INDUSTRIAL FISHERY TECHNOLOGY

A Survey of Methods for Domestic Harvesting, Preservation, and Processing of Fish used for Food and for Industrial Products

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Preface

"Industrial Fishery Technology" aims to give the reader an insight into the operations of the commercial fisheries, especially as currently practiced in the United States. In Part II the major individual fisheries are described and in Part III the principal by-products and industrial products industries are covered. This treatment is followed by Part IV in which the subject is developed from a somewhat different point of view by a description of the principal preservation methods employed in the commercial fisheries.

Whereas some books in this field have covered not only the fisheries but also other products derived from the sea such as solar salt and other minerals, except for a short chapter on seaweed, the present work is restricted to coverage of the major fish products of industrial importance. While some brief consideration is given to world fisheries, the chief emphasis is upon fisheries of the United States.

The book is not intended as a treatise on research in fishery technology. The material in Parts I and V on fishes and fishery methods and on food science applications is included primarily as background information.

As is inevitable with a book written by a large group of specialists, there is some duplication, and certain areas are not covered as thoroughly as are others of perhaps somewhat less importance. Specialists tend to emphasize those areas in which they are especially interested. While these problems are partially overcome by editorial limitations on the fields to be covered, unless the editor imposes his ideas to an unwarranted extent upon the specialist, some duplication as well as gaps in coverage are bound to occur.

Yet some duplication is not entirely valueless. Approaching the same subject from several points of view gives a broader perspective to the processes involved. Thus, although California sardine meal, oil, and solubles are no longer produced in any great volume, a fairly extensive discussion of this field has been retained in the chapter which includes sardines since we should all be interested in the views of the author of this chapter who did so much of the early pioneer development of fish soluble production.

While space does not permit coverage of every fishery, the material in Part II on the description of the major fisheries of the United States covers directly the sixteen leading species on a value basis. Most of the species not directly covered are handled by methods quite similar to those which are included.

MAURICE E. STANSBY

Seattle, Washington
June, 1963

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PART I

Fishes and Fishery Methods

CHAPTER 1

Characteristics of Fishes

DAYTON L. ALVERSON

In the systematic arrangement of animals, fish are grouped in the phylum Chordata which encompasses all vertebrates including lampreys, sharks, bony fishes, amphibians, reptiles, birds, and mammals. The fishes are generally subdivided by taxonomists into two major classes: Selachii and Pisces. The Selachii, which include the sharks, rays, and chimaeras, differ considerably in external shape, but have a fundamental similarity in that all have cartilaginous skeletons with primitive ribs and a complete brain case (condocranium).

In Pisces, or the true fishes, the skeleton is normally bony and comprised of a vertebral column, ribs, and a skull having many distinct bones. Through general use, both shellfish (mollusks and crustaceans) and the whales and porpoises (cetaceans) are at times included with the fishes. However, these animals are structurally far removed from "fin fishes."

Form

Fishes possess a wide variety of external shapes or forms. The most common fish shape is that normally referred to as fusiform, that is, roundish and somewhat compressed and tapering towards the head and tail. The fusiform is considered to offer minimum resistance in water. The Pacific salmon is a good example of this shape (Figure 1.1a).

In some fishes the bodies are greatly compressed such as in the bramids (Figure 1.1b) and sunfishes. Those fishes that are thin and flat are referred to as depressed and include such fishes as the skates and rays. Flatfishes

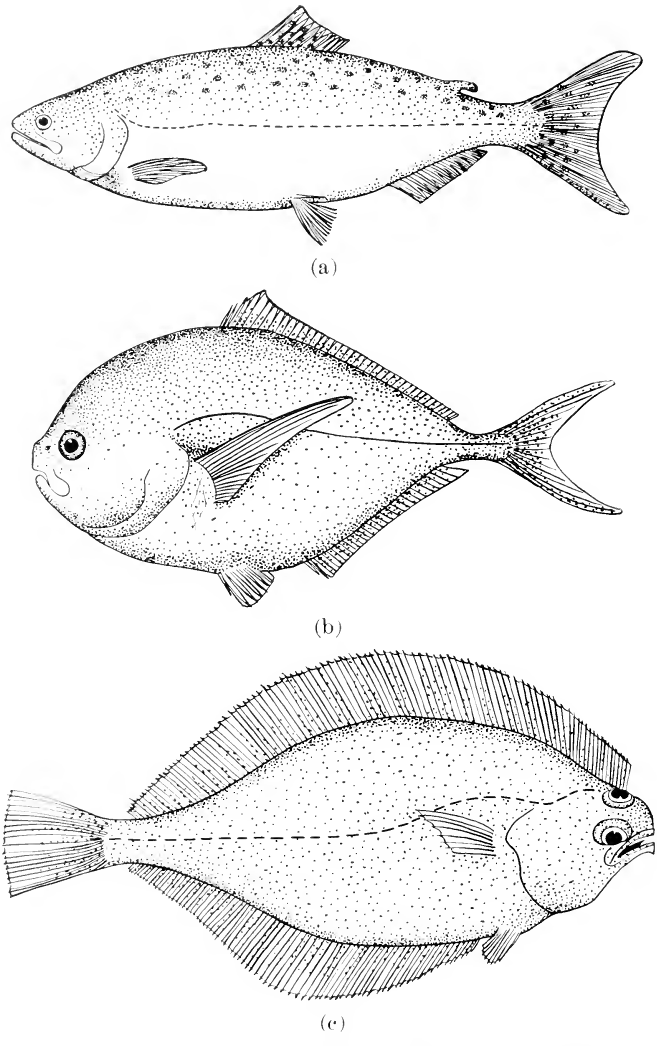
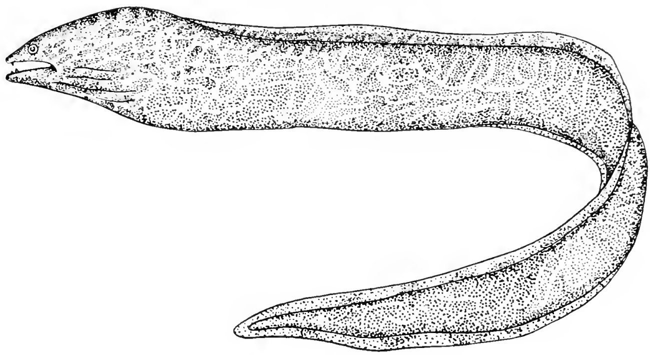


Figure 1.1. (a) King salmon (*Oncorhynchus tschawytscha*). (b) Pomfret (*Brama raii*). (c) Petrale sole (*Eopsetta jordani*).

or flounders are often thought of as being depressed as they appear flat and thin. Actually, these fish are compressed, and the adults orient themselves with one side down during swimming and feeding (Figure 1.1c). In the eels, which are also true fishes, the body is roundish and snake-like (Figure 1.2a).

Fins

The appendages of fishes may be considered analogous to the limbs of mammals. They are normally two pairs of lateral fins: the pectorals which lie just behind or below the gill opening, and the pelvic or ventral fins which lie near the median ventral line. The pelvics may be positioned well back on the fish as in the sharks, herring, and salmon, or forward near the pectoral fins, such as in the tunas (Figure 1.2b). Fins on the



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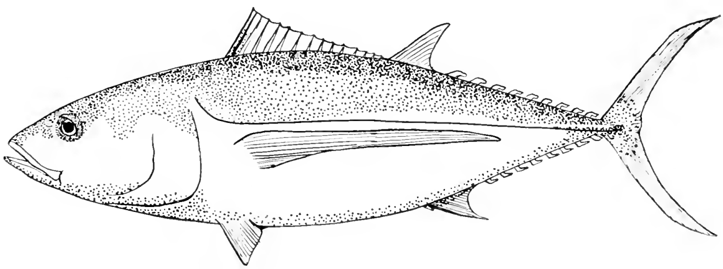

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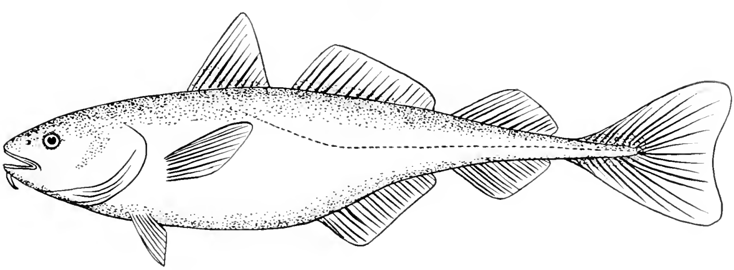

(c)

Figure 1.2. (a) Moray eel (*Gymnothorax mordax*). (b) Albacore tuna (*Germo alalunga*). (c) Pacific true cod (*Gadus macrocephalus*).

median line of the back are termed dorsals, and depending on the species, there may be one, two, or three such fins. Along the median ventral line there may be one or two fins which are termed anals. The tail of the fish is referred to as the caudal fin. Various fins are, at times, absent, depending on the species, or may be (in the case of the dorsal and anal fins) continuous along the back or mid-ventral line. In some fishes such as smelts, trout, and salmon the second dorsal is characterized by a complete lack of supporting rays, the fin being a fleshy protuberance. A fin of this type is referred to as an adipose.

Fins of fishes are characterized by the nature of the supporting rays. Those fishes whose fins lack spiny supporting rays, such as salmon and trout, are called soft-rayed fishes, while those having fins supported partly or totally by spinous rays are referred to as spiny-rayed fishes.

The greatest number of median fins generally occurs in the cod family which has three dorsals and two anals (Figure 1.2c). The clupeoids (herring, sardine, menhaden, etc.) possess only one dorsal fin.

There are a number of adaptations of fins for specialized uses. In the remoras the first dorsal has been modified into a sucker-like disc which the fish utilizes in attaching itself to other marine animals. By contrast, lump suckers have a modification of the pelvic fins which form an adhesive disc. In the trigger fishes (Balistidae) the first dorsal has a strong, stout spine which may be locked into an open position when assuming a defensive posture. In some of the more rapid swimming fishes (tuna and marlin) grooves occur along the median and ventral line into which the dorsal and anal fins may be recessed during swimming. The elongation and enlargement of the pelvic and pectoral fins in flying fishes is an excellent example of specialized use of the paired fins. Although these fins are not used for actual flying in the sense of propulsion, they are employed for gliding or soaring.

A fish generates most of its propulsive power through undulations of the body and rapid lateral motion of the caudal fin in the water. The remaining fins generally serve in balance and turning. However, in some fishes the lateral fins are also utilized for propulsion.

