equipment used for transportation of processed or partially processed bulk food shall be constructed of smooth, corrosion-resistant, nontoxic materials, and shall be so designed and constructed as to be easily cleanable.

Delivery equipment used to handle readily perishable food requiring refrigeration, in addition to the requirements mentioned, shall be provided with mechanical aeration equipment or other methods or facilities capable of maintaining a product temperature of 45°F (7°C) or below. Delivery equipment used for handling frozen food shall be capable of maintaining the product temperature at 0°F (−18°C) or lower.

Delivery equipment used for delivery of readily perishable or of frozen foods shall be equipped with a thermometer or other appropriate means for measuring and indicating the air temperature in the shipping compartment. The dial or reading element of the temperature-measuring device must be located where it can be easily read from the outside of the conveyance.

## Preloading controls

All conveyances which are under the carrier's control and are offered to shippers for the purpose of transporting food shall, at time of delivery, be in a clean and sanitary condition, be in good repair, and be of adequate design and construction for the intended purpose. The carrier shall take all

reasonable precautions, including the following, to assure that such conveyances will not contribute to contamination or deterioration of food products:

- (1) Effective measures shall be taken to remove and exclude all vermin (including, but not limited to birds, rodents, and insects). The use of pesticides for this purpose shall include precautions to prevent contamination of food or packaging material with illegal chemical residues.
- (2) The interior of each conveyance shall be cleaned as needed to ensure removal of all debris, filth, mold, toxic chemicals, undesirable odors, or any other objectionable condition that may result in the contamination of food. When appropriate to control microbiological contamination, food-contact surfaces shall be sanitized with a safe and effective sanitizing agent.
- (3) All doors and hatches shall be kept in good repair, be tight fitting, and when closed and sealed shall be capable of excluding rodents, birds, and other pests.
- (4) All refrigeration equipment shall be in proper working condition, and capable of holding transported food products at temperatures specified by the shipper.
- (5) Except in the case of assigned equipment, the carrier at the time of delivery shall certify to the shipper that the equipment has been inspected in accordance with and conforms to these regulations. Such inspection records shall be retained by the carrier for 1 year from the date of issuance.

The shipper shall inspect all equipment offered or intended for food loading to determine if said equipment is in acceptable physical condition or whether it contains any potential food contaminant. The shipper shall refrain from loading food into any equipment deemed unacceptable until such time as all noted defects are corrected. When defects noted in carrier-controlled equipment cannot be corrected at the shipper's plant, the shipper shall reject such defective equipment to the carrier, stating the reasons for said rejection. The shipper shall maintain inspection records of all defects that cause equipment to be rejected and shall maintain such records for 1 year.

## Loading controls

Food products to be loaded shall be free from contaminants which may contribute to adulteration during transit of other products in the load or which may result in the contamination of the conveyance.

All packaged food products shall be loaded in such a manner as to minimize physical damage while in transit.

All containers used for transporting food shall be of such design and construction to protect the contents from damage and/or contamination under usual conditions of loading, shipment, and transshipment.

In the loading of food products, adequate precautions shall be taken to minimize contamination of the vehicle through hatches, pipes, hoses, vents, conveyors, or other potential routes of contamination. Food products shall not be loaded into the same vehicle or shipped with fungicides, insecticides, rodenticides, or any other poisonous, toxic, or deleterious industrial chemicals.

Before and after closing doors or hatches of the loaded conveyance, persons responsible for the loading operation shall take all other precautions as may be appropriate to protect the integrity of both the vehicle and its contents.

The transshipment and en route storage of food products should be under such conditions as will prevent contamination and will protect against undesirable deterioration of the product or containers.

## Unloading controls

All incoming conveyances shall be carefully examined upon arrival at the delivery point to determine if doors or hatches are intact and untampered. Where appropriate, the seal numbers of the doors and hatches shall be recorded prior to their removal. Any broken or damaged seals shall be noted and reported to the carrier.

Upon opening and prior to unloading of the food, the interior of the conveyance shall be examined for evidence of any detectable signs of potential contaminants and adulterants including but not limited to insects, rodents, mold, or undesirable odors. This examination shall continue during the entire unloading operation.

Before unloading refrigerated products, the internal temperature of the food products shall be taken and recorded.

A record shall be kept indicating the type and disposition of damaged, adulterated, and deteriorated products or conveyance. Such record shall indicate the disposition of the defective products and/or conveyance.

All food products, dunnage, debris, and other materials connected with the inbound shipment shall be completely removed from the conveyance before returning or releasing such conveyance to the carrier.

### **Special handling and protection of perishable, readily perishable, and frozen foods**

All perishable foods shall be protected at all times from extreme temperatures that may cause or permit damage or deterioration of the food.

All readily perishable food shall be transported and handled in transit at a product temperature of 45°F (7°C) or lower, except that during loading and unloading the product temperature shall not exceed 60°F (17°C). All frozen food shall be transported and handled in transit at a product temperature of 0°F (−18°C) or lower, except that during defrost cycles, loading and unloading such product temperature shall not exceed 10°F (−10°C).

Any variation from these temperature limits due to failure or faulty operation of temperature control equipment during transportation should be reported by the carrier to the nearest office charged with enforcing these regulations.

### **Special concerns: railcars**

Because of the special nature of food, there are now evolving special categories of railcars for use with food shipments. Of particular interest, in relation to these guidelines, is the XF boxcar. This car, specially prepared with an easily cleanable, FDA-approved interior white coating, can be effective in protecting food shipments if it is maintained in good condition. All users of these specialized railcars should realize that extra care in maintaining the condition and cleanliness of this equipment is an investment in protecting the food supply.

Three types of railcars are used to transport food: the free-running car; the car dedicated to food or related-product service; and the car assigned to the

use of a particular shipper. Although there are some differences in the specific responsibilities of shippers, carriers, and receivers when different cars are considered, the basic principles remain the same. A car must be clean and in good repair in order to protect the food.

A **clean car** is free from evidence of vermin infestation (including but not limited to birds, rodents, and insects); and free from debris, filth, visible mold, undesirable odors, and evidence of residues of toxic chemicals. A car in **good repair** should have structurally sound interiors and exteriors, including doors and hatches that are tight-fitting and, when closed and sealed, are capable of excluding rodents, birds, and other pests.

For many new users of railcar service, and for some experienced users, questions arise over who takes responsibility for certain activities involved in transporting food by rail. The following information is intended to provide guidance as to what the shipper, carrier, and receiver is responsible for.

**Ordering a car** is the shipper's responsibility, of course. The shipper should place car orders with the appropriate railroad personnel, specifying in each order:

- (1) type and size of car required (e.g., Class I—50' boxcar, airslide car, etc.);
- (2) the commodity to be loaded;
- (3) whether commodity is bulk or packaged;
- (4) date required;
- (5) location (track and door number if applicable) where car is to be spotted;
- (6) load destination and route (if known).

### **Furnishing car**

Where cars are required for transportation of food or related items, the carrier is responsible for furnishing cars suitable for the intended purpose and for providing cars that are in a clean condition, in good repair, and of adequate design and construction for the intended purpose.

In furnishing free-running cars, the carrier must take necessary precautions to ensure that the car is suitable for the intended purpose. Where cars are dedicated to food or related product category use, the carrier is to furnish cars with doors and hatches closed and sealed.

Although most responsibilities in furnishing cars falls on the carrier, the shipper does assume one

responsibility: where a car is assigned to a shipper's exclusive use, the shipper must inspect and maintain the car in a clean and sanitary condition.

### Car loading

It is the shipper's responsibility to inspect all railcars offered or intended for loading to determine if they are clean and in good repair. Shippers should refrain from loading any railcar deemed unsuitable until such time as all noted defects that may contribute to contamination are corrected. Such defects may include:

- (1) damage to floors, walls, ceilings, doors, and hatches;
- (2) protruding nails or bolts;
- (3) dunnage, trash, or other debris;
- (4) residue of prior loading;
- (5) evidence of contamination by prior toxic material loading;
- (6) vermin infestation or visible mold;
- (7) objectionable odors.

Whenever defects noted in a railcar are not corrected at the shipper's plant, the shipper should reject the defective railcar to the rail carrier, stating the reasons for rejection, and maintain inspection records of all defects causing railcars to be rejected.

The shipper should load only products which are themselves uncontaminated and are free from substances or components which are likely to contribute to contamination of other products in the load during transit or are likely to result in contamination of the railcar. All packaged food products are to be appropriately packaged and loaded in order to minimize physical damage or contamination under reasonable transportation conditions and procedures.

In the loading of products, shippers should take adequate precautions to minimize contamination of the railcar through hatches, pipes, hoses, vents, conveyors, or other potential routes of contamination. They also must see that persons responsible for the loading operation take all other precautions, as may be appropriate, to protect the integrity of both the transportation equipment and its contents. Once the car is loaded, the shipper is responsible for closing and sealing all doors and hatches and then tendering the billing instructions to the carrier.

### Car transporting and delivery

The carrier should remove the car(s) from shipper's siding and transport them to destination with all due care for the integrity of the lading. The carrier must also use reasonable diligence to prevent unauthorized entry into cars and maintain all seals intact and secure all doors and/or hatches.

In the event of derailment or other type of major accident or damage, natural catastrophe (such as a flood), or detection of unauthorized entry into car, it is the carrier's responsibility to notify the shipper and the receiver promptly.

Once the car has reached its destination, the carrier will notify the receiver that the car has arrived and will spot the car according to the receiver's instructions. The carrier will also notify the receiver if a car is in the shipper's assigned service or is dedicated to food or related product category use.

### Car unloading

The receiver is responsible for examining all incoming railcars carefully to determine if doors, hatches, and seals are intact and untampered with. Whoever is inspecting the cars should record the seal numbers of the doors and hatches prior to their removal, and the receiver should note any broken or damaged seals and report such findings to the rail carrier and shipper.