Protective Covering

In the majority of modern fishes the body is covered with scales, although a few are naked. Fish scales vary greatly in shape and size and are usually grouped into two categories: cycloid and ctenoid. Cycloid scales are characterized by smooth posterior margins and are frequently found in fish having soft dorsal fins, such as salmon and trout[4]. Ctenoid scales have comb-like (spinous) posterior margins. They are commonly found in fishes having spinous rays in the dorsal fin. Both types of scales occur on some fishes. In the more primitive, bony fishes such as sturgeon, scales consist of bony plates covered by ganoin (ganoid scales). The protective covering in sharks is in the form of scale plates, each containing a small spine which stands upward or curves slightly back. The scale-like features of the sharks have a dentine base and a spine normally capped with hard enamel. They are formed in a similar manner to teeth and may be considered as minute teeth set into the skin[7]. The scales of sharks are known as placoid scales, and the minute teeth-like structures are referred to as denticles.

Eyes

The eyes of most elasmobranch and teleost fishes follow the normal vertebrate structure. They are provided with a lens capable of throwing an image upon the photosensitive retina, and according to Nicol[11] show the following layers: a felt-work of optic nerve fibers, two layers of ganglion cells separated by a synaptic layer, a basal layer of rods and cones, and the photoreceptors proper.

Fishes generally have their eyes positioned on the sides of the head. However, in some they may be placed in a superior position (on top of the head). Most of the bony fishes are myoptic (adjusted for near vision), and the eyes at rest are set for near vision. It has generally been considered that fishes do not have acute vision. However, there is increasing evidence that the sharks have distant vision (hypermetropia) and may be able to distinguish between the shapes of small objects at a considerable distance.

Of the two types of photosensory cells, the rods and the cones, the rods are most effective at low intensities and the cones, being less sensitive to light, are able to function over a range of higher intensities.

Bony fishes which inhabit areas where wide ranges of light intensities occur have both rods and cones in the eyes. Forms which inhabit dimly lighted areas at great depths may contain pure rod retinas[11]. The eyes of fishes inhabiting dimly lighted regions are considered to be the most sensitive in existence; however, in some of the very deep-water fishes the eyes may be degenerate and the fishes become blind.

Considerable debate has occurred regarding the capabilities of fish to detect differences in color. There seems to be sufficient evidence now to indicate that many species of fish do detect color differences[11], although considerable variation between species may occur in the ranges of colors that can be delineated.

Smell

The chemoreceptors in bony fishes are localized in the nasal pits, forward of the eyes on the dorsal surface of the snout, and in sharks and rays the olfactory pits are located on the ventral surface of the snout. Olfaction in fishes is important in determining certain behavior patterns such as providing clues for orientation, searching for food, and avoidance reactions. Chemoreception in the selachians and bony fishes is highly developed, and experiments have indicated that the fish can detect extremely small differences in concentrations of dissolved substances. Brett and Mackinnon[2] demonstrated that adult salmon were repelled by water in which human hands had been rinsed, and Hasler[6] relates an experiment in which fingerling salmon (*Oncorhynchus*) were capable of detecting solutions of morpholene in concentrations as low as 1×10^{-11} ppm.

Other Sense Organs

Although fishes do not have external ears, an elaborate inner ear (labyrinth) system exists. The labyrinth consists of two vertical and one horizontal semicircular canals which connect to a membrane sac, the sacculus, containing the earbone organs (otoliths). In the bony fishes there is no direct connection with the exterior. However, in sharks and rays there may be an external opening through a small duct.

Lowenstein[10] states the labyrinth has four functions: (1) to maintain and regulate muscular tone, (2) to act as a receptor for angular accelerations, (3) to act as a gravity receptor, and (4) to act as a sound receptor.

The lateral line system in fishes is normally well developed and may be seen along the sides of most fishes. Most often the lateral line can be seen starting back of the gill opening on the flanks of the fish and extending back toward the caudal fin. In some fishes several lateral lines may exist. Although not always detected, branches of the lateral line extend onto the head. The lateral line system acts in a sensory capacity and is considered by most physiologists to be concerned with orientation or "distant touch." Lowenstein[10] states that "In aquatic environment where optic orientation is of reduced accuracy, these organs are capable of supplementing vision by helping to localize objects at a distance. These objects may be moving (prey animals) and thus constitute the focal point of a mechanical disturbance, or their presence and localization may be perceived and computed from the time relations of reflected water waves set up by the swimming movements of the fish itself."

In the sharks and rays there is a system of jelly-filled canals in the rostral region called the Ampulla of Lorezino. The exact function of this canal system is not well understood. It has been suggested that it functions in detecting changes in hydrostatic pressure. There is more evidence, however, that it may be a thermoreceptor.

Reproduction

Fishes may give birth to living young which develop as embryos in the uterus. They may incubate the eggs internally, or they may spawn the eggs into the water where they are subsequently fertilized. In some sharks the embryo is completely developed internally and the female gives birth to fully developed young. The gestation period in sharks is relatively long, and in the dogfish shark (*Squalus*) it may be as much as 20 months. In some of the sharks and rays the embryos are partially developed internally, and subsequently, the female deposits the developing embryo in a capsulated "egg case" from which further development and hatching takes place. In the bony fishes the viviparous perch (Embiotocidae) are an example of a group which gives birth to living young. In the majority of fish, however, the eggs are spawned and fertilization takes place in the water. The number of eggs spawned varies considerably between species and may exceed a million eggs (cods and halibuts). The eggs in some species are deposited directly onto the sea floor (demersal); in others, they may be laid in large sticky masses where they adhere to rocks or plant growth. In many of the pelagic (offshore) fishes the eggs drift freely with currents.

Some fishes such as the Pacific salmon (*Oncorhynchus*) spawn only once and then die; however, the majority of fishes spawn several times, and fishes such as halibut which have a long life span may spawn many times. Generally a female will spawn only once each year, but the peak spawning period of a species may extend over several months.

Air Bladder

Any fisherman or sportsman who has cleaned marine fishes has probably noticed an elongated, double-lobed sac lying close to the back bone in the abdominal cavity. This thin-walled, semitransparent sac is referred to as an air or swim bladder, and it presumably functions as a hydrostatic organ. Fishes living at mid-depths or in surface waters are required to expend energy to maintain their position whenever their body density differs from that of the surrounding water. When a fish moves vertically, it passes through pressure gradients, and thus the gasses in the air bladder are expanded or contracted and the fish's density altered, depending on the direction of movement (up or down). Because of the change in the volume of gasses in the air bladder, the fish then must bring itself back into equilibrium with the ambient water. This is accomplished through exchange of gases across the body wall of the bladder or by means of a duct which connects directly into the gastrointestinal tract. Gases are added when the fish moves into depths of higher pressure, and gases are removed when the fish travels to regions of less pressure. Through the function of the air bladder, the fish is capable of maintaining energy expenditure. The air bladder also functions as a sound receptor, and in some fishes as a sound producer, as a lung, and in sensory functions[8].

Respiration

The gills of fishes are analogous to the lungs of higher vertebrates and serve as an organ of respiration. Free oxygen enters into the circulatory system, and carbon-dioxide is expelled through the slender gill filaments.

Migrations

The migrations of fishes is a topic which is of considerable interest to the general public, and the homing of salmon to parental streams is well known even to the school boy. In recent years it has been found that the Pacific salmon (*Oncorhynchus*) inhabit the ocean waters at great distances from shore through most of their marine life, and on approaching maturity migrate vast distances to the rivers of their birth. Although homing is well developed in the salmon, some straying to other streams does occur. The king salmon is known to migrate even to headwaters of large rivers such as the Columbia, Yukon, and Sacramento. Fish such as salmon, and shad (*Alosa sapidissima*), which migrate up rivers to carry out spawning are referred to as anadromous forms, and fish such as the eel (*Anguilla*) which migrate from fresh water to salt water to spawn are referred to as catadromous.

Although the homing of salmon to their parental stream is one of the most often discussed migrations of fishes, many marine forms show similar spectacular migratory patterns. Atlantic cods undertake extensive migrations. Such migrations include movements to and from nursery or feeding areas and distance migrations such as from West Greenland to Iceland and from the Norwegian Coast to the Berents Sea[12]. For some of the tunas the migrations may be transoceanic. Albacore (*Thunnus alalunga*) tagged off the Pacific Coast of the United States[3] have been recovered off the coast of Japan. Not all tunas, however, seem to display extensive migrations. The yellowfin (*Neothunnus macropterus*) of the eastern Pacific do not appear to be involved in transoceanic movement. At least one species of Pacific flounder, *Eopsetta jordani*[1], has been noted to undertake rather extensive migrations along the coasts of Washington (U.S.) and British Columbia (Canada), the movement being north in the summer and south during the winter months. There is some evidence that the adults of this species may return each year to the same spawning area. Sharks may also undertake long migrations, and there is at least one record of a dogfish shark (*Squalus*) tagged off the Washington coast subsequently being recovered off Japan[9].

Although geographic migrations of the type noted above are the best documented movements of fishes, a number of species are known to undertake seasonal vertical movements, and in some, large-scale diurnal vertical movements occur. The Dover sole (*Microstomus pacificus*) may move from relatively deep water along the continental slope (200–400 fathoms) in the winter, to the shallower water (60–150 fathoms) of the continental shelf and upper slope during the summer months.

The patterns of migration of fishes vary considerably between species, and may vary within species, depending upon age. Among bottom fish there is a general "rule of the thumb" that the larger, older fishes will inhabit deeper waters than the young (Heinckle's Law). There are many causative factors responsible for fish movements. Local movements may be related to changing physical or chemical conditions in the ocean or varying food supplies[5]. The homing of fish to certain areas for spawning is probably most closely related to the need to provide a requisite spawning media for the developing egg.

The patterns of migration and behavior of fishes may have considerable influence on fisheries which seek to harvest them. Some of the more pronounced migratory patterns such as the movement of adult salmon, shad, and other species to fresh water make them easily accessible to man. Similarly, in ocean fishes the seasonal movement of fishes along coastal areas and the movement of fishes into inshore areas for spawning are patterns which have made these species susceptible to harvest. In addition to migrations, patterns of distribution play an important role in fish harvest. Those species which aggregate into large schools such as herring, cods, tunas, etc., can be taken in large quantities. However, those species which are dispersed through much of their adult life are more difficult to harvest and must generally have a high market value if they are to come under exploitation.

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CHAPTER 2

Conservation of Marine Resources

A. T. Pruter

The term "conservation" as applied to a living resource, such as fish or shellfish, has an entirely different meaning from that applied to a nonliving resource such as minerals or oil. The latter are nonrenewable. Man must exploit them with reserve, recognizing that once used they cannot be restored.

In contrast, failure to use a living resource is to waste it. If not utilized by man, fish eventually die of old age or other natural causes. They are continually being replaced by new individuals. As long as enough adult fish are left to perpetuate the species, the surplus can be harvested.

The generally accepted objective of conservation of a living aquatic resource is to maintain the populations at levels which provide maximum yields to man on a sustainable basis. This involves balancing removals by man and losses from natural causes with additions to the populations from recruitment of new individuals and their growth in weight. The problem is complicated because populations differ in their rates of removal and additions. Thus, conservation must be adapted to each population according to its particular rate of recruitment, growth, and mortality.

Need For Conservation

Soon after intensive fishing activities began in this country, it became clear that man could over-exploit marine resources. Populations of Atlantic and Pacific salmon have been decimated by man. Intensive sealing activities twice brought the fur seal of the North Pacific to the verge of extinction. As early as the 1920's it was evident that the Pacific halibut was becoming over-fished. Some of our beaches have been denuded of clam and oyster resources.

Future needs for conservation will be even more pressing than in the past. The population of the world is expected to increase by 1.2 to 1.6 billion people by 1980. Some of the food required to feed this increased population must come from the sea. For the United States alone it is estimated that by 1980 we will require an additional 2 to 3½ billion pounds of fish and shellfish annually.

Our increase in human consumption of marine products during the past 20 years has been satisfied by importations, but we cannot depend on imports to take care of future increases in our needs. Other countries may soon have to use all they can harvest from the sea to feed their own peoples. Many of our present fisheries already are being exploited to or beyond their maximum productivity. Consequently, we will have to expand our harvest of presently underfished resources and begin harvesting unfamiliar species. This will create a multitude of conservation problems.

Theory of Fishing

Four primary factors determine the size of any exploited marine population. They are: recruitment of new individuals, growth, deaths due to natural causes, and deaths due to fishing. By harvesting the resources, man directly determines the last factor. His actions also may indirectly affect the others since they are often interdependent.

In the unfished state, population levels are in balance with their environment, and growth and reproduction are balanced by deaths from natural causes. Consequently, when fishing begins, most of the yield is derived from the accumulated population. Sharp initial declines in population size are inevitable since there is no immediate acceleration in the compensating forces, namely, reproduction, growth, and recruitment of new fish to the fishable stock. These initial declines in population size sometimes are mistakenly attributed to over-fishing.

After the fishery has operated for some time, lowered natural mortality, accelerated growth, and increased recruitment will bring the population into a new state of equilibrium. Increased growth rates result from the fewer remaining fish having more food available per individual. Reduction in crowding of the population also may lower disease and parasitic infestations and thus provide a higher survival rate for the remaining individuals.

The harvest will increase with increasing fishing intensity to the point of maximum average catch. Beyond this point the sustainable catch actually decreases with increasing fishing effort (Figure 2.1). By applying the appropriate amount of fishing effort, a population may be stabilized at any level of density between its environmental maximum and near-extinction. At each population level it can provide a particular level of yield. Populations about midway between near-extinction and virgin

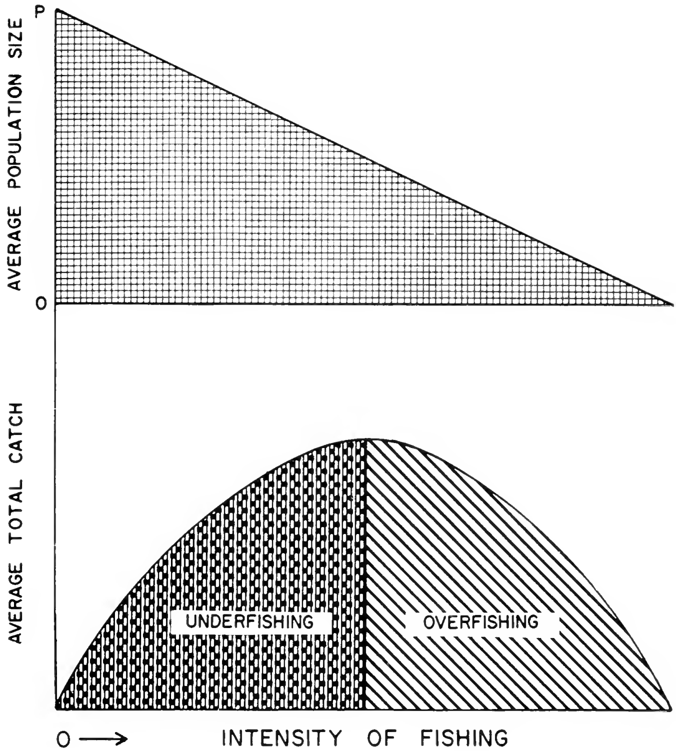

Figure 2.1. Relations between fishing intensity, population size, and average sustainable total catch from a fish population. After Schaefer from Encyclopedia of Science and Technology, 1960. (*McGraw-Hill Book Co.*)

levels generally are believed to be those capable of providing the maximum sustainable yield[5]. Therefore, maximum sustainable yields may be obtained by regulating the amount of fishing to bring the populations to these "mid-levels."

If stable environmental conditions exist, once the optimum percentage of the population available for harvesting is exceeded, the sustainable catch not only decreases but the costs of production increase. With prolonged over-fishing, costs of production may exceed the value realized from the catch. This usually prevents over-fishing of a population to the point of extinction.

Management

Living resources of the sea are common property, open to all who care to exploit them. They are important sources of food and recreation for the entire country; it is, therefore, to the public's best interest that they be managed to provide their maximum sustained productivity.

Many marine species occur in extraterritorial waters and are exploited by fishermen of several nations. Others are highly migratory, traveling freely from waters of one nation to those of others. Management of such species often requires conservation treaties among the nations concerned. These treaties usually establish international commissions to effect the rational use of the resources.

Whether a fish resource is confined to estuarine waters or to the high seas, the objective of management is the same, namely, to obtain the maximum sustainable catch. There are several ways control agencies may accomplish this. The most direct way is through annual catch quotas or restrictions on fishing intensity. Other management devices commonly used include: minimum size limits which serve to protect the young, fast-growing fish; closure of nursery areas to fishing; seasonal restrictions to protect spawning populations which may be particularly vulnerable to fishing during spawning activities; and restrictions on types of fishing gear that may be used.

Successful management of a marine resource requires detailed knowledge concerning the life history of the species concerned. For example, is the species resident or migratory? At what age and size does it first reproduce? Is it particularly vulnerable to fishing during its reproduction season? What is the relationship between the numbers of spawners and the numbers of surviving offspring produced by them? What is the rate of growth of different segments of the population? What fraction of the population is dying from natural causes and what fraction is removed by fishing? What is the size of the population? Answers to all these questions and more are required to successfully manage a resource.

Since World War II much progress has been made in developing methods of obtaining answers to these questions. New analytical approaches have evolved which greatly contribute to our understanding of the complex mechanisms governing populations of marine organisms. Investigators now have a number of methods available from which to choose those best suited to the population they are studying.

Fluctuations in Abundance

Many marine species of fish and shellfish are characterized by large, and often unpredictable, fluctuations in abundance. Since the livelihood of fishermen depends upon an adequate supply of fish for harvesting, these fluctuations are of grave concern. During periods of poor fishing entire communities suffer.

Fluctuations in abundance occur from natural causes and from man-made causes. A great amount of study has been devoted to evaluating the relative effects of man-made factors and natural factors on the abundance of marine species of fish and shellfish. There is agreement that man's impact upon the stocks has introduced an additional element into the already complex and fluctuating conditions under which a species may exist. Differences of opinion as to the relative weight that should be placed upon man's impact as opposed to changes brought about by natural causes chiefly arise from incomplete knowledge concerning the species in question.

Natural Causes *Changing Availability to Capture.* For some species drastic changes in catches occur from year to year as a result of changing availability of the fish to capture. This may arise when a population changes its normal migratory route. Wide variations in year-to-year catches of albacore tuna off the states of Oregon and Washington exemplify this process. In the spring, albacore appear off southern California and shortly thereafter are taken northward along the Pacific Coast. In some years they have been caught as far north as southeastern Alaska; at other times they have not been taken beyond Oregon or Washington. In some years they may enter coastal waters, but in other years they remain offshore. Failure of the California albacore fishery from 1928 to 1934 is generally attributed to low availability of the fish. The albacore population probably was as large as usual, but did not enter the range of the fishing fleet.

Varying Survival Rates. Fluctuations in abundance (and catches) also result from varying survival rates due to changes in the natural environment. In some years conditions in the ocean may favor survival, while in other years adverse conditions, such as abnormally high or low water temperatures or scarcity of food, may hinder survival. Thus, the number of fish reaching fishable size (or age) each year may vary widely, often without any apparent relation to the number of parents that spawned them.

The relative numerical sizes of different age groups of fish may be determined from studying their age composition in the commercial catches and the amount of effort expended by the fishing fleet in taking the catches. Used together, these studies provide a convenient measure of year-class strength, i.e., the relative size of different broods produced from year to year. Those species primarily affected by environmental factors rather than fishing often are characterized by wide fluctuations in year-class strength. Among 14 successive year classes of western Atlantic mackerel studied, the largest year class in the series was somewhere around 15,000 times as abundant as the smallest year class[6]. Clearly, fluctuations of such great magnitude must be due to environmental causes rather than fishing.

Some investigators have proposed that the more critical period in survival of a year class may occur during development of the eggs prior to spawning, after the eggs are released into the water, or during the larvae stages. Others believe the critical survival periods occur during the post-larval period when food requirements are stringent or during the period when the young are particularly vulnerable to predators. Irregularities in survival rates probably occur at all stages. However, most evidence suggests that survival through the egg and larval stages is the most critical one in determining year-class strength.

Diseases and Parasites. Diseases and parasites also affect animal populations in the sea. One of the most striking examples of the effect of parasites on fish is the severe decline in catches of trout in the Great Lakes brought about by an influx of sea lampreys. The influx of lampreys resulted from opening the Great Lakes to navigation by ocean-going vessels. Fortunately, measures were quickly adopted to control the predatory sea lampreys. These included treatment of streams with a chemical lampricide that kills all generations of developing lamprey buried in the stream beds and installation of electrical barriers that prevent reinfestation of treated streams.

Diseases often are very destructive to animals and plants on land. One might expect diseases to play an equally important role among animal and plant communities in the sea. The scanty information that is available suggests this may be true. Fungi have been found to infect many species of fish and animals which serve as food for fish. For example, during severe fungi epidemics many North Atlantic herring have been observed to succumb to this pathogenic organism[7].