Once these steps are completed, but before unloading begins, the receiver should examine the railcar's exposed interior for any evidence of potential contaminants and adulterants including but not limited to insects, rodents, mold, or undesirable odors. Continue this examination during the entire unloading operation. In the event of notice of contaminants and/or adulterants, the following steps should be taken:

- (1) Notify rail carrier to make an inspection and provide an inspection report.
- (2) Notify shipper for disposition.
- (3) Where the shipment contains contamination or damage which could lead to contamination of the receiver's establishment, do not permit the product to enter the building; in other cases, separate damaged or contaminated product from the remaining load.
- (4) Keep a record indicating the type and disposition of damaged, adulterated, and deteriorated product, and of railcar.

Before releasing a car to the carrier as “empty,” the receiver must completely remove all products, including damaged or refused product, dunnage, debris, and other materials connected with the inbound shipment from the railcar. Two additional steps that should be completed before the car is released to the carrier are (1) reporting all contamination, physical damage, or other conditions incompatible with further use of the car for food and related products to the carrier and (2) replacing and/or securing all bulkheads and other appurtenances that are a part of the railcar.

Once these prerelease conditions are met, the receiver should close all doors and hatches. If a car is in a shipper’s assigned service or is dedicated to food or related product service, the receiver should seal the car after complete unloading.

### Removing empty car and subsequent handling

It is the carrier’s responsibility to determine that the car has been completely unloaded and emptied as required. A car sealed by the receiver is considered to have been completely unloaded and emptied. The carrier should not remove a car if it is not completely unloaded and free from product, dunnage, or other debris.

If the carrier is notified by the receiver that a car contains contamination or physical damage, it must take necessary action for cleaning and/or upgrading the car before returning it to food or related product category use.

### Special concerns: air shipping

With approximately 6 billion lb ( $2.72 \times 10^9$  kg) of seafood currently shipped by air, the air cargo industry is responsible for transporting about 4% of the world’s annual catch of approximately 154 billion lb ( $69.9 \times 10^9$  kg) of seafood. Forecasts suggest that in the coming decades the air cargo industry can expect a growing demand for air shipment of fish and seafood.

Air transport provides the essential link between landlocked communities and the world’s great fishing ports. However, successful air transport of fishery products requires special care in preparation and handling of the shipments, and excellent communication among the shipper, carrier, and con-

signee. This section contains voluntary guidelines developed through the cooperation of the Air Transport Association of America (ATA) and the National Fisheries Institute (NFI) for the handling, packaging, and acceptance of fresh fish and seafood.

Prospective shippers need to keep a number of issues in mind. Narrow-body aircraft are common in US fleets, as are hub airports that may necessitate cargo transfers under tight schedules. In addition, the reliance on combination passenger-cargo aircraft in many markets, as well as volatility in pricing, entry, and exit in all markets can influence the transport of fishery products. Finally, and most importantly, the air shipment of improperly packaged fishery products is a safety hazard because of potential damage to the interiors and control mechanisms of aircraft. In one recorded case, for example, a major US carrier removed an aircraft from service for an entire week, spending \$750,000 to repair damage that resulted from leaking seafood packages.

For prospective seafood shippers, these factors mean that air carriers must seek to eliminate leakage from seafood shipments. In addition, airlines are likely to require shipments packed in light-weight units that can be transferred easily and handled manually within the confines of the smaller aircraft in a carrier’s fleet. Many airlines will prefer gross weight limits of 60–80 lb (27–36 kg), although individual carriers will accept units of 100–150 lb (45–68 kg) or perhaps more.

The air shipping environment is the sum of all conditions affecting a shipment: scheduling, weather, shock variables, handling techniques and equipment, and vulnerability to theft and pilferage. A prospective shipper must follow an approach to packaging, handling, and tendering seafood for air transport that accounts for all aspects of this environment. These ATA/NFI voluntary guidelines seek to assist prospective shippers by guiding them in the selection of packaging materials and development of practices to preserve their perishable but highly valuable cargo in prime condition through air shipment to final destination, and to prevent leakage and damage to expensive aircraft interiors, other cargo, or passenger baggage that may result.

ATA and NFI recognize that many suitable packaging systems have been developed for air transport of fishery products. These guidelines are not



intended to exclude the use of proven shipping containers or those that may be developed in the future. Therefore, if a shipping container that lies outside the scope of these guidelines is being considered, the shipper must communicate with the carrier to establish whether the packaging is acceptable for its intended use.

### General considerations for packing

Whole or dressed fish should be cooled to 32°F (0°C) before packing. Several practices are used to reduce temperatures, including icing, brine chilling, and other chilling methods. Time is a major factor when reducing product temperature because cooling is a gradual process; therefore, random temperature checks are recommended regardless of the cooling method used. By cooling fish, a shipper can slow spoilage and reduce the melting of the refrigerant used in shipping containers.

Prechilling of shipping containers before packing will prevent fish from absorbing heat from the packaging. Take care to avoid overfilling the package, which increases the risk of damaging product, the package itself, and the aircraft during shipment. When packed in shipping containers, all fish should be near 32°F (0°C).

The temperature of packed fish can be effectively maintained but not easily reduced; therefore, packing procedures should be quick and efficient to minimize temperature rise. Coolants, such as gel refrigerants, dry ice, and wet ice sealed in polyethylene bags, should be placed along the bottom and at the top of the container to absorb heat from the outside. Poor placement of coolant will reduce its effectiveness (see Figure 29.1). An absorbent pad should be placed in the package to absorb possible leakage, unless packaging design ensures that liquids cannot escape.

Fish packed for shipment should be placed on vehicles as soon as possible for transport to the airport. If a delay is anticipated, it is recommended that packages be placed in refrigerated storage. However, even when held in refrigeration, the time between packing and shipment should be minimized.

As with whole and dressed fish, handling procedures for fillets should be rapid and well organized. Fillets cut from small and medium-sized fish are

not very thick and although this means that they chill very quickly, it also means that they warm up rapidly as well. The need to precool fillets to 32°F (0°C) before packing is equally important as with whole and dressed fish. In some cases, fillets may be chilled by brief immersion in ice water. Chilling by short exposure to subfreezing temperatures is another satisfactory cooling method, but care should be taken to avoid freezing the fillets.

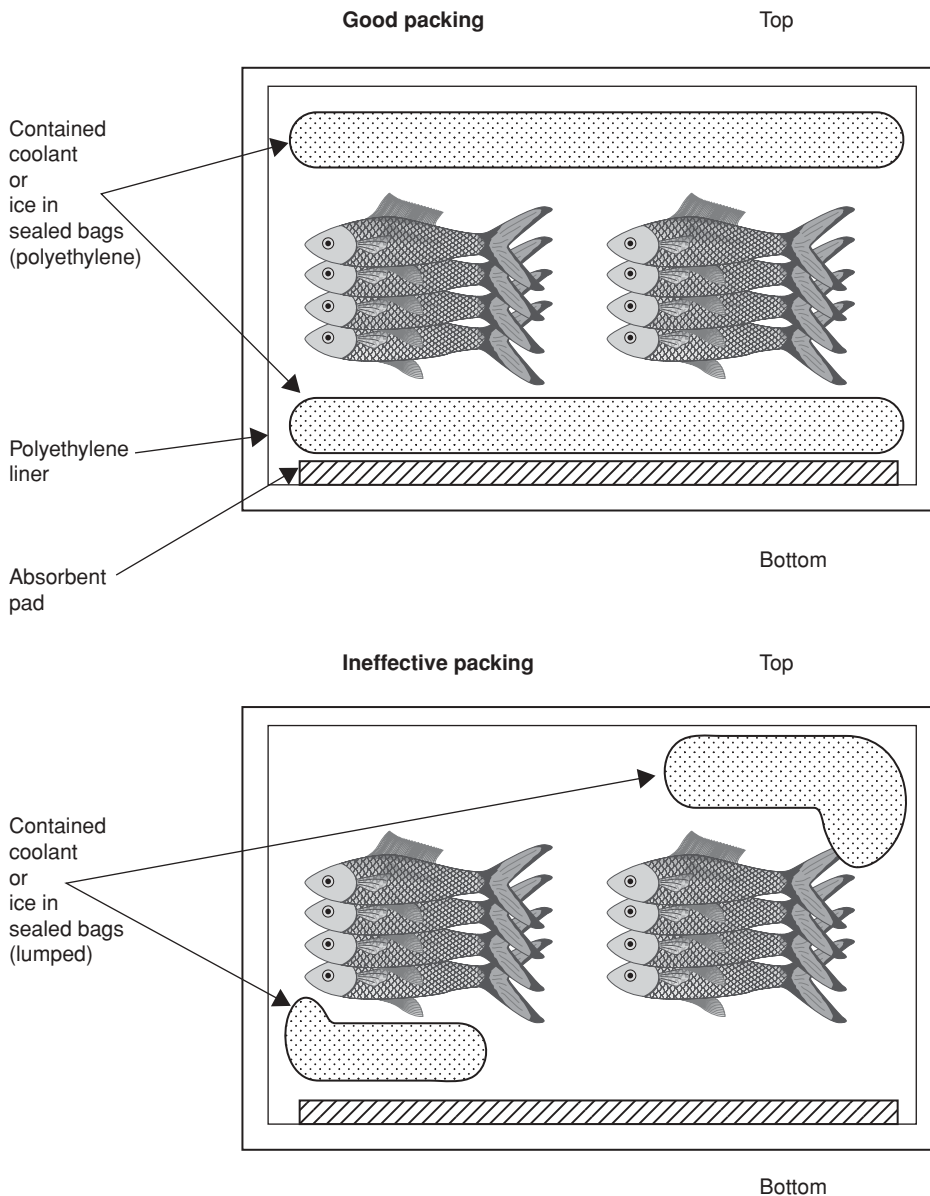
A wide variety of packing materials and styles of packing fillets for distribution are utilized. These include special tubs, tins, and other containers, as well as polyethylene bags, polyethylene sleeves, tray packs, and so on. These styles are all widely accepted for air shipment when they are subsequently packed and handled by methods and in shipping containers similar to those described for whole and dressed fish.