Although diseases may be an important cause of fluctuations of marine animals and plants, they have received little study to date. In the future, scientists can be expected to devote increasing attention to the effects of disease-causing viruses, fungi, bacteria, and other groups of organisms on animals and plants in the sea.

Changes in Ocean Circulation. Temporary vagaries in ocean circulation have caused deaths of marine organisms by exposing them to waters of above or below normal temperatures. Intrusions of the warm *El Nino* current off the Pacific coast of South America frequently are cited as causing mass mortalities of marine organisms.

Toxic Organisms. Sudden blooms of dinoflagellates, which are microscopic free-swimming protozoan organisms, have caused mass mortalities of fish and other marine animals from time to time, probably by some direct poisoning effect. The term "red tide" is often applied to such blooms because the organisms become so abundant that the water takes on the animal's characteristic red coloration. A bloom of the dinoflagellate *Gymnodinium* off Florida in 1946–1947 killed porpoises, barnacles, oysters, and fishes. Dead fish washed ashore were so numerous they had to be buried with bulldozers[4].

Man-Made Causes. *Over-Fishing.* Man affects the yields from fisheries in many ways. The most obvious way is by his fishing operations. Fishing most noticeably affects demersal (bottom-dwelling) species which are particularly vulnerable to man because they often are available to capture during most of their lives. Major changes observed in the abundance of the demersal Atlantic haddock and Pacific halibut, for example, can be explained by sizes of catches taken.

Pacific Halibut Fishery. The history of the Pacific halibut fishery is particularly illuminating for it clearly portrays the course an unrestricted fishery can take and the benefits to be reaped by proper management. The Pacific halibut management program has attracted world-wide attention, since it represents one of the few cases where a sea fishery has been thoroughly managed on an international basis. Since its inception in 1888, the Pacific halibut fishery has evolved to one of the major longline fisheries in the world. It is prosecuted by both United States and Canadian fishermen who enjoy reciprocal landing privileges.

By 1910 all readily accessible fishing banks were being exploited, and halibut in protected waters were becoming scarce. Landings of Pacific halibut by United States and Canadian fishermen reached 50 million pounds by 1907. Expansion northward into Alaskan waters and to the deeper banks off Washington and British Columbia resulted in landings of 69 million pounds in 1915. Continued expansion to new fishing grounds and introduction of diesel power to a progressively larger fleet were not accompanied, however, by corresponding increases in catches. On the contrary, the catches subsequently declined, and by 1931 the total Pacific Coast catch of halibut was only 44 million pounds.

As a result of declining yields, a conservation treaty for halibut was signed by the United States and Canada. Effective regulation, based on holding the catches slightly below additions being made to the populations by growth and addition of new recruits, began in 1932. Management of this resource has been strikingly successful, as shown by the fact that since 1932 production has increased from 44 million pounds annually to an average level of about 70 million pounds in recent years. Present harvests of Pacific halibut are thought to be close to the maximum sustainable yield level[2].

Pelagic Species. Until recently it was generally believed that abundance of most pelagic (offshore free-swimming) species, such as the herring and tuna-type fishes, was little affected by fishing. For these species natural fluctuations were assumed to transcend the effects of man. Some investigators now believe, however, that increased catches of European Atlantic herring in recent years may account for an observed reduction in size of some of the stocks[3]. Similarly, fishing has been shown to significantly affect the yield and stock size of yellowfin tuna in the tropical Pacific Ocean[1]. On the other hand, many stocks of herring and tuna-type fishes throughout the world yet are little affected by fishing. Major changes observed in the size of tropical Pacific skipjack tuna populations apparently have not been related to man's fishing activities; they can only be attributed to changes that have occurred in the natural environment[1].

Alteration of Environment. The effects of man's fishing activities often are difficult to assess. However, his effects on anadromous fishes, such as salmon, during upstream migration of adults or downstream movement of young are all too apparent. Dams take their toll by interfering with and sometimes preventing the passage of both adults and young fish. Careless logging and farming practices have caused erosion which has resulted in deposition of silt in stream beds. Improperly screened irrigation diversions have allowed young salmon and trout to stray into irrigation canals where they have perished. Removal of gravel from stream beds has destroyed valuable salmon and trout-spawning areas.

Pollution. By polluting streams and parts of the sea with sewage and industrial wastes, man has destroyed fish and shellfish resources. Pollution is a particularly insidious problem since the quantities of introduced waste materials are usually small at first and increase from year to year. Thus, destruction of a resource often proceeds slowly, making it difficult to determine whether a pollutant or some other environmental factor is to blame. With the tremendous growth in human populations throughout the world forecast to take place in the near future, pollution will become an increasingly vital problem.

With the coming of the atomic age man has created new problems in conservation which may well be the most important he has yet faced. More and more nuclear fission power plants will be used to produce electricity in future years. Generation of nuclear power produces radioactive fission products which must be disposed of in places where they will not endanger man. Because of the limited disposal sites available on land, particularly in densely populated areas, it may be necessary to use the oceans for this purpose.

Many of the radioactive isotopes present in fission products decay very slowly. Thus, their effects could be felt for many years after dumping. The Atomic Energy Commission, which is charged with responsibility for the ultimate fate and possible effects of atomic waste products, is sponsoring studies of the physical, chemical, and biological processes involved in their disposal. This already has resulted in vastly accelerated studies of the nature of the oceans and of the marine life inhabiting them.

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CHAPTER 3

Distribution and Description of Fisheries

F. Heward Bell

There are at least 40,000 species of fish and an even larger number of other aquatic organisms, but, as with land plants and animals, few are abundant and still fewer exist in concentrations to be harvested economically. This is indicated by the preponderant contribution made by a few fish groups: herring-like fish (the sardines, anchovies, menhadens, sauries, and herrings) and cod-like fish (the hakes, haddocks, and cods) constitute 40 percent of the present world catch of aquatic organisms.

Aquatic organisms account for about 4 per cent of the world production of food including allowances for the contribution of aquatic products to land production. The generally quoted 10 per cent contribution of aquatic products to the world's protein supply is probably high if due regard were given to the essential amino acid contribution of vegetable and animal proteins.

Life Conditions in the Sea

The food chain of the sea starts with small surface plants or phytoplankton which through photosynthesis use solar energy to build organic tissues from dissolved inorganic components. This occurs only in the light-penetrable surface layers. The sinking of the dead plankton rapidly depletes the nutrients of the surface. However, the bottom, enriched by this "planktonic rain," cannot support plant growth due to a lack of light except in shallow seas.

The standing crop of phytoplankton must be large to maintain a large stock of small surface animals called zooplankton upon which small pelagic fish may feed. These can be a food source for larger pelagic species or for the demersal fish of shallower seas. Such food chains tend to be long and inefficient as there is great loss at each link.

Fish production depends upon the rate of replenishment of surface water layers and upon the extent of the shallower water shelf. Practically all harvestable fish stocks are found in the limited oceanic areas where there is substantial upwelling or mixing. Dispersed and economically unfishable stocks are found throughout the oceans where replenishment is slower.

Replenishment of the surface is effected by upwelling or overturn and to some degree by evaporation or by accretion from nutrient-containing run-off from the land. Upwelling is greatest at divergences of opposite moving water masses or in proximity to land due to offshore winds. Replenishment also occurs from the slow but massive overturn between the cold waters of higher latitudes and the warmer waters of lower latitudes as well as that which occurs everywhere between winter and summer.

The fertility of the seas is thus dependent upon immutable geophysical forces such as the earth's rotation, solar radiation, physiography of the bottom, and the distribution of the land masses.

On land, life processes occur *in situ* within inches of the surface. Unlike the fluid seas, the growing medium, or soil, is practically stable and resident organisms are accessible. The land can be cultivated and fertilized and the plants and animals domesticated to best suit man's needs. Terrestrial food chains are short, efficient, and can be modified to maximize the food crops, plant and animal.

Fisheries of the World

World Production. Commercial fisheries usually develop in countries proximal to productive fishing grounds as with Norway, Canada, Peru, Iceland, and other countries. Also industrialization initially in the United Kingdom and later in most other countries created demand and also facilitated production and distribution. In densely populated Japan a survival need for fish prevailed. A dearth of other exports to balance needed imports has sometimes stimulated fishing as in Iceland.

Production by Continents. The recent world production* by continents has been as follows, in billions of pounds.

* Food and Agriculture Organization, 1959.

	World	Africa	North America	South America	Asia	USSR	Europe	Oceania
1951	50.1	2.8	7.8	1.2	18.6	4.4	15.2	.2
1952	54.0	3.3	7.6	1.3	22.1	4.2	15.4	.2
1953	55.6	3.6	8.3	1.3	22.3	4.4	15.6	.2
1954	59.5	3.7	8.7	1.5	23.8	5.0	16.7	.2
1955	62.5	3.8	8.7	1.8	25.5	5.5	16.9	.2
1956	65.8	4.0	9.5	2.0	26.3	5.8	17.9	.3
1957	67.9	4.3	8.7	2.5	29.4	5.6	17.1	.3
1958	70.7	4.3	8.8	3.5	31.3	5.8	16.8	.3
1959	77.9	4.6	9.4	6.0	34.1	6.1	17.5	.3

With allowances for evident errors in the rate of increase reported for Mainland China (Asia) and for lesser cases of statistical zeal in other countries, the mean annual rate of increase in world production has declined since 1955.

In North America and Europe, which account for 40 per cent of the world catch, production is leveling off, even declining in some countries. The USSR increase continues but at a reduced rate. South America manifests the usual sharp rise from initial exploitation but contributes only 8 per cent to the 1959 world catch.

Fish Production and Trade by Countries. In 1959, of the 213 political units with a reported (F.A.O., 1959) fish catch, only 21 accounted for 83 per cent of the world's production as shown in Table 3.1.

Iceland, Canada, Peru, Norway, S.W. Africa, the Union of South Africa, and Portugal with small populations have large exportable surpluses from intensive development of productive grounds mostly adjacent to their coasts.

United States, United Kingdom, and West Germany are major net importers with France, USSR, Denmark, Netherlands, and the Philippines to a lesser degree. For the Netherlands, imports and exports balance.

Japan, in spite of high domestic demand, maintains substantial exports. Spain, India, and Indonesia have inconsequential imports and exports. No data are available for South Korea and Mainland China.

Expanding population and more widespread economic well-being will cause exportable surpluses to decline. Many countries are endeavoring to increase domestic production by expanding to distant waters. This often means entry of new participants into already fully-exploited fisheries, which only redistributes the catch and ultimately results in a net decline in total catch for all.

TABLE 3.1. DOMESTIC PRODUCTION OF AQUATIC ORGANISMS BY LIVE WEIGHT AND FISHERY IMPORTS AND EXPORTS BY PRODUCT WEIGHT FOR 21 MAJOR FISH PRODUCING NATIONS IN 1959 AND RECENT ESTIMATES OF THEIR POPULATIONS

Country	Recent Population	Domestic Production		Trade	
		Total*	Freshwater	Imports	Exports
	Millions	Millions of Pounds		Millions of Pounds	
Japan	95.0	12,949	86	11	961
China	655.0	11,064	4,452	no data	
United States	180.0	6,370	145	1,426	227
USSR	214.4	6,083	1,025	313	150
Peru	10.6	4,408	66	+	778
Norway	3.6	3,542	2	141	1,230
Canada	18.0	2,316	86	40	639
United Kingdom	53.0	2,162	2	1,082	126
Spain	31.0	1,862	13	55	55
India	403.0	1,814	527	35	75
W. Germany	56.0	1,690	24	1,049	168
S.W. Africa and Union S. Africa	15.0	1,653	+	11	480
Indonesia	90.0	1,543	661	40	2
Denmark	4.5	1,485	9	231	498
Iceland	.1	1,411	—	—	476
Philippines	24.0	1,142	38	104	+
France	45.5	1,126	2	379	90
Portugal	9.1	941	+	51	201
South Korea	33.0	842	2	no data	
Netherlands	11.5	705	35	454	399
Totals	1952.3	65,108	7,175	5,422	6,555
World Totals	2900.0	77,900	9,477	—	—

* Including shells of molluscs.

Present expansion is manifested in the development of the large stern trawler by the United Kingdom and its expanding use by the USSR and other nations; the increasing growth in size and range of tuna vessels, particularly of Japan; and the extensive use of motherships long used in Antarctic whaling but heretofore only sporadically in the fisheries. No part of the earth is outside the range of present-day fleets.

The present challenges faced by nations in realizing the full food potentials of the ocean are: increased efficiency in harvesting the natural stocks; their scientific management to assure high and sustained yields; equitable division of such yields among nations; and cultivation to increase the natural food fish potentials of the enclosed or enclosable bodies of fresh and salt waters of the world.

Fisheries of the United States

The Fisheries by Regions. The production by regions during four decades is shown in Table 3.2. The historical yields of important species are given in Table 3.3.

The values of the 1959 landings and the wholesale values of the products manufactured from either a portion of the landings or from importations from other domestic regions or foreign countries are also shown in

TABLE 3.2. AVERAGE ANNUAL LANDINGS BY PERIODS OF ALL SPECIES, BY REGIONS, 1921 TO 1959, AND VALUES OF LANDINGS AND MANUFACTURED PRODUCTS IN 1959

Period	New England	Middle Atlantic	Chesapeake Bay	South Atlantic	Gulf	Pacific Coast	Lakes	Mississippi	Alaska	U.S. Total*
	Annual Landings in 1959 in Millions of Pounds									
1921–1925	403	323	321	226	146	455	78	106	557	2117
1926–1930	661	163	287	284	167	755	80	no data	658	3090
1931–1935	543	185	294	188	157	1048	87	82	690	3329
1936–1940	648	280	309	363	223	1640	85	no data	800	4433
1941–1945	582	389	275	396	350	1549	77	no data	609	4414
1946–1950	923	533	370	261	508	1244	78	105	563	4593
1951–1955	931	774	385	349	751	852	77	97	348	4567
1956–1959	994	842	479	406	889	828	74	80	375	4972
	Annual Value in 1959 in Millions of Dollars									
Landings	66	23	38	19	78	75	7	8	32†	346
Manufactured products	113	75	57	40	123	234	17	7	62	728‡

* Includes Alaska which is shown separately from other Pacific Coast states. Also, "U.S. Totals" includes estimates for data lacking in some regions in some years.
† Includes $3 million for Hawaii.
‡ Not including $24 million produced in Puerto Rico, Hawaii, and American Samoa.

Table 3.2. The two values, though not additive, are jointly good indicators of the economic flow generated in each region.

New England States. The maritime portion of this region includes Massachusetts, Maine, Rhode Island, Connecticut, and New Hampshire. Important fishing centers are Gloucester, Boston, and New Bedford, in Massachusetts; and Portland, Rockland, and Eastport in Maine.

Several factors are responsible for the stature and diversity of the region's fisheries, particularly in Massachusetts and Maine, which in 1959 ranked second and ninth respectively, both in volume and in value of landings by states (Table 3.5). Their waters lie with the rich boreal biotic region with a large continental shelf and proximity to larger shelf areas

TABLE 3.3. AVERAGE ANNUAL LANDINGS BY PERIODS OF PRINCIPAL SPECIES, BY REGIONS, 1921 TO 1959

Periods	Landings in Millions of Lbs.																		
	New England States										Middle Atlantic States				Chesapeake Bay States				
	Haddock	Perch	Whiting	Flounder	Cod	Herring	Mackerel	Lobster	Scallop	Industrial Fish	Menhaden	Oysters	Clams	Scup	Menhaden	Oysters	Crabs	Croaker	Striped Bass
1921–25	94	—	8	31	93	62	27	10	1	—	228	26	2	6	150	48	30	25	2
1926–30	253	—	9	49	93	87	52	11	2	—	44	25	3	7	108	35	65	20	2
1931–35	171	17	10	39	100	51	53	10	3	—	86	17	6	8	138	30	53	19	1
1936–40	157	71	29	50	110	48	32	11	7	—	158	14	8	7	131	34	49	39	3
1941–45	134	124	58	65	91	84	54	17	6	1	268	13	9	10	103	32	38	43	4
1946–50	151	202	70	68	67	152	33	23	14	29	409	16	20	14	158	33	68	13	5
1951–55	149	188	102	52	38	112	7	26	18	104	665	14	17	21	197	36	60	7	3
1956–59	129	143	108	54	36	151	4	27	19	169	739	5	24	22	299	36	51	12	4

TABLE 3.3 (*Continued*)

Periods	Landings in Millions of Lbs.																		
	South Atlantic				Gulf States			Pacific States (not inc. Alaska)							Alaska			Great Lakes	
	Shrimp	Menhaden	Mullet	Crab	Shrimp	Menhaden	Mullet	Tuna	Salmon	Sardine	Halibut	Mackerel	Flounder	Rock Fish	Salmon	Halibut	Herring	Lake Trout	Whitefish
1921–25	24	148	9	*	47	19	31	37	103	174	13	3	*	*	—	41	98	12	4
1926–30	30	184	9	*	73	11	26	72	108	430	18	24	14	7	422	42	169	10	7
1931–35	24	101	7	*	77	9	21	83	100	685	29	71	12	6	489	21	174	10	8
1936–40	28	250	9	*	112	12	29	166	72	1181	29	90	17	5	560	22	208	9	4
1941–45	44	277	12	*	145	65	30	146	72	1059	21	69	28	26	445	33	117	10	4
1946–50	36	308	11	18	133	265	28	307	86	505	15	44	43	26	353	36	157	4	9
1951–55	29	284	10	28	213	427	26	307	85	127	20	22	45	23	246	29	53	2	3
1956–59	26	272	8	33	182	530	32	302	59	99	23	45	48	28	215	29	105	1	1

* Not available.

off Canada, source of 15 per cent of the region's 1959 production. Also, dense populations of national origins and religious faiths inclined to the consumption of fish provide a strong local demand.

The region is the most important producing area for lobsters, flounders, sea scallops, haddock, cod, ocean perch, sea herring, whiting, pollock, and butterfish (Table 3.4), but their relative importance has changed markedly (Table 3.3). Haddock and then ocean perch which supplied the growing demand for fillets offset declines in cod and mackerel. Since 1948 increased whiting and non-food fish catches have offset declines in haddock, ocean perch, and flounders. Unclassified non-food fish for animal feeds has increased from under one million pounds in 1948 to probably over 200 million in 1959 and accounts for the recent slight rise in the New England catch.

Sea scallop production, the second most valuable in the region in 1959, accounted for 15 per cent of the total value, rising from 8th position 20 years ago when it represented only 5 per cent of the total value. Landings of the valuable lobster have tripled during the past 40 years and are being well maintained under present management practices.

Middle Atlantic States. This region, including New Jersey, Delaware, and New York, as well as inland Pennsylvania, is very important as a fishery manufacturing and consumption center for fish from all parts of the country. Important ports are Lewes, Delaware; Port Monmouth, New Jersey; and New York City.

The offshore shelf is smaller and also less productive than off new England but produces a very large and increasing yield of the pelagic menhaden representing 86 per cent of the region's 1959 landings. New Jersey and Delaware receive most of the catch.

Clam production has increased steadily, New Jersey being the nation's major clam-producing state (Table 3.4). Predators and other destructive organisms have caused cataclysmic declines in oyster yields from Delaware Bay and other grounds. Some cod, flounders, whiting, and over half of the Atlantic scup is produced by a limited demersal fishery.

Chesapeake Bay Region. Chesapeake Bay, bordered by Virginia and Maryland, is the largest coastal bay in the United States and its productive waters are the scene of very important but contrasting fisheries. Centers of operation are Reedville, Virginia; Norfolk, Virginia; and Crisfield, Maryland.

Most of the nation's oysters and blue crabs originate here. These high unit-value products contrast with the low unit-value (but large production) of menhaden which is used almost exclusively for oil and meal. Since 1958 most of the menhaden were taken within the Bay rather than offshore.

Oyster yields from private beds have been well maintained despite predators and pollution. However, since 1959 there has been a very sharp decline, particularly in Virginia. Crab production appears to have become stabilized at a moderately high level (Table 3.3).

South Atlantic States. This 1000-mile coast includes North and South Carolina, Georgia, and the east coast of Florida.

Except for heavy landings of menhaden, chiefly at Beaufort-Moorehead City, North Carolina, the region is not an important fish-producing area. There are substantial yields of blue crab and lesser ones of shrimp and oysters, the latter being greatly eclipsed by their respective yields in the Gulf area and in Chesapeake Bay (Table 3.4).

There is a modest production of catfish and bullheads from Florida's lakes and of mullet and sea trout from salt water areas. Over 81 per cent of the Florida production by value is taken off the Gulf Coast.

Gulf of Mexico Region. This region includes the 1500-mile coastline of Texas, Louisiana, Mississippi, Alabama, and the west coast of Florida. Louisiana ranks first in volume and fifth in value by states in this region. Alabama ranks very low. Tampa, Florida; Empire, Morgan City, and Cameron, Louisiana; Pascagoula and Biloxi, Mississippi; and Port Arthur, Texas are important centers.