The successful air shipment of live seafood depends on factors similar to those involved in whole/dressed fish and fillets. However, there are some additional considerations because the product is live. For instance, adequate air for live product is essential. **Do not seal bags containing live seafood.**

One general set of conditions applies to the handling and shipping of a wide variety of live seafood, such as crabs, lobsters, crawfish, clams, mussels, and oysters. The method of storing the animals before shipments may vary with the shipper or the species but should in any case be capable of maintaining temperatures between 34°F and 45°F (2°C and 7°C). The cool temperature beneficially slows the body metabolism. Only the healthiest of animals should be selected for shipment.

As with other fishery products, packing procedures should be quick and efficient to minimize handling time and temperature rise. Refrigerants should be placed at the bottom of the containers, and a layer of moist packing material (burlap, seaweed, and synthetic products are common) placed over the refrigerant to protect the animals from direct contact with refrigerant and provide the high relative humidity needed to prevent mortality. Both the packing material and container should be prechilled.

Live seafood should be carefully packed in successive layers. The final layer of animals should be topped with a layer of moist packing material.



**Figure 29.1** Example of proper packaging.

Generally, it is recommended that an additional layer of refrigerant be added before closing the container. Once packed, the same considerations for shipment of whole/dressed fish and fillets apply.

A summary of important handling and packing considerations for all seafood are as follows:

- (1) Select appropriate packing materials according to durability, watertightness, and insulation.
- (2) Prechill product before packing to preserve low temperatures for as long as possible.
- (3) Prechill live seafood to reduce body metabolism. Adequate air for live product is essential. **Do not seal bags containing live seafood.**
- (4) Choose proper cooling media, for example, gel refrigerant, wet ice in sealed bags, or dry ice (check regulatory compliance for dry ice).

- (5) Place cooling media to absorb heat entering package from top and bottom.
- (6) Minimize time between packing and shipment.

### Fish and seafood acceptance by air carriers

#### Acceptable weights per box or carton

Differences in the kinds of aircraft and ground support equipment used by the various air carriers require that each airline has its own limitations on weight and dimensions of acceptable shipments. The most common maximum acceptable weight per box for carriage on passenger aircraft is 150 lb (68 kg); however, many airlines have the capability to accept heavier weights per box or container and some have lower acceptable weights. A shipper's ability to pack in 60–80 lb (27–36 kg) increments facilitates handling in aircraft. In designing containers for heavier weights, provision should be made for a pallet base to accommodate a forklift. Shippers should verify each carrier's limitations on size and weight of containers.

#### Acceptable refrigerants and insulation

Most air carriers prefer that shippers use chemical coolants or dry ice; however, many air carriers will also accept wet ice if it is contained in sealed polyethylene bags. Information on acceptable refrigerants may be obtained from each carrier. (Note: Under normal conditions, wet ice by itself will melt five times faster than chemical/gel type refrigerants.)

The refrigerant used, in combination with insulation, should protect product for the length of exposure to ambient temperatures, taking into consideration the time required for consignee pickup. Additional protection should be provided for shipments requiring transfer to connecting carriers because of longer transit times, possible exposure to higher temperatures, more frequent handling, weather delays, and so on. Every attempt is made to keep seafood shipments refrigerated at airport facilities; however, because of differences in available facilities, refrigeration cannot be guaranteed without specific arrangements, thus making proper insulation essential.

With regard to insulation, the following selected materials are listed in descending order of their

ability to insulate:

- (1) Urethane foam
- (2) Polystyrene foam
- (3) Shredded paper
- (4) Double-wall corrugated cardboard
- (5) Excelsior

(Note: The insulating abilities of materials are additive, so that a packaging system assembled of various components, for example, a fiberboard box with expanded polystyrene inserts, would have insulation properties from the EPS (expanded polystyrene) and a small amount from the fiberboard.)

#### Dry ice

Because it transforms from solid to gaseous carbon dioxide, dry ice has the ability to displace oxygen in enclosed spaces such as aircraft interiors and cargo holds.

Dry ice is, therefore, considered dangerous for goods in air transport, even when used as a refrigerant, and is subject to parts of the governmental regulations controlling dangerous goods. Among these controls are restrictions on placing packages containing dry ice in compartments with live animals, such as pets accompanying passengers.

A shipper who uses dry ice must comply with specific governmental regulations, which specify that packages containing dry ice be designed to permit carbon dioxide gas to escape without rupturing the package. In addition, shippers using dry ice must supply specific information on the air waybill (these special requirements are discussed in detail later) and mark the net quantity of dry ice on each package (see Section "External markings and labeling"). It is strongly suggested that a shipper make advance arrangements with the carrier when the net quantity of dry ice exceeds 5 lb (2.3 kg) per package. This information is essential, as carriers must notify pilots of the presence of dangerous goods and must obey federal regulations restricting the total amount of dry ice to 440 lb (200 kg) per inaccessible cargo compartment. By stating this information on the air waybill and marking it on the outside of each package, shippers enable carriers to determine the total amount of dry ice present in all shipments aboard an aircraft.

## External markings and labeling

Seafood transported as air cargo should be identified on the outside of the carton by markings or labels which state, PERISHABLE SEAFOOD or PERISHABLE FISH.

Arrows, such as the ISO standard arrows or THIS SIDE up markings, should be used to indicate the upright position. Also, packages containing live product should carry special LIVE SEAFOOD warnings for extra care in handling.

It is essential that complete contact information be displayed on the outside of the carton. Contact information should include a 24 hr telephone number for the shipper, which should also be included on the air waybill. Labels should be designed to adhere to the external surface material. Indicate on the outside of the package whether the contents are LIVE, FRESH, or FROZEN.

In addition to the preceding guidelines, there are special dry ice marking requirements. According to governmental regulations, the net weight of dry ice (carbon dioxide, solid) must be marked on the outside of each package in which it is used as a refrigerant, so that carriers may monitor the quantity of dry ice loaded aboard their aircraft. For example, a package containing 5 lb of dry ice should be marked DRY ICE, UN 1845, NET WEIGHT 5 LBS. (Note: Some states require that the name of the species and total weight of each species be stated on the shipping unit.)

Additional marking requirements are imposed in the United States under the Federal Lacey Act Amendments of 1981 (16 USC 3376(a) (2)). These rules require containers of fish to be marked with the term FISH or the common name of the species, and be accompanied with a "readily accessible" document containing the following information:

- (1) Name and address of the shipper and consignee
- (2) Total number of packages in the shipment
- (3) Common name of each species in the shipment
- (4) Number or weight of each species in the shipment
- (5) Country of origin

The term **fish** as defined in the Lacey Act encompasses shellfish as well as other types of fish.

## Banding

Banding and other types of external sealing materials should be designed not to cut or damage the container or other packages with which it may come into contact. Cartons should have a minimum of two bands around the width of each box.

## Factors involved in packaging design

### Inside packaging

Inside the box, the product should be completely enclosed in a sealed polyethylene bag of sufficient thickness to resist puncture and retain liquids. A polyethylene bag of at least 3 mL, or two bags of 2 mL should be sufficient. In special cases, polyethylene bags may be omitted if container design ensures against leakage (i.e., combinations of paper/fiberboard, and molded EPS). In appropriate cases, protective padding, absorbent materials, or wrapping such as seaweed or EPS inserts should be used to assure a puncture-proof inner package. Exposed fins, claws, or other sharp objects should never be in direct contact with an inner bag.

Adequate absorbent material or padding should be used between the sealed polyethylene product bag and the inner wall of the outer packaging, unless packaging design ensures that liquids cannot escape.

Polyethylene bags containing product (excluding live shellfish) should be large enough to overlap and fold closed. Polyethylene bags used for live seafood must not be sealed.

### Outside packaging

Outer boxes should be constructed of corrugated paper board or solid fiberboard. In some cases, the various plies of paperboard should be wax-saturated, impregnated, wax-coated, or treated by other water-resistant processes. Treatments or coatings to the paperboard are necessary to provide wet-strength in case of exposure to moisture. A gusseted style is recommended whenever container design permits.

Containers of molded expanded polystyrene are virtually leak proof. However, the combination of a corrugated box and a molded foam box is recommended. Of course, other methods of combining

insulation, leak proofness, and external strength are acceptable.

Box and container design should take account of the density of the product to be transported. The ability to withstand the strain of dense inside weight is as important as the ability to withstand external compression and strains. External puncture-resistance is critical to assuring that the shipping container will remain leakproof in transportation. The complete package (i.e., the assembly of all package components) should be designed to withstand shock, handling, and stacking to at least five units high without damage to the package. (Note: Governmental regulations require that packages containing dry ice be designed to release carbon dioxide gas. In general, this is not a problem with seafood shipments, since leakproof container designs are not normally airtight. A possible exception is when "barrier" (gas-impermeable) bags are used inside containers of vacuum or modified atmosphere stored shipments; for these packages, dry ice is not recommended.)

### Shipments in unit load devices

Shippers should contact individual carriers for specific policy on accepting and loading shipments packed in large shipping containers (ULDs).

### Transportation from packing house to airport

Complete package design should provide conditions suitable for maintaining the product temperature as near as possible to 32°F (0°C). It is essential that the packaged fish reach the airport quickly. Transporting shipments in refrigerated or insulated vehicles is useful when packages may be exposed to elevated temperatures and/or when long trips to the airport are expected. Packages should be loaded in transport vehicles so as to minimize movement and susceptibility to drop in temperature. In addition, any stacks of seafood packages should be planned to avoid tilted or overhanging boxes that would place undue stress on any package structure. Methods and equipment used to load and unload shipments must protect package integrity.