The very large shelf, whose productivity is lower than that off New England, sustains extensive shrimp and menhaden fisheries of high value and high volume respectively.

The Gulf in 1959 produced about 80 per cent of the nation's shrimp, the country's most valuable fishery. During the past 30 years the fishery has grown markedly and spread throughout the area. However, the present trend and composition of the catch and the widening area exploited suggests a decline with higher production costs and increasing competition with imports.

Menhaden production, though now very heavy, has varied due to demand. There are substantial oyster, mullet, and crab fisheries and a small but steady yield of red snappers.

California. The shelf off the 700-mile California coast is narrow with a bottom habitat of medium productivity but with a richer surface environment possessing a variable abundance of pelagic species. Large urban populations consume a variety of market fishes. Major ports are Terminal Island, San Diego, and San Francisco.

The fishery economy was formerly built upon sardines (the California pilchard), all taken in contiguous waters. Production rose from 150 million pounds in the early 1920's to 1.5 billion pounds in the mid-thirties with a disastrous fall to only 9 million pounds in 1953 due to causes yet unknown. Production of sardines since then has remained relatively low.

TABLE 3.4. PRODUCTION IN 1959 BY REGIONS OF UNITED STATES OF 55 SPECIES BY VALUE RANK; PERCENTAGE OF TOTAL CATCH OF EACH TAKEN BY EACH TYPE OF GEAR AND YEAR OF RECORD PRODUCTION

Species or Groups Thereof	Totals (in millions of lbs., dollars)		Rank (in millions of lbs., dollars)		Catch by Regions (in millions of lbs.)									Record Production (in millions of lbs.)		Gear Used (% of 1959 catch)					
	Volume	Value	Volume	Value	New England	Middle Atlantic	Chesapeake	South Atlantic	Gulf States	California****	Oregon & Washington	Alaska	Great Lakes & Mississippi	Year	Weight	Seines	Trawls	Lines	Gillnets	Traps	Others
Shrimp	240	58	4	1	*	*	—	26	_193_	2	6	13	—	1954	268	—	100	—	—	—	—
Tuna	286	37	2	2	3	*	—	—	*	_269_	14	—	—	1950	391	27	—	73	—	—	—
Salmon	202	36	6	3	—	—	—	—	—	7	48	_147_	—	1936	791	49	—	13	36	2	+
Oysters	65	30	13	4	**	1	_33_	4	14	2	11	—	—	1908	152	—	69	—	—	—	31
Menhaden	2203	26	1	5	53	653	414	331	_752_	—	—	—	—	1959	2203	98	—	—	—	2	+
Crabs	175	15	7	6	2	3	_45_	39	30	17	16	23	—	1959	175	—	10	16	—	72	2
Lobsters, northern	29	15	24	7	_27_	2	*	—	—	—	—	—	—	1889	31	—	4	—	—	96	—
Flounders	122	13	9	8	_57_	11	5	2	1	19	27	*	—	1948	139	+	99	+	+	1	+
Scallop, sea	24	12	26	9	_20_	4	**	—	—	—	—	—	—	1959	24	—	100	—	—	—	—
Clams	45	12	18	10	7	_29_	7	**	*	—	1	**	—	1959	45	—	70	—	—	—	30
Haddock	113	11	11	11	_113_	*	—	—	—	—	—	—	—	1929	294	—	98	2	—	—	+
Halibut	54	8	15	12	**	—	—	—	—	*	_24_	30	—	1915	67	—	—	100	—	—	+
Ocean Perch, Atlantic	137	6	8	13	_137_	—	—	—	—	—	—	—	—	1951	258	—	100	—	—	—	—
Catfish & bullheads	34	5	22	14	—	*	4	10	5	—	—	—	_15_	1956	35	6	—	42	6	46	—
Cod	60	4	14	15	_41_	5	**	—	—	—	13	*	—	1880A	295	—	85	11	4	—	+
														1916P	43						
Herring, sea	236	3	5	16	_121_	1	*	—	—	2	5	107	—	1902A	201	92	+	—	—	8	+
														1937P	263						
Snapper, red	11	3	36	17	—	—	—	1	_10_	—	—	—	—	1902	23	—	+	100	—	—	—

Scup or porgy	47	3	17	18	9	26	12	*	*	—	—	—	—	1959	47	9	78	—	—	13	—
Unclassified industrial fish	248	3	3	19	153	3	7	2	83	—	—	—	—	1959	248	+	100	+	+	+	+
Mullet	41	2	19	20	—	*	*	8	33	—	—	—	—	1902	43	25	—	—	75	—	—
Whiting	115	2	10	21	110	5	**	—	—	—	—	—	—	1957	133	—	99	+	+	1	—
Chubs	11	2	35	22	—	—	—	—	—	—	—	—	11	1958	12	—	12	—	88	—	—
Buffalofish	17	2	29	23	—	—	—	—	1	—	—	—	16	1950	26	16	—	2	44	38	—
Croaker	12	2	34	24	—	*	9	3	*	—	—	—	—	1945	65	44	25	+	5	26	—
Sardine	74	1	12	25	—	—	—	—	—	74	—	—	—	1936	1502	100	—	—	—	—	—
Striped bass	8	1	42	26	*	1	6	1	—	—	*	—	—	1959	8	23	+	1	61	15	—
Sea trout	11	1	51	27	—	***	1	4	5	—	—	—	—	1945	41	15	29	8	43	5	+
Lobster, spiny	4	1	>	28	—	—	—	***	3	***	—	—	—	1936	9	—	+	—	—	100	+
Rockfishes	28	1	25	29	—	—	—	—	—	15	13	*	—	1945	58	+	87	13	+	—	—
Carp	31	1	23	30	*	*	1	**	*	**	**	—	29	1908	43	43	—	1	16	40	—
Scallops, bay	1	1	>	31	***	**	—	*	*	—	—	—	—	1953	3	—	81	—	—	—	19
Seabass, Atlantic	8	1	43	32	**	4	3	*	*	—	—	—	—	1952	22	+	70	1	+	29	+
Shad	9	1	41	33	2	2	3	1	—	—	**	—	—	1890	43	21	+	—	61	18	—
Yellow perch	12	1	32	34	—	—	*	*	—	—	—	—	12	1934	16	+	—	—	28	72	—
Yellow pike	3	1	>	35	—	—	—	—	—	—	—	—	3	1946	8	3	—	—	61	36	—
Pollock	25	1	27	36	25	*	*	—	—	—	—	—	—	1938	41	—	90	1	9	+	—
Jack mackerel	38	1	20	37	—	—	—	—	—	38	—	—	—	1952	147	96	4	—	+	—	+
Mackerel, Pacific	38	1	21	38	—	—	—	—	—	38	—	—	—	1935	146	49	+	+	—	—	51
Butterfish	11	1	37	39	5	4	2	**	—	—	—	—	—	1939	17	3	71	—	7	19	—
Herring, lake	13	.8	31	40	—	—	—	—	—	—	—	—	13	1899	60	+	+	—	100	+	—
Groupers	7	.8	48	41	—	—	—	*	6	**	—	—	—	1945	9	—	+	100	—	—	—
Sablefish	9	.8	40	42	—	—	—	—	—	2	5	2	—	1945	18	—	35	65	—	—	—
Sheepshead, f.w.	14	.7	30	43	—	—	—	*	**	*	—	—	13	1959	14	25	+	3	9	63	—
Spot	9	.7	39	44	—	*	4	5	**	—	—	—	—	1952	16	65	3	2	15	15	—
Alewives	51	.7	16	45	14	*	22	14	*	—	—	—	—	1908	90	25	+	—	5	67	3
Spanish mackerel	7	.6	46	46	—	*	*	2	5	—	—	—	—	1945	12	4	+	8	88	+	—
Swordfish	2	.6	>	47	1	*	—	—	—	**	—	—	—	1929	7	—	—	—	—	—	100

TABLE 3.4 (*Continued*)

Species or Groups Thereof	Totals (in millions of lbs., dollars)		Rank (in millions of lbs., dollars)		Catch by Regions (in millions of lbs.)									Record Production (in millions of lbs.)		Gear Used (% of 1959 catch)					
	Volume	Value	Volume	Value	New England	Middle Atlantic	Chesapeake	South Atlantic	Gulf States	California****	Oregon & Washington	Alaska	Great Lakes & Mississippi	Year	Weight	Seines	Trawls	Lines	Gillnets	Traps	Others
Squid	24	.6	28	48	3	1	*	*	*	20	*	—	—	1946	40	84	7	—	—	9	—
Abalone	1	.5	>	49	—	—	—	—	—	1	—	—	—	1957	1	—	—	—	—	—	100
Whitefish, common	1	.5	>	50	—	—	—	—	—	—	—	—	1	1885	18	1	—	—	51	48	—
Bluefish	4	.5	55	51	*	1	*	2	1	—	—	—	—	1897	23	5	3	31	47	14	—
Lake Trout	1	.5	>	52	—	—	—	—	—	—	—	—	1	1903	16	—	—	+	98	2	—
Sea Bass, white	3	.5	43	53	—	—	—	—	—	3	*	—	—	1959	3	—	+	6	94	—	—
Smelt	10	.4	38	54	*	—	—	—	—	***	2	*	7	1958	13	11	3	—	10	66	10
Lingcod	7	.4	45	55	—	—	—	—	—	1	6	*	—	1944	14	+	84	16	+	—	—
Totals	4991	335			905	757	580	457	1143	512	192	323	122								
Other	131	11			28	3	9	12	12	30	15	1	21								
Grand totals	5122	346			933	760	589	469	1155	542	207	324	143								

* 1–250,000 pounds
** 251,000–500,000 pounds
*** 651,000–1,400,000 pounds

> volume rank greater than 55
A. Atlantic
P. Pacific

**** California includes 17 million for Hawaii, (14 Tuna—3 other)

Tuna is now the basis of the California fisheries. It is practically all canned and accounts for California ranking first by states in value of fish production. Current packs represent about 30 per cent of the nation's canned food fish. The fish are caught largely off central and South America or are imported.

Mackerel production rose rapidly from the 1920's to the late 1930's, then declined. Fish of lesser consequence include sea basses, rockfishes, lingcod, flounders, sablefish, crabs, squids, and many others of still lower importance.

Oregon and Washington. Washington ranks 8th and Oregon 15th in value of production by states (Table 3.5). and their fisheries are important to the economies of these two states. Landing centers include Astoria, Oregon and Seattle and Bellingham, Washington.

The adjoining shelf is not wide and the bottom and surface habitats only moderately productive. There is a modest trawl fishery and 55 per cent of the 1959 catch, chiefly flounders and rockfish, came from the more extensive and productive shelf off British Columbia.