Although advance arrangements are not essential for all seafood shipments, they are advisable for large loads. The carrier will be better able to accom-

modate such a shipment if advance arrangements have been made.

### Air waybill

Inclusion of a 24 hr telephone number of the shipper is essential on the air waybill, as well as on the container.

Information about the contents of shipments, such as whether the seafood is live, fresh, or frozen should be noted in the "Handling Information" box of the air waybill. Other details, such as in the following examples for use of coolers, should also be stated in the Handling Information box:

- "In case of delay, please refrigerate if available."
- "Hold in cooler for pickup, if available."

Limits of liability are shown in the carrier's "Contract for Carriage" on the air waybill. Such limits vary among carriers, and shippers may wish to declare the value of a shipment for insurance above the carrier's limits. There is an additional charge for such declarations.

### Air waybill requirements for dry ice

Dry ice, when shipped by air, is considered a dangerous good. (See comments on dry ice and special marking requirements for dry ice.)

No "Shipper's Declaration for Dangerous Goods" form (a special dangerous goods air waybill) is required when dry ice is used as a refrigerant. Instead, the normal air waybill must be filled out so that the entry for handling information shows the words "Dangerous Goods-Shipper's Declaration Not Required." The entry for the "Nature and Quantity of Goods" box should describe the seafood and present the following information on dangerous goods (in this sequence):

- (1) Proper shipping name for the dangerous goods, which in this case is either "carbon dioxide, solid (dry ice)" or "dry ice."
- (2) Hazard class or division number for the dry ice, which is "9."
- (3) UN identification number for the dry ice, which is "UN 1845."
- (4) The number of packages containing dry ice.



- (5) Net quantity of dry ice per package.
- (6) UN Packing Group for the dry ice, which is "III."

For example, the entry in the "Nature and Quantity of Goods" box for a shipment of four packages of fresh fish, each containing 5 lb of dry ice, would read: "FRESH FISH, DRY ICE 9 UN 1845, 4 X 5 lbs III."

### Seafood claims

Every effort is made by the air carrier to meet delivery needs and arrival notification within operational constraints. However, if an unforeseen delay or other problem results in a delayed shipment, a consignee should nevertheless be prepared to take delivery and remember that settlement procedures exist for resolution of any claims following final delivery of the cargo. Where there is a potential for a loss, all relevant records should be kept.

### Final delivery

As with tendering to the air carrier from the packing house, timely delivery of the seafood shipment from the air carrier to the consignee is vital to assuring freshness of the seafood and ultimately to assuring customer satisfaction.

### Conclusions

ATA and NFI believe that the use of guidelines described will promote customer satisfaction in the seafood manufacture, packaging, shipping, and air transport industries. With packaging that meets the needs of the air transport environment and with shipments prepared to stay in prime condition through the journey, air carriers can provide the key link to delivering quality products to distant markets.

### Distributors that take ownership of product

To ensure product wholesomeness and proper sanitation, the food distributor must have the commitment of top management, and that commitment must be implemented by operating supervision and supported by the entire food distribution staff. Pre-

ventive sanitation—the performance of inspection, sanitation, building maintenance, and pest control functions designed to prevent insanitation in preference to correcting it—should be an important goal of food distribution management and of food distribution operations.

### Organization and programs

A program to ensure continued success in safeguarding the wholesomeness of food and in providing good sanitation will ordinarily include the following:

- (1) An organizational chart showing chain of authority and responsibility.
- (2) A flow diagram of receiving, storage, and shipping operations.
- (3) Regular maintenance schedules.
- (4) Regular sanitation programs.
- (5) Regular pest control programs.
- (6) An effective program of follow-up and control including reports to responsible executive officer(s).

### Checkpoints and additional guides

#### Grounds

- (1) Keep nearby grounds free of liquid or solid emissions that could be sources of contamination.
- (2) Prevent grounds from providing conditions for insect or rodent harborage.
- (3) Check paving, drainage, weed, and litter control regularly.
- (4) Stack materials which are stored in the open neatly and away from buildings and on racks above ground level where feasible.
- (5) No-vegetation strips around exterior building walls and at property lines adjacent to properties containing potential harborages are helpful for discovering and discouraging travel by rodents.

#### Buildings

- (1) Provide separate and sufficient space for placement of equipment and storage of materials necessary for proper operations.

- (2) Separate activities that might cause contamination of stored foods by chemicals, filth, or other harmful material.
- (3) Check structural conditions, pest barriers, repair of windows, screens, and doors continuously.
- (4) Seal and clean floor—and-wall junctions and fill holes and cracks; a painted inspection strip is also recommended.
- (5) Keep offices, including overhead offices, clean and do not permit them to become attractants or harborage for insects or vermin. Include them in the pest control program.
- (6) Check false ceilings for harborage of insects and possibly rodents.
- (7) Give basements, attics, elevators, and rail sidings special attention.
- (3) If damaged merchandize is accepted, segregate it for special handling.
- (4) Make sure that incoming and outgoing vehicles are free of conditions that could contaminate products; no birds, rodents, insects, spillage, or objectionable odor should be evident.
- (5) At the receiving point, code or mark food received to ensure proper stock rotation.
- (6) To facilitate handling of rejected and suspect product, it is a good idea to develop procedures with individual shippers, carriers, and/or manufacturers for reinspections, returns, and so on.

### Sanitary operations

- (1) Keep walls, ceilings, and rafters free of soil, insect webbing, mold, and similar materials.
- (2) Do not leave unscreened doors and windows open unnecessarily.
- (3) Do not permit dust to accumulate.
- (4) Keep floors free of product spillage, oil drip-page, and buildup in all areas.
- (5) Provide proper trash and refuse storage and removal.
- (6) Store tools and equipment properly.
- (7) Clean and flush floor drains regularly.
- (8) Maintain railroad and truck courts free of debris, and properly patrol them for pest control.
- (9) Keep eating and break areas, locker rooms, and so on, clean and orderly. Vending machines are often overlooked; keep them and adjacent areas clean and sanitary. Maintain equipment in a properly functioning condition and do not permit it to serve as a source of sanitation or harborage problems.

### Receiving and inspection

- (1) Inspect the materials which are being received for evidence of damage; insect, bird, rodent, or other vermin infestation; and moisture, odor, or chemical contamination.
- (2) Exclude contaminated materials, including product, pallets, and slip sheets from the building.
- (1) Store products in an orderly manner and with date codes visible for proper rotation.
- (2) Generally, it is desirable to stack foods on pallets or racks (or on slip sheets, where a clamp truck operation is utilized), and away from walls to allow for inspection aisles between stacks and walls. Painting inspection aisles in a light color is often helpful in maintaining their effectiveness. Where full inspection aisles are not provided, take special care (such as more frequent inspection, rotation, and removal of product for cleaning) to ensure sanitary, pest-free conditions.
- (3) Separate bagged foods to provide visibility between stacks.
- (4) Dispose of contaminated or infested merchandize, or otherwise promptly remove it from the premises.
- (5) Promptly remove damaged merchandize and broken containers from general food storage areas. Handle and process salvageable merchandize separately in an area isolated from general food storage; this area probably will require extra sanitation and pest control attention.
- (6) If salvage operations include the repackaging or other manipulation of exposed foods, conduct such operations in compliance with good food sanitation practices, guidelines, or regulations.
- (7) Do not intermingle chemicals, including pesticides, with food or food products. Such products are best separated by an aisle way.

### Storage

## Pest control

- (1) Maintain written schedules, log activity, and monitor traps and bait stations regularly.
- (2) Use covered bait stations which are of such types and so located as to reduce the danger of spillage; and where appropriate, use moisture-proof bait stations.
- (3) Keep pesticides used in the facility secure and separate from foods. Permit their use only by properly trained personnel. Use only types registered and approved by an appropriate government agency for the intended use.
- (4) Check especially for rodent burrows in nearby grounds, activity at floor-wall junctions and doorways, and insect crawl marks in dust accumulation, especially on overhead pipes, beams, and window sills.
- (5) Where feasible, seal load levelers at docks to prevent trash accumulations and rodent harborage and entry, and clean them frequently.
- (6) Look for insect activity in folds of bagged ingredients.
- (7) Use black light, supplemented with means for distinguishing other chemicals that fluoresce, to check for rodent urine stains; use flashlights to check for other evidence of contamination.

## Shipping

- (1) Make sure that transportation equipment into which food is loaded is maintained in a sanitary condition comparable to that of a food warehouse.
- (2) Make sure that railcars, trailers, and trucks are free of birds, rodents, and insects or contamination from them; are free of odors, nails, splinters, oil, and grease; are free of accumulations of dirt or dunnage; and are in good repair and have no holes, cracks, or crevices that could provide entrances or harborages for pests.

*Follow-up:* Exercise programs of follow-up and control to ensure that your employees, consultants, and outside services are doing their jobs effectively.

## Warehousing

As mentioned earlier, if proper care is not given to good handling and warehousing practices, all the effort put into harvesting and processing will

have been for naught. This aspect of the food handling system is just as important as any other. We begin our study of this subject with the following principles. Ten rules for food warehousemen are as follows:

- (1) Promote personal cleanliness among employees.
- (2) Provide proper toilet and hand-washing facilities.
- (3) Adopt good housekeeping practices.
- (4) Keep food handling equipment clean.
- (5) Reject all incoming contaminated foods.
- (6) Maintain proper storage temperature.
- (7) Store foods away from walls.
- (8) Rotate stock and destroy spoiled foods.
- (9) Do not use or store poisonous chemicals near foods.
- (10) Maintain an effective pest control program:
  - Assign inspection and reporting duties to a dependable employee.
  - Keep buildings insect-, bird-, and rodent-proof.
  - Keep doors closed when not in use.
  - Follow label directions exactly when applying insecticides or rodenticides.
  - Use highly toxic rodenticides only in locked bait boxes.
  - Remove and prevent litter around buildings.
  - Be alert for signs of rodents and insects.

The goal is to protect the public health and avoid economic loss for both warehousemen and customer. The Federal Food, Drug, and Cosmetic Act requires that foods be clean, free from insect, bird, rodent or other animal filth, and chemicals which may render the food harmful to health. Warehousemen have the burden for compliance if they receive, ship, or store foods in interstate commerce. Failure to comply may result in seizure of adulterated foods and prosecution of responsible individuals. FDA inspectors leave a written report of objectionable conditions.

## Buildings and grounds

### Maintain grounds around food warehouses in a sanitary manner

- (1) Maintain the grounds around food warehouse building under the control of the operator in

a well-drained condition, and free from conditions that are likely to lead to contamination of foods in the food warehouse, leaving the warehouse, or being delivered to the warehouse.

- (2) Keep grounds including wharf areas clean and free of discarded equipment, lumber, litter, waste, refuse, and uncut weeds or grasses within the immediate vicinity of the food warehouse which may provide breeding places or harborage for rodents, insects, and other pests.
- (3) Locate outside waste disposal containers on properly drained areas, clean them as needed, and keep them covered between use.
- (4) Maintain and surface driveways, truck aprons, and rail sidings at receiving and shipping areas and parking areas to facilitate good drainage and to minimize dust and dirt being blown or tracked into the food warehouse. Maintain them in a clean, well-drained condition.
- (5) If the food warehouse buildings are closely bordered by grounds not under the operator's control, exercise special care in the food warehouse, by inspection, extermination, or other means, to exclude and control pests, dirt, and other potential contaminants originating from such noncontrolled grounds.

### **Maintain and operate food warehouse buildings and structures in a sanitary manner**

- (1) Provide floors and interior walls which are adequately cleanable and keep them clean and in good repair.
- (2) Suspend fixtures, ducts, and pipes which are over working areas so as to prevent drip or condensate from contaminating food or food packages.
- (3) Maintain adequate separation by location or other effective means for those operations which may cause contamination of foods with undesirable chemicals, filth, or other extraneous material.
- (4) Provide adequate lighting to areas where food is received, stored, held, or assembled for delivery, in order to facilitate handling, processing, and examination of merchandize and to permit adequate inspection, cleanup, and repair of the buildings and their structures.

- (5) Provide adequate lighting in hand-washing areas, dressing and locker rooms (if present), and toilet rooms.
- (6) Employ appropriate special efforts to maintain sanitation whenever necessitated by unique features of structure or design.
- (7) In a food warehouse utilizing light bulbs, light fixtures, skylights, or other glass over exposed food, use safety type bulbs or shielded fixtures to prevent food contamination in case of breakage.

### **Fixtures and equipment**

Provide food warehouse equipment that is suitable as used and maintained and is of design, material, and workmanship which permits it to be adequately cleaned and properly maintained by the methods used at the establishment. Use and maintain the equipment so as to prevent the adulteration of foods with lubricants, fuel, metal fragments, contaminated water, or any other contaminants. Install and maintain equipment in a manner which will facilitate its cleaning and the cleaning of adjacent spaces.

### **Sanitary facilities**

Provide the food warehouse with adequate sanitary facilities and accommodations.

### **Water supply**

From an adequate source, provide water supply which is sufficient for the food warehouse operations.

### **Sewage**

Dispose of sewage into an adequate sewerage system or through other appropriate means.

### **Plumbing**

Install and maintain plumbing of adequate capacity and design and in accordance with applicable governmental sanitation requirements, if any, so as to provide sufficient quantities of water to required locations through the food warehouse, and to

properly convey sewage and liquid disposable waste from the food warehouse.

### **Toilet facilities**

Provide toilet facilities which are adequate, kept in good repair, conveniently located, well ventilated, and are in compliance with applicable governmental sanitation requirements, if any. They should have self-closing doors; and walls, ceilings, and floors which are tight fitting and of a material which can be easily cleaned and kept in good repair. Maintain them in a clean condition, furnish with toilet tissue, and post signs instructing employees to wash their hands with soap or detergent before returning to work.

If toilet rooms are located near areas where exposed foods might be subjected to airborne contamination, provide them with self-closing doors which do not open directly into such areas.

### **Hand-washing facilities**

Provide adequate hand-washing facilities in the toilet rooms or in places convenient to the toilet rooms for hand washing after use of the toilets. Furnish such facilities with hot and cold running water, hand-cleansing soaps or detergents, sanitary towels, or other suitable drying devices.

Provide adequate receptacles, with covers, for disposal of hand-drying articles or waste material. Maintain the washing facilities and the surrounding areas in a clean condition.

### **Dressing and locker areas**

If dressing and locker areas are present, provide them with adequate ventilation and lighting, and maintain them in a clean and orderly condition.

Provide lockers with sufficient ventilation to keep them dry for the retardation of mold and odors, and maintain them in a clean condition, free from trash, food scraps, or litter which serve as insect or rodent attractants. Keep the tops of lockers clean and do not use them as surfaces for the storage of materials.

### **Eating areas**

If there are eating areas in the food warehouse, enclose them adequately or locate them in areas away from operations. Provide adequate space,

light, and ventilation. Clean eating areas regularly, and provide a sufficient number of covered receptacles for disposal of meal trash. Clean such trash receptacles regularly and do not permit them to become insect or rodent attractants.

Clean and inspect vending machines and surrounding areas at regular and frequent intervals to detect and correct unsanitary conditions which may exist. If drinking fountains are provided, locate them conveniently and clean them regularly.

### **Sanitary operations**

Keep buildings and equipment sanitary:

- (1) Maintain buildings, fixtures, equipment, and other physical facilities of the food warehouse in good repair and in a sanitary condition.
- (2) Conduct cleaning operations in such a manner as to minimize the danger of contamination. For cleaning and sanitizing procedures, utilize detergents, sanitizers, and other supplies which are safe and effective for their intended uses.
- (3) Exclusive of packaged products held for distribution, store and use only such toxic materials as are required for necessary activities, such as for maintaining sanitary and pest free conditions; for use in laboratory testing procedures; or for food warehouse and equipment maintenance and operation. Identify and use such products only in such manner and under such conditions as will be safe.
- (4) Use pesticides only under such precautions and restrictions as will prevent the contamination of food and food packaging materials.

Convey, store, and dispose of rubbish in a manner which will minimize the development of odor, prevent waste from becoming an attractant and harborage or breeding place for vermin, and prevent contamination of warehoused food, food containers, ground surfaces, and water supplies.

Another important factor in sanitary operations is the pest control program. It is necessary to follow the following in this regard:

- (1) Establish and maintain positive control programs designed to exclude and eliminate pests from the food warehouse and to deny them harborage, in order to protect against the



contamination of food in or on the premises by animals, birds, and vermin (including, but not limited to, rodents and insects).

- (2) Keep trained security dogs out of actual storage areas to avoid excreta contamination of food stored at floor level. Keep cats out of the food warehouse.
- (3) Implement these programs as an integral part of the construction, maintenance, operational, and personnel programs.

## Procedures and controls

Conduct operations in receiving, inspecting, transporting, handling, segregating, recouping, and storing of foods in accordance with appropriate sanitation principles. Implement overall sanitation under the supervision of an individual assigned responsibility for this function. Take reasonable precautions, including the following, to assure that warehouse procedures do not contribute to contamination of foods by harmful chemicals, objectionable odors, or other objectionable materials:

- (1) *Incoming product shipments:* The integrity of the sanitation program requires that the materials, including foods and their packaging, do not expose the food warehouse to contamination by reason of infestation by insects, birds, rodents, or other vermin, or by introduction of filth or other contaminants. It is often useful to work with suppliers and shippers in advance to establish guidelines for acceptance, rejection, and where appropriate, reconditioning of particular product, taking into consideration factors such as the nature, method of shipment, and ownership of the product, in order to effectively implement these programs:

- (a) Within a reasonable time after arrival of a car or truck and before unloading, the product should be inspected to the extent permitted by the loading of the vehicle for evidence of damage or of insect or rodent infestation, objectionable odor, or other forms of contamination. Where an adequate inspection has not been possible prior to unloading, further inspect such product during and immediately after unloading.

- (b) If damaged product has been accepted, keep it separate and recondition or otherwise handle it as necessary in a manner which will not expose foods or the food warehouse to contamination or infestation.
  - (c) If the inspection reveals evidence of infestation or contamination, determine whether the condition is only "suspect," or is superficial (such as surface infestation of flying insects which may be on, but have not penetrated, soiled, or compromised the integrity of the packaging) and might be fully correctable by fumigation or other means. In each such a case, remove the product from the food warehouse area, utilizing the vehicle in which it arrived, if feasible, after closing and sealing it. In case of contamination, if rejection is appropriate (based on the origin and ownership of the product), promptly notify the carrier and shipper of the time, place, and circumstances of the rejection. After removal from the food warehouse because of suspect and/or superficial conditions, concentrated efforts can be made to evaluate further the actual condition of the product, and to recondition it when possible.
  - (d) Give special attention to product which has previously been rejected, or has otherwise been removed from the food warehouse because of suspect and/or superficial conditions, when it is subsequently received again, to assure that the product and packaging are fully acceptable on reinspection.
  - (e) In the event of serious question, or of a failure to agree with the shipper or carrier as to the condition or reconditioning, consider requesting evaluation of the suspect or rejected product by appropriate federal, state, or local authorities.
- (2) *Store product properly:* Place foods received into the food warehouse for handling or storage in a manner which will facilitate cleaning and the implementation of insect, rodent, and other sanitary controls and will maintain product wholesomeness.
  - (3) *Proper stock rotation:* Adopt and implement effective procedures to provide stock rotation appropriate to the particular food.