The fishery economies of the two states are based largely upon five species of anadromous salmon destined for many rivers, particularly the Columbia and Fraser. Also, most of the salmon processed in Alaska is transhipped through Washington. About 45 per cent of the United States halibut catch taken chiefly off Alaska or British Columbia is landed in Washington. Also, most Alaska-landed halibut is transhipped frozen through Seattle.

The introduced Pacific oyster makes an important contribution to Washington fisheries, and the production of Dungeness crab in both states is normally substantial. Sablefish and lingcod, the former of high fat content, provide small but consistent supplies for the smoking and fresh fish trades respectively.

Alaska. One-half of the 3600-mile coast of Alaska is largely icebound, the remainder bordering more productive temperate to subarctic seas. The shelf is very wide at places, at others very narrow. Demersal fisheries, except for halibut and king crab, have not yet been developed except by Japan and Russia in the eastern Bering Sea.

Salmon, which comprise five anadromous species, dominate the fisheries of Alaska since first exploited 90 years ago and led the nation in value until shrimp and tuna recently assumed first and second places respectively. Salmon yields are declining either induced by man or by man and natural factors.

Salmon are canned at many isolated places, but Ketchikan, Petersburg, Juneau, Sitka, and Pelican are important centers.

Halibut, herring, and to a minor extent shrimp and crab comprise the

TABLE 3.5. RANKINGS BY VOLUME AND VALUE OF 1959 LANDINGS BY STATES

State	Weight		Value	
	Thousands of Pounds	Rank	Thousands of Dollars	Rank
Alabama	25.0	19	3.7	18
Alaska	323.5	7	28.8	3
Arkansas	5.7	28	.9	27
California	524.8	4	47.5	1
Connecticut	10.8	26	1.1	26
Delaware	285.8	8	3.8	17
Florida	231.0	11	23.2	7
Georgia	21.6	22	2.7	23
Hawaii	16.6	24	3.2	19
Illinois	7.6	27	.8	28
Indiana	.2	39	+	39
Iowa	4.0	30	.5	30
Kansas	+	41	+	40
Kentucky	3.0	31	.3	32
Louisiana	556.6	1	25.8	5
Maine	266.0	9	19.6	9
Maryland	63.0	16	12.7	10
Massachusetts	537.6	2	40.9	2
Michigan	22.3	21	2.7	22
Minnesota	14.6	25	1.1	25
Mississippi	254.5	10	6.5	14
Missouri	+	38	+	37
Montana	.1	40	+	41
Nebraska	+	37	+	36
New Hampshire	1.0	34	.4	31
New Jersey	359.5	5	10.1	11
New York	115.7	15	9.0	12
North Carolina	342.6	6	8.2	13
North Dakota	.1	35	+	38
Ohio	19.5	23	1.7	24
Oklahoma	+	36	+	35
Oregon	51.8	17	6.4	15
Pennsylvania	1.1	33	.1	34
Rhode Island	117.8	14	4.3	16
South Carolina	23.4	20	2.9	20
South Dakota	2.9	32	.2	33
Tennessee	5.4	29	.6	29
Texas	211.2	12	26.3	4
Virginia	526.3	3	25.8	6
Washington	155.2	13	21.5	8
Wisconsin	30.4	18	2.7	21
Wyoming	+	42	+	42

balance of the state's fisheries. Unfished stocks of shrimp and crab possess potentialities for development, but herring possibilities appear limited and are also hindered by cost factors.

Halibut landings in Alaska (Table 3.3) do not reflect the size of the contiguous stocks as the fleet is largely noncaptive to any port and land not only in Alaska but in British Columbia and Washington as well. Also, Canadian vessels fish off Alaska.

Great Lakes, including the International Lakes of Minnesota. New York, Pennsylvania, Ohio, Indiana, Michigan, Illinois, Wisconsin, Minnesota, as well as Ontario and Manitoba in Canada participate in the fisheries of the Great Lakes (Ontario, Erie, Huron, Michigan, and Superior). The small international lakes of Minnesota provide a small yield.

Increased production costs, changing relative value between species, gear modifications and restrictions, natural and fishery-induced fluctuations, introduction of exotic species and of predators characterize the region's fisheries. The valuable lake trout and whitefish have declined to negligible quantities primarily due to an influx of parasitic sea lampreys and have been largely replaced in the catch by less valuable chubs, yellow perch, smelt, and lake herring.

Mississippi River and Watershed. Twenty river states produced 78 million pounds in 1959 with Wisconsin, Alabama, and Illinois accounting for one-half. The fish in this region are taken both from the rivers and from many small lakes in the watershed area. The region produces most of the country's catfish and all of the domestic shell for "pearl" buttons whose production shows a long-term decline. Some shell is exported for use in pearl culture in Japan. Catfish, buffalofish, carp, and sheepshead comprise about 77 per cent of the 1959 catch and mussel shells about 16 per cent.

The Fisheries by States. Though most fisheries extend beyond the borders of single states, jurisdiction is exclusively by state. Federal authority intervenes only where there are international commitments or where federal pure food, interstate commerce, or power laws may apply.

In Table 3.5 the 1959 volume and value ranking by states are shown. All federal fishery statistics exclude sport or subsistence catches which are often substantial. In world statistics (FAO 1959), there is inconsistent inclusion of such catches.

Production by Habitat Groups. The percentages of the total United States annual production contributed by major biological or habitat groups during the past 50 years and for the world catch in 1959 are shown in Table 3.6.

The foregoing reflects the rising production of shrimp and the decline of oyster yields. The stability of freshwater fish yields lowers their representation. The increasing proportion of pelagic fish, 1908 to 1937, resulted from the growth of the California sardine fishery whose collapse has been partly counteracted by increased menhaden production. Demersal fisheries have contributed a steady fifth of the catch during the past half-century, recent Atlantic declines being offset by a minor Pacific trawl fishery. Miscellaneous includes turtles, seaweeds, and other items not including whale products, the latter being of minor importance in this century. Compared to the rest of the world, 1959 ratios reflect the higher relative importance of oyster, shrimp, and menhaden yields and relatively low yields of freshwater fish in United States.

TABLE 3.6. TYPES OF FISH CAUGHT BY YEARS

	1908	1930	1937	1945	1950	1955	1959	
	United States						U.S.	World
	%	%	%	%	%	%	%	%
Crustacea	5	6	6	7	8	9	9	2
Mollusca	13	7	4	4	4	4	3	1
Freshwater fish	11	5	4	4	4	5	3	15
Marine demersal fish	21	22	17	23	19	19	21	27
Marine pelagic fish	50	60	69	62	65	63	64	54
Miscellaneous	+	+	+	+	+	+	+	1

(+ less than 1 per cent)

Disposition of Production and Imports. Fish is used chiefly for human food directly or for livestock and for technological or pharmaceutical purposes. Domestic landings by product groups and food fish imports since 1921 are given in Table 3.7. Industrial products are meal, oil, solubles, homogenized condensed fish, shell products, bait, fur-animal or pet food, and other items. Cured fish includes dried, salted, smoked, or pickled.

Industrial products' totals chiefly reflect the changes in Pacific pilchard and Atlantic menhaden yields and the increased demand for animal feeds. The decline in cured products reflects changing food habits and increased use of frozen fish. Canned production depends upon the vicissitudes of Pacific salmon, tuna, and pilchard and of the Atlantic herring fisheries. Fresh and frozen fish cannot be segregated as round weights except for recent years. Frozen fish has increased at the expense of fresh and cured fish but the recorded production is probably slightly below the actual.

The almost exclusive use of the dominant menhaden catch for reduction accounts for the high proportion used as industrial products compared to the rest of the world (Table 3.7). The larger proportion of frozen and canned products and lower proportions of fresh and cured fish in the

United States largely reflect the greater technological development and the greater need for such preservation to permit continental distribution in a country as large as the United States.

Product weights of edible imports are available since 1921 and as round weights since 1946. They emphasize the growing dependence upon imports, increasing from 17 per cent of the total supply in 1947 to 45 per cent in 1959. Imports of industrial fishery products have also risen from 23 per cent of the total supplies in 1948 to 33 per cent in 1959.

TABLE 3.7. DISPOSITION OF LANDED CATCHES OF AQUATIC ORGANISMS BY MAJOR PRODUCT GROUPS AND IMPORTS OF FOOD FISH BY FIVE-YEAR PERIODS, 1921 TO 1959 AND COMPARISON OF THE DISPOSITION OF UNITED STATES AND WORLD CATCHES IN 1959
(In round weights except as noted)

	Landed Catch							Food Fish Imports	
		Edible					Industrial Products		
Periods	Total U.S.	Total Edible	Fresh & Frozen	Canned	Cured	† Frozen		Product Wt.	Round Wt.
			Millions of Pounds					Millions of Pounds	
1921–1925	2646	1819*	856	725	178	87	823	274	—
1926–1930	3090	2364	1150	1055	159	125	726	335	—
1931–1935	3329	2253	1069	1051	133	117	1076	287	—
1936–1940	4433	2762	1309	1322	131	182	1671	338	—
1941–1945	4414	2903	1489	1299	115	259	1511	330	—
1946–1950	4593	3152	1546	1506	100	278	1441	493	766
1951–1955	4567	2708	1470	1153	85	306	1859	731	1223
1956–1959	4972	2725	1513	1126	86	482	2247	944	1642
1959 U.S.	5122	2599‡	988	977	83	551	2523		
% Total	100	51	19	19	2	11	49	—	—
World	77801	62373	33061	6832	15868	6612	15428	—	—
% Total	100	80	43	9	20	8	20	—	—

* Minor differences in cross totals due to some categories not available in 1921.
† Product Weight. Not included in "Total Edible."
‡ Fresh only. Frozen shown as gross weight for 1959.

Increased imports are largely a result of inadequate or depleted stocks in contiguous waters and the inability of the United States to compete in fisheries off other countries except in the distant eastern Pacific tuna fishery and to a limited extent in the nearby Gulf shrimp fisheries off Mexico and trawl fisheries off Canada, out of Oregon, Washington, and New England.

Canada, Japan, Mexico, Peru, Norway, and Iceland, which collectively accounted for over 81 per cent of the edible imports in 1959, are more propitiously situated with respect to productive fish stocks and have lower production costs.

Production by types of gear are summarized in Table 3.8. The large seine catch reflects the importance of menhaden, 98 per cent of the 2.2 billion pound catch in 1959 being taken by purse seine. Table 3.4 shows the predominating gears used in each fishery in 1959. The gear used changes from time to time and differs from region to region. Restrictive legislation based on socio-economic or conservation considerations, or on both, has also controlled the type of gear.