- (4) *Contaminated or damaged foods*: Unless promptly and adequately repaired or corrected at or near the point of detection, promptly separate foods which are identified as being damaged or are otherwise suspect from other foods for further inspection, sorting, and disposition. Promptly destroy or remove from the food warehouse any product determined to present a hazard of contamination to foods already in the warehouse.
- (5) *Hazardous nonfood products*. Nonfood products which present hazards of contamination (undesirable odors, toxicity, or otherwise) to foods in the warehouse should be handled and stored in a manner which will keep them from contaminating the foods. Take special measures to safeguard from damage and infestation those foods, which are particularly susceptible to such risks.
- (6) *Avoid damage to packaging*: Exercise care in moving, handling, and storing product to avoid damage to packaging which would affect the contents of food packages, cause spillage, or otherwise contribute to the creation of unsanitary conditions.
- (7) *Shipping*: Prior to loading with foods, inspect railcar and truck and trailer interiors for general cleanliness and for freedom from moisture; from foreign materials which would cause product contamination (such as broken glass, oil, toxic chemicals, etc.) or damage to packaging and contents (such as boards, nails, harmful protrusions, etc.); and from wall, floor, or ceiling defects that could contribute to unsanitary conditions. Clean, repair, or reject them as necessary to protect foods before loading. Exercise care in loading foods to avoid spillage or damage to packaging and contents. Maintain docks, rail sidings, truck bays, and driveways free from accumulations of debris and spillage.
- (8) *Warehouse temperatures*: Maintain warehouse temperatures (particularly for refrigerated and frozen food storage areas) in compliance with applicable governmental temperature requirements, if any, for maintaining the wholesomeness of the particular foods received and held in such areas.
- (9) *Housekeeping, sanitation, and inspection*: Establish a regularly scheduled program of general housekeeping, sanitation, and inspection to maintain floors, walls, fixtures, equipment, and other physical facilities in a state of sanitation sufficient to protect foods from contamination or adulteration, and to prevent waste from becoming an attractant and harborage or breeding place for vermin. In addition, develop and implement an effective program and procedure for timely cleanup of any debris and spillage resulting from accidents or other unscheduled occurrences.
- (10) *Pest control measures*: Implement pest control measures designed to prevent the entrance of pests, to deny them harborage, and to detect and eliminate them. Use scheduled instructions and procedures employing trained and qualified personnel or professional representatives when necessary. Base measures on the nature of the foods and other products handled, the structure and condition of the building and equipment, and the surroundings and environment of the warehouse. Monitor traps and bait stations, whether inside or outside of buildings, on a regular basis. Use covered interior bait stations designed, located, or protected to prevent spillage. Where appropriate, use bait stations constructed of moistureproof material.
- (11) *Pesticides*: Use only pesticides with labels showing USDA or EPA registration numbers, and only for the uses specified in the labeling. Have them applied only by responsible personnel in accordance with manufacturer's labeling instructions and in a manner which prevents contamination of foods. While not in use, clearly mark and store pesticides in a secure place apart from foods.
- (12) *Audit food warehouse sanitation programs*: Establish programs internally and/or through outside consultants for effectively auditing the food warehouse sanitation program.

## Personnel

### Employee practices

- (1) Prohibit employees affected by communicable disease while carriers of such disease, or while afflicted with boils, sores, infected wounds, or other abnormal sources of bacterial infection,

from working in the food warehouse in capacities in which there is a likelihood of food becoming contaminated or of disease being transmitted to other persons.

- (2) Prohibit clothing or other personal belongings from being stored, food and beverages from being consumed, and tobacco from being used in areas where foods are handled or stored.
- (3) Instruct employees who are working in direct contact with exposed or partially exposed foods to maintain personal cleanliness and to conform to hygienic practices to avoid contamination of such foods with microorganisms or foreign substances such as human hair, perspiration, cosmetics, tobacco, chemicals, and medicants. If gloves are used in handling such foods, use only gloves which are of an impermeable material and maintain them in a clean and sanitary condition.

### Management responsibilities

- (1) Assign responsibility for the overall food warehouse sanitation program and authority commensurate with this responsibility to persons who, by education, training, and/or experience are able to identify sanitation risks and failures and food contamination hazards.
- (2) Instruct employees regarding sanitation and hygienic practices appropriate to their duties and locations of their work assignments. Instruct employees to report observations of infestations (such as evidence of rodents, insects, or harborage) or construction defects permitting entry or harborage of pests, or other developments of unsanitary conditions.
- (3) Exercise programs of follow-up and control to ensure that employees, consultants, and outside services are doing their jobs effectively.

### Temperature control and handling practices

#### Foods for freezing

- (1) Quick freezing seldom changes original quality; hence, only sound and wholesome raw materials at an optimum level of freshness should be frozen.
- (2) Freezing should be performed with appropriate equipment in such a way as to minimize phys-

ical, biochemical, and microbiological changes. With most products this goal is best achieved by ensuring that the product passes through the temperature range of maximum crystallization (for most products +30°F to +23°F/-1—5°C) in an appropriate time.

- (3) On leaving the freezing apparatus, the product should be minimally exposed to humidity and warm temperatures and moved into a cold warehouse as quickly as practical and then allowed an adequate dwell time for temperature equilibration.
- (4) Where a processor has his own freezer and warehouse, product should leave the warehouse at 0°F (-18°C) or lower.

### Packaging and identification of frozen foods

- (1) Packaging and outer cases for frozen foods should be of good quality in order to prevent contamination, ensure the integrity of the product during normal transit and storage, and minimize dehydration.
- (2) Package coding should be adequate for effective identification.
- (3) Outer case coding is useful to enable proper stock rotation of individual cases. It can be preprinted on shipping cases, leaving the number to be applied at the moment of packaging, if necessary. It may also be printed on an adhesive label or applied to the case at the moment of packing. Ideally, it should appear on two or three sides of the shipping case.
- (4) Lot, pallet, or unit load identity is useful in enabling loads to be properly rotated while the identity of the load is maintained.

### Warehouse equipment

- (1) Each warehouse should have adequate capacity and should be equipped with suitable mechanical refrigeration to maintain, under anticipated conditions of outside temperature and peak loading, a reasonably steady air temperature of 0°F (-18°C) or colder, in all cold storage areas where frozen foods are stored.
- (2) Each storage area should have an accurate temperature measuring device installed to reflect correctly the average air temperature. Every day the warehouse is open, temperatures of each area should be recorded and dated, and a

file of such temperatures should be maintained for a period of at least 2 years.

### Warehouse handling practices

- (1) The warehouse operator should record the product temperature of each lot of frozen food received and should accept custody only in accordance with good commercial practice. He should retain lot arrival temperature records for a period of at least 1 year.
- (2) Whenever frozen food is received with product temperatures of 15°F (−9°C) or warmer, the warehousemen should immediately notify the owner or consignee and request instructions for special handling. These procedures may consist of any available method for effectively lowering temperatures such as blast freezing, low temperature areas with air circulation, and proper use of dunnage or separators in stacking.
- (3) Before a shipment of frozen food is placed in storage, it should be code marked for effective identification.
- (4) Frozen food should be moved promptly over loading and unloading areas to minimize exposure to humidity, elevated temperatures, or other adverse conditions.
- (5) During defrosting, product should be effectively covered or removed from beneath areas of accumulated frost.
- (6) Frozen food going into a separate breakup room for order assembly should be moved out promptly unless the breakup room is maintained at a reasonably uniform temperature of 0°F (−18°C) or colder.
- (7) As many operations as practicable (casing, palletizing, etc.) should be carried out in the cold storage area to reduce the heat gain and concomitant quality deterioration, energy, and dollar loss resulting from the exposure of frozen product to ambient temperatures.
- (8) If slip sheets are employed, the bottom unit load should be spaced from the floor of the cold warehouse by pallet or other means. To permit air circulation, sufficient space must be allowed between stacks and walls.

### Transportation

- (1) All vehicles used to transport frozen foods, for example, trucks, trailers, or containers, railcars,

ships, and aircraft should be:

- so constructed, properly insulated, and equipped with appropriate refrigeration continuously to maintain product temperature of 0°F (−18°C) or colder;
  - equipped with an appropriate temperature-recording device to measure accurately the air temperature inside the vehicle. The dial or reading element of the device should be mounted in a readily visible position;
  - equipped with tight-fitting doors and suitable closure for drain holes to prevent air leakage;
  - clear and free from dirt, debris, offensive odors, or any substances that could, with reasonable possibility, contaminate the food;
  - precooled prior to loading. The object of precooling is to establish a gradient across the insulation from 0°F (−18°C) on the inner surface to the prevailing temperature on the outer skin. If the interior of the truck is exposed to warm, humid air during loading, precooling is not recommended, since it leads to condensation on internal surfaces.
- (2) Product temperatures should be measured and be at 0°F (−18°C) or colder when tendered to the carrier for loading. The carrier should not accept product tendered at a temperature warmer than 0°F (−18°C).
  - (3) The shipper, consignor, or warehouseman should not tender to a carrier any container which has been damaged or defaced to the extent that it is in unsalable condition.
  - (4) Free air circulation all around the load is essential during transport. Slip sheets should be supported on a pallet (not loaded directly onto the floor of the vehicles) to allow for adequate air circulation under the load.
  - (5) The thermostat on the vehicle's refrigeration unit should be set to maintain an air temperature of 0°F (−18°C).

### Storage on retail premises

- (1) Frozen food storage facilities should be capable of maintaining a reasonably steady product temperature of 0°F (−18°C) or colder. In addition, they should be of sufficient size to provide for proper stock control.
- (2) Frozen food storage facilities should have sufficient circulation of refrigerated air. Cases of

frozen food should be on a pallet or other means of providing adequate air circulation between the bottom case and the floor. To permit air circulation, sufficient space should be allowed between stacks and walls.

- (3) Frozen food storage facilities should be equipped with a thermometer (accurate to  $\pm 2^{\circ}\text{F}/1.1^{\circ}\text{C}$ ) which is easily read and cited to measure representative air temperatures.
- (4) Frozen food storage facilities should be defrosted, as necessary, to maintain refrigeration efficiency.

### Temperature measurement

- (1) *Measuring temperature without opening packages:* Select seven cases of frozen foods. Stack any three of the seven on the floor area of the natural cold environment for the lot being sampled. Cut sidewall of top case (number 3 of stack) at either end with a sharp knife. Bend the cut tab outward. Insert probe of temperature measurement device at about the center of the first stack of packages and between the first and second layers of packages so that all of the sensing element is in firm contact with package walls. Stack the other four cases on top of the case containing the probe. Read and record the temperature observed when the needle gives a steady reading. This is generally 5 minutes or less for a dial thermometer. Close and tape the cut sidewall areas of the case. For solid pack products, cut sidewall of case at either end and insert probe at approximate center of first stack and between the first and the second layers of packages so that all of the sensing element is in firm contact with package walls. For poly bags, insert probe in the same direction as the length of the bag and deep enough for firm contact between bags. For products in paperboard packages with metal ends, turn case on side to give end view, cut sidewall of case, and follow the same procedure as mentioned earlier. For products with an air space between edge of wall of individual carton, cut any side of case and then follow the aforementioned procedure.
- (2) *Measuring temperature by opening packages:* Whenever there is doubt about product temperatures measured without opening packages, the following procedure should be used. (It is also recommended for product packed in cans,

because the bead rim of cans does not allow for firm contact of the probe and sidewall surfaces.) Cut the cover of the case to expose a package or can that is surrounded by other packages. Using a sharp instrument such as an ice pick, punch a hole through the cut portion of the case wall and into the central area of the exposed package or can. Insert the probe so that all of the sensing element is in central portion of package and records steady temperature. Replace the punctured container with a good container from a case reserved for this purpose. Close and tape case cover.

- (3) *Another approach:* Choose a reliable, accurate ( $\pm 1^{\circ}\text{F}$ ) thermometer with a short response time (time required to reach a steady reading) which must be calibrated frequently. Calibration can most easily be carried out by immersing in melting ice ( $32^{\circ}\text{F}/0^{\circ}\text{C}$ ). Mercury-in-glass or alcohol-in-glass thermometers are available with either flat blade or needle probes. Bimetal dial thermometers, which can be easily calibrated, are also suitable. Highly satisfactory digital thermometers are available with either flat blade or needle probes. Before recording a temperature, precool the probe by inserting it between two packets of frozen food and waiting until a steady reading is reached. If the product is a large bulk and an internal temperature is required, precool the drill before boring the hole for the thermometer probe. To obtain a reading, insert the precooled probe into a hole bored in the product or between packets, ensuring that good contact is made with the packages. The temperature of individually quick frozen product exiting from a freezing tunnel is best measured by filling a previously precooled vacuum flask with the product closely surrounding the probe and reading the thermometer when a steady reading is reached.

### Food security guidelines

Operators of food importing establishments should consider the following:

- (1) Preparing for the possibility of tampering or other malicious, criminal, or terrorist actions.
- (2) Assigning responsibility for security to knowledgeable individual(s).



- (3) Conducting an initial assessment of food security procedures and operations, which should be kept confidential.
- (4) Having a crisis management strategy to prepare for and respond to tampering and other malicious, criminal, or terrorist actions, both threats and actual events, including identifying, segregating, and securing affected products.
- (5) Planning for emergency evacuation, including preventing security breaches during evacuation.
- (6) Becoming familiar with the emergency response system in the community.
- (7) Making management aware of 24-hour contact information for local, state, and federal police/fire/rescue/health/homeland security agencies.
- (8) Making staff aware of who in management they should alert about potential security problems (24-hour contacts).
- (9) Maintaining any floor and food flow plan in a secure, off-site location.
- (10) Promoting food security awareness to encourage all staff to be alert to any signs of tampering or malicious, criminal, or terrorist actions or areas that may be vulnerable to such actions, and to report any findings to identified management (e.g., providing training, instituting a system of rewards, building security into job performance standards).
- (11) Having an internal communication system in form and update staff about relevant security issues.
- (12) Having a strategy for communicating with the public (e.g., identifying a media spokesperson, preparing generic press statements and background information, and coordinating press statements with appropriate authorities).

## Supervision

- (1) Providing an appropriate level of supervision to all staff, including cleaning and maintenance staff, contract workers, data entry and computer support staff, and especially, new staff (e.g., supervisor on duty, daily visits by supervisor, two staff on duty at all times, monitored video cameras, one way and two way windows).

- (2) Conducting routine security checks of the premises and critical computer data systems (at a frequency appropriate to the operation) for signs of tampering or malicious, criminal, or terrorist actions, or areas that may be vulnerable to such actions.

## Recall strategy

- (1) Identifying the person responsible, and a backup person.
- (2) Providing for proper handling and disposition of recalled product.
- (3) Identifying customer contacts, addresses, and phone numbers.

## Investigation of suspicious activity

- (1) Investigating threats or information about signs of tampering or other malicious, criminal, or terrorist actions.
- (2) Alerting appropriate law enforcement and public health authorities about any threats of or suspected tampering or other malicious, criminal, or terrorist actions.

## Evaluation program

- (1) Reviewing and verifying, at least annually, the effectiveness of the security management program (e.g., using knowledgeable in-house or third party staff to conduct tampering or other malicious, criminal, or terrorist action exercises and mock recalls and to challenge computer security systems), revising the program accordingly, and keeping this information confidential.
- (2) Performing random food security inspections of all appropriate areas of the facility (including receiving and storage, where applicable) using knowledgeable in-house or third party staff, and keeping this information confidential.

## Personnel

Under Federal law, operators of food-importing establishments are required to verify the employment eligibility of all new hires in accordance

with the requirements of the Immigration and Nationality Act, by completing the INS Employment Eligibility Verification Form (INS Form I-9). Completion of Form I-9 for new hires is required by 8 USC 1324a and nondiscrimination provisions governing the verification process are set forth at 8 USC 1324b.

### **Screening (prehiring, at hiring, posthiring)**

Examining the background of all staff (including seasonal, temporary, contract, and volunteer staff, whether hired directly or through a recruitment firm) as appropriate to their position, considering candidates' access to sensitive areas of the facility and the degree to which they will be supervised and other relevant factors (e.g., obtaining and verifying work references, addresses, and phone numbers, participating in one of the pilot programs managed by the Immigration and Naturalization Service (INS) and the Social Security Administration (These programs provide electronic confirmation of employment eligibility for newly hired employees. For more information call the INS SAVE Program toll free at 1-888-464-4218, fax a request for information to (202) 514-9981, or write to US/INS, SAVE Program, 425 I Street, NW, ULLICO-4<sup>th</sup> Floor, Washington, DC 20536. These pilot programs may not be available in all states), having a criminal background check performed by local law enforcement or by a contract service provider (Remember to first consult any state or local laws that may apply to the performance of such checks).

### **Daily work assignments**

- (1) Knowing who is and who should be on premises, and where they should be located, for each shift.
- (2) Keeping assignment information updated.

### **Identification**

- (1) Establishing a system of positive identification and recognition that is appropriate to the nature of the workforce (e.g., issuing uniforms, name tags, or photo identification badges, with individual control numbers, color coded by area of authorized access), when appropriate.

- (2) Collecting the uniforms, name tag, or identification badge when a staff member is no longer associated with the establishment.

### **Restricted access**

- (1) Identifying staff that require unlimited access to all areas of the facility.
- (2) Reassessing levels of access for all staff periodically.
- (3) Limiting access so staff enter only those areas or have access to only those segments of the operation necessary for their job functions and only during appropriate work hours, including access to data operating systems for purchasing, storing, and distributing imported foods (e.g., using key card or keyed or cipher locks for entry to sensitive areas, color coded uniforms (remember to consult any relevant federal, state, or local fire or occupational safety codes before making any changes)).
- (4) Changing combinations, rekeying locks and/or collecting the retired key car when a staff member who is in possession of these is no longer associated with the establishment, and additionally as needed to maintain security.

### **Personal items**

- (1) Restricting the type of personal items allowed in nonpublic areas of the establishment.
- (2) Allowing in the establishment only those personal use medicines that are necessary for the health of staff and ensuring that these personal use medicines are properly labeled and stored away from food handling or storage areas.
- (3) Preventing staff from bringing personal items (e.g., lunch containers, purses) into food preparation or storage areas.
- (4) Providing for regular inspection of contents of staff lockers (e.g., providing metal mesh lockers, company issued locks), bags, packages, and vehicles when on company property (Remember to first consult all federal, state, or local laws that may be related to such inspections).

### **Training in food security procedures**

- (1) Incorporating food security awareness, including information on how to prevent, detect, and

respond to tampering or other malicious, criminal, or terrorist actions or threats, into training programs for staff, including seasonal, temporary, contract, and volunteer staff.

- (2) Providing periodic reminders of the importance of security procedures (e.g., scheduled meetings, providing brochures, payroll stuffers).
- (3) Encouraging staff support (e.g., involving staff in food security planning and the food security awareness program, demonstrating the importance of security procedures to the staff).

### Unusual behavior

Watching for unusual or suspicious behavior by staff (e.g., staff who, without an identifiable purpose, stay unusually late after the end of their shift, arrive unusually early, access files/information/areas of the facility outside of the areas of their responsibility; remove documents from the facility; ask questions on sensitive subjects; bring cameras to work).

### Staff health

Being alert for atypical staff health conditions that staff may voluntarily report and absences that could be an early indicator of tampering or other malicious, criminal, or terrorist actions (e.g., an unusual number of staff who work in the same part of the facility reporting similar symptoms within a short time frame), and reporting such conditions to local health authorities.

### Visitors (e.g., contractors, supplier representatives, delivery drivers, customers, couriers, pest control representatives, third-party auditors, regulators, reporters, tours)

- (1) Inspecting incoming and outgoing vehicles, packages and briefcases for suspicious, inappropriate or unusual items or activity, to the extent practical.
- (2) Restricting entry to the establishment (e.g., checking visitors in and out at security or reception, requiring proof of identity, issuing visitor badges that are collected upon departure, accompanying visitors).

- (3) Ensuring that there is a valid reason for the visit before providing access to the facility—beware of unsolicited visitors.
- (4) Verifying the identity of unknown visitors.
- (5) Restricting access to food handling and storage areas (e.g., accompanying visitors, unless they are otherwise specifically authorized).
- (6) Restricting access to locker rooms.

## Facility

### Physical security

- (1) Protecting perimeter access with fencing or other deterrent, when appropriate.
- (2) Securing doors (including freight loading doors when not in use and not being monitored, and emergency exits), windows, roof openings/hatches, vent openings and trailer bodies, to the extent possible (e.g., using locks, “jimmy plates,” seals, alarms, intrusion detection sensors, guards, monitored video surveillance (remember to consult and relevant federal, state or local fire or occupational safety codes before making any changes)).
- (3) Using metal or metal-clad exterior doors to the extent possible when the facility is not in operation, except where visibility from public thoroughfares is an intended deterrent (remember to consult any relevant federal, state or local fire or occupational safety codes before making any changes).
- (4) Securing bulk unloading equipment (e.g., augers, pipes, conveyor belts, and hoses) when not in use and inspecting the equipment before use:
  - (a) Minimizing the number of entrances to restricted areas (remember to consult any relevant federal, state or local fire or occupational safety codes before making any changes).
  - (b) Accounting for all keys to establishment (e.g., assigning responsibility for issuing, tracking and retrieving keys).
  - (c) Monitoring the security of the premises using appropriate methods (e.g., using security patrols either uniformed and/or plain-clothed and video surveillance).
  - (d) Minimizing to the extent practical, places that can be used to temporarily hide

intentional contaminants (e.g., minimizing nooks and crannies, false ceilings).

- (e) Providing adequate interior and exterior lighting, including emergency lighting, where appropriate, to facilitate detection of suspicious or unusual activity.
- (f) Implementing a system of controlling vehicles authorized to park on the premises (e.g., using placards, decals, key cards, keyed or cipher locks, issuing passes for specific areas and times to visitors' vehicles).
- (g) Keeping parking areas separated from entrances to food storage and processing areas and utilities, where practical.

### **Storage and use of poisonous and toxic chemicals (e.g., cleaning and sanitizing agents, pesticides)**

- (1) Limiting poisonous and toxic chemicals in the establishment to those that are required for the operation and maintenance of the facility and those that are being held for sale.
- (2) Storing poisonous and toxic chemicals as far away from food handling and storage areas as practical.
- (3) Limiting access to and securing storage areas for poisonous and toxic chemicals that are not being held for sale (e.g., using keyed or cipher locks, keycards, seals, alarms, intrusion detection sensors, guards, monitored video surveillance (remember to consult any relevant state or local fire codes before making any changes)).
- (4) Ensuring that poisonous and toxic chemicals are properly labeled.
- (5) Using pesticides in accordance with the Federal Insecticide, Fungicide, and Rodenticide Act (e.g., maintaining rodent bait that is in use in covered, tamper-resistant bait stations).
- (6) Knowing what poisonous and toxic chemicals should be on the premises and keeping track of them.
- (7) Investigating missing stock and other irregularities outside a normal range of variation and alerting appropriate law enforcement and public health authorities about unresolved problems, when appropriate.

## **Operations**

### **Incoming products**

- (1) Using only known and appropriately licensed or permitted (where applicable) sources for all products.
- (2) Taking reasonable steps to encourage suppliers, distributors and transporters to practice appropriate food security measures (e.g., auditing, where practical, for compliance with food security measures that are contained in purchase and shipping contracts or letters of credit or using a vendor approval program).
- (3) Authenticating labeling, packaging configuration, tamper-evident packaging and product coding/expiration dating systems (where applicable) in advance of receipt of shipment, especially for new products.
- (4) Requesting locked and/or sealed vehicles/containers/railcars, and, if sealed, obtaining the seal number from the supplier, and verifying upon receipt, making arrangements to maintain the chain of custody when a seal is broken for inspection by a governmental agency or as a result of multiple deliveries.
- (5) Requesting that transporters have the capability to verify the location of the load at any time, when practical.
- (6) Establishing delivery schedules, not accepting unexplained, unscheduled deliveries or drivers, and investigating delayed or missed shipments.
- (7) Supervising off-loading of incoming materials, including off-hour deliveries.
- (8) Reconciling the product and amount received with the product and amount ordered and the product and amount listed on the invoice and shipping documents, taking into account any sampling performed prior to receipt.
- (9) Investigating shipping documents with suspicious alterations.
- (10) Inspecting incoming products and product returns for signs of tampering, contamination or damage (e.g., abnormal powders, liquids, stains, or odors, evidence of resealing, compromised tamper-evident packaging) or "counterfeiting" (inappropriate or mismatched product identity, labeling, product lot

coding or specifications, absence of tamper-evident packaging when the label contains a tamper-evident notice), when appropriate.

- (11) Inspecting incoming products for authenticity, packaging/product integrity, and evidence of unauthorized relabeling/repackaging (e.g., shipping cases and described contents not consistent with actual contents) and verifying batch/lot/containers codes.
- (12) Verifying conformance with FDA requirements for product safety, quality, effectiveness, and labeling (may require contact with and verification from the foreign manufacturer/processor).
- (13) Evaluating the utility of testing incoming products and product returns for detecting tampering or other malicious, criminal, or terrorist action.
- (14) Developing and implementing procedures for inspecting shipping containers, vehicles.
- (15) Investigating damage and loss and alerting appropriate authority of discrepancies.
- (16) Rejecting suspect food.
- (17) Alerting appropriate law enforcement and food public health authorities about evidence of tampering, "counterfeiting" or other malicious, criminal, or terrorist action.

## Storage

- (1) Having a system for receiving, storing, and handling distressed, damaged, returned, and reworked products that minimizes their potential for being compromised or to compromise the security of other products (e.g., destroying products that are unfit for human or animal consumption, products with illegible codes, products of questionable origin, and products returned by consumers to retail stores).
- (2) Keeping track of incoming products, salvage products, and returned products.
- (3) Minimizing reuse of containers, shipping packages, cartons, and so on, where practical.
- (4) Investigating missing or extra stock or other irregularities outside a normal range of variability and reporting unresolved problems to appropriate law enforcement and public health agencies, when appropriate.

## Outgoing products

- (1) Ensuring that public storage warehousing and shipping (vehicles and vessels) practice appropriate security measures (e.g., auditing for compliance with food security measures that are contained in contracts or letters of guarantee).
- (2) Performing random inspection of storage facilities, vehicles, and vessels.
- (3) Requesting locked and/or sealed vehicles/containers/railcars and providing the seal number to the consignee (remember to consult any relevant federal, state or local fire or occupational safety codes before making any changes).
- (4) Establishing scheduled pickups and not accepting unexplained, unscheduled pickups.
- (5) Restricting access to distribution process to employees with appropriate clearance.
- (6) Requesting that the transporter have the capability to verify the location of the load at any time.
- (7) Advising sales staff to be on the lookout for counterfeit products during visits to customers and notify management if any problems are detected.
- (8) Investigating missing or extra stock or other irregularities outside a normal range of variation and alerting appropriate law enforcement and public health authorities about unresolved problems, when appropriate.

## Security of water and utilities

- (1) Limiting, to the extent practical, access to controls for airflow, water, electricity, and refrigeration securing nonmunicipal water wells, hydrants, storage, and handling facilities.
- (2) Ensuring that water systems are equipped with backflow prevention.
- (3) Chlorinating water systems and monitoring chlorination equipment, where practical, and especially for nonmunicipal water systems.
- (4) Testing nonmunicipal sources for potability regularly, as well as randomly, and being alert to changes in the profile of the results.
- (5) Staying attentive to the potential for media alerts about public water provider problems, when applicable.
- (6) Identifying alternate sources of potable water for use during emergency situations where



normal water systems have been compromised (e.g., bottled water, trucking from an approved source, treating on-site or maintaining on-site storage).

#### Security of ventilation system (where applicable)

- (1) Securing access to air intake points for the facility, to the extent possible (e.g., using fences, sensors, guards, video surveillance).
- (2) Examining air intake points for physical integrity routinely.

#### Mail/packages

Implementing procedures to ensure the security of incoming mail and packages (e.g., following US Postal Service guidance, locating the mailroom away from food handling and storage areas, securing mailroom visual or x-ray mail/package screening)

#### Access to computer systems

- (1) Restricting access to critical computer data systems to those with appropriate clearance (e.g., using passwords, firewalls).
- (2) Eliminating computer access when a staff member is no longer associated with the establishment.

- (3) Establishing a system of traceability of computer transactions.
- (4) Reviewing the adequacy of virus protection systems and procedures for backing up critical computer based data systems.
- (5) Validating and periodically challenging the computer security system and procedures.

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