TABLE 3.8. PRODUCTION BY TYPES OF GEAR

	Catch			
	Volume		Value	
Chief Gear Types	Millions of Pounds	% of Total	Millions of Dollars	% of Total
Seine				
Nets, purse, haul, stop, etc.	2807	55	60	17
Trawls				
Otter, beam, dredges*	1293	25	142	41
Lines				
Set, troll, trot	383	7	56	16
Traps				
Weirs, pound, floating, fyke, pots	344	7	37	11
Gillnets				
Trammel, drift, set	202	4	28	8
Other				
Tongs, rakes, forks, harpoons, dip, or scoop nets, etc., including hands	93	2	23	7
Totals	5122		346	

* For molluscs.

The Fishery by Species. While 151 kinds of organisms contributed to the 1959 total production, 55 accounted for 97 per cent of the total. They are ranked by value in Table 3.3 with the year and amount of record production. The latter were usually taken from virgin accumulations. Sustainable yields would be lower. As indicated by underlined totals, New England possesses the greatest diversity, being the main producing region for 12 of the 55 items, and Alaska the least, being the center for only one, namely salmon.

The proportions of the 1959 national production contributed by the first 12 most valuable species as listed in Table 3.4 and their bimonthly production are shown in Table 3.9 as percentages. The seasonal landings of all food and all industrial fish are also shown in this table.

TABLE 3.9. PROPORTION OF TOTAL U.S. CATCH BY VOLUME AND VALUE OF THE 12 MOST VALUABLE SPECIES IN 1959 AND THEIR SEASON OF PRODUCTION

Value Rank	Species or groups thereof	Proportion of U.S. Totals			Season of Production (Proportion of Annual Total)					
		Value	Volume	Volume	Jan Feb	Mar Apr	May June	July Aug	Sept Oct	Nov Dec
		%	%	Millions of pounds	%	%	%	%	%	%
1	Shrimp	17	5	240	6	6	16	27	29	16
2	Tuna	11	6	286	14	19	18	24	14	11
3	Salmon	10	4	202	+	+	8	83	7	2
4	Oysters	9	1	65	26	23	6	2	14	29
5	Menhaden	8	43	2203	+	1	29	38	23	9
6	Crabs	4	3−	175	14	12	15	23	21	15
7	Lobsters, northern	4	+	29	5	4	10	25	38	18
8	Flounders	4	2−	122	12	15	19	20	19	15
9	Scallops, sea	3	+	24	9	14	20	22	19	16
10	Clams	3	1−	45	14	17	18	18	17	16
11	Haddock	3	2	113	13	25	21	17	14	10
12	Halibut	2	1	54	+	4	57	31	8	+
	Total	78	68	3558						
	All U.S. food fish			2599	8	11	20	29	20	12
	All U.S. industrial fish			2523	1	2	30	38	21	8

Production Status of Major Fisheries. Economic factors and stock conditions as they may have been affected by the fishery or by natural factors play a prominent role in the development of uncontrolled fisheries. The fisheries can be classified according to the following developmental stages, oysters and crabs differing from one region to another. (A) refers to Atlantic, (G) Gulf, (P) Pacific, and (L) Lakes.

I. Initial fishing; slowly increasing production; abundant stocks; high profits.

II. Rapidly rising production; some decline of stocks; rising costs.

Scallops (A) Unclassified industrial fish (A)

III. Slower rise in production; continued but slower or no decline in stocks; rising costs.

Whiting (A)	Menhaden (A)	Scup (A)	Flounders (P)
Lobster (A)	Clams (A)	Crab (A)	Rockfish (P)

IV. Production ceases to increase regardless of increased fishing effort; production and stocks sometimes below optimum; costs moderately to increasingly high.

Flounder (A)	Crab (A)	Shrimp (G)	Yellowfin
Oysters (A)	Striped Bass (A)	Mullet (G)	Tuna (P)

V. Production declining and below optimum; lowest cost participants maintain marginal fishery.

Haddock (A)	Oysters (A)	Lake Trout (L)	Mackerel (P)
Ocean Perch (A)	Croaker (A)	Whitefish (L)	Herring (P)
Cod (A)	Shrimp (A)	Salmon (P)	
Mackerel (A)	Mullet (A)	Sardine (P)	

The above fisheries accounted for 81 per cent of the value and 91 per cent of the volume of the 1959 total United States production. Those in stages III, IV, and V are either in the mature or declining state as a result of biological or economic factors.

The statistics herein have been developed from those in *Historical Statistics of the United States, Colonial Times to 1957*, U.S. Bureau of the Census, 1959, which were verified and partly compiled by this author and from the publications of the United States Bureau of Commercial Fisheries, or predecessor agencies, and particularly from recent *Annual Statistical Digests* compiled under the direction of Edward A. Power whose critical examination of this text is gratefully acknowledged.

CHAPTER 4

Fishing Gear and Methods

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The history of man's use of fishing paraphernalia is not well documented. We can, however, be confident that fishing was one of his earliest skills for obtaining food. The hand spear was probably the earliest device used to take fish, and we can imagine that man soon learned to use barriers in shallow creeks or at the mouths of tidal inlets to impound fish. Radcliff[5] noted that ancient man used the "gorge" in the Paleolithic era. The "gorge," which was perhaps the forerunner of the hook, was a short, straight, or curved piece of wood, bone, or other material sharpened at both ends. The "gorge" probably was baited and attached to the end of a fiber line. The device when taken by a fish, became wedged in his mouth.

The use of bait to lure and capture fish is considered by Augur[2] as a great step forward in man's progress. He remarked that: "This was a tremendous advance in the development of fishing methods. Surely the catches increased enormously, and the intelligence of the new device must have spread rapidly among tribes. We may confidently believe that at this time the older men, seeing the jubilant and heavily-laden fishermen returning day after day from the fishing grounds, originated the remark which has been handed down throughout the ages and which in its simplest form runs something like this: 'If this keeps on the good fish will all be caught out of the water in about three years.'" When attempting to improve and maintain their economic status through the adoption of technological advancements, today's fishermen are continually plagued with similar remarks.

The barbed hook, nets, gaffs, sinkers, and fiber lines were all, according to Radcliff[5], used in neolithic times. The history of early Mediterranean culture leaves little doubt that many techniques were used by the Egyptians, Greeks, and Romans for commercial fishing, and angling for sport is attributed to the early Egyptians. The Greeks built large traps between the Mediterranean and Black Sea to capture migrating tuna. Use of the hook and line, net, harpoon, and trap is also reported in early Mayan, Aztec, and Chinese fisheries. Spun silk fish lines were used in China as early as 1500B.C. It appears that the net, harpoon, etc., cannot be traced to a particular early culture, but were widespread among primitive peoples throughout the world.

The methods used in the Stone Age, that is, the hook and line, nets, and traps, still are the main tools used by man to harvest fishes. Obviously there has been great improvement in materials, in the design of nets, in methods of detecting fish, and in the vessels employed to carry man to the fishing grounds.

Fishing gear used today may be grouped into the following categories:

(1) Fishing with animals (cormorants, otters, etc.)
(2) Wounding gear (spears, harpoons, explosives, etc.)
(3) Gear for gathering sessile animals (shovels, tongs, pumps, rakes, and dredges)
(4) Traps and barriers (pots, wiers, etc.)
(5) Hook and line techniques (handlines, longlines, troll)
(6) Nets (seines, tanglenets, trawls, gillnets, etc.)
(7) Devices dependent upon the physiological reaction of fish to physical or chemical properties (electricity, air bubbles, light, chemicals, etc.)
(8) Fishing vessels

Fishing with Animals

Cormorants trained to retrieve fish are still used in certain parts of the world. The Japanese and Chinese have used this method for centuries. The wings of birds which are trained from infancy are clipped and a ring placed around the lower end of the necks. The rings prevent the cormorants from swallowing larger fish which are retrieved by the trainer. A single fisherman may use from six to a dozen cormorants. In Europe, otters have been used on a limited scale to assist in the capture of fish. The otters are used more in herding or chasing fish into nets rather than for direct capture. A unique use of a fish, the remora, to capture sea turtles is still practiced in tropical seas. The remora has a specialized sucker-like organ which is a modification of the first dorsal fin. By means of the sucker the remora attaches to fish and sea turtles. When employed for fishing, the remora is tied to a line and taken to an area where turtles have been observed. The fish is then cast into the sea in the general direction of the reptile. The remora swims to the turtle and attaches itself. The fisherman, through use of the line, then plays the turtle until it tires and can be retrieved.

Wounding Gear

The most advanced development of a wounding device is the harpoon employed to harvest whales or porpoises. Whaling harpoons weigh about 200 pounds each and are 6 feet in length. The harpoon is propelled towards the whale from a black powder gun mounted on the bow of the vessel. The harpoon is generally made more lethal by adding a grenade to the point, which is preset to detonate about 3 to 4 seconds after the gun discharges. Whalers now use nylon ropes about 3 inches in circumference for a leader or "cast" and a heavy hemp rope for a play line. Modern whaling is carried out extensively in the Arctic and Antarctic. In the United States it is still practiced from the ports of San Francisco, California and Astoria, Oregon. Another type of wounding gear is the large hand-thrown harpoon which is used to take swordfish. Although not legal in most areas of the United States, explosives have been used to capture fishes.

Gear for Gathering Sessile Animals

Included in this category are the many techniques employed to harvest marine animals which remain more or less fixed (sessile) within their environment, such as oysters, clams, abalone, and sponges. The simpler devices include shovels, tongs, and rakes. In harvesting oysters and scallops the dredge is one of the most commonly employed techniques (Figure 4.1). A dredge consists of a triangular or oblong metal frame to which a bag or net made of wire mesh iron links or cotton webbing is attached. The leading, lower edge of the dredge is generally equipped with a raking bar having teeth on the underside. Dredges vary between areas or regions, depending on fishermen's ideas regarding efficiency for harvesting particular shellfish. On the East Coast of the United States hydraulic dredges are used to harvest clams. Dredges of this type are equipped with a series of high-pressure jets located on the front bar of the dredge. The jets wash the clams free of the bottom. They are then collected on a cow-catcher device in back of the jets. A trailing bag on a sled may be used to collect the clams. In the soft-shell clam fishery a hydraulic dredge is commonly used with a conveyor which brings the clams up to the vessel.

In the Atlantic oyster industry, large suction dredges are commonly employed. The oysters are removed from the bottom and brought to the surface by suction applied to the dredge head.

Perhaps one of the most unique methods is that employed to harvest abalone and sponges. These animals are taken by hard-hat or skin divers.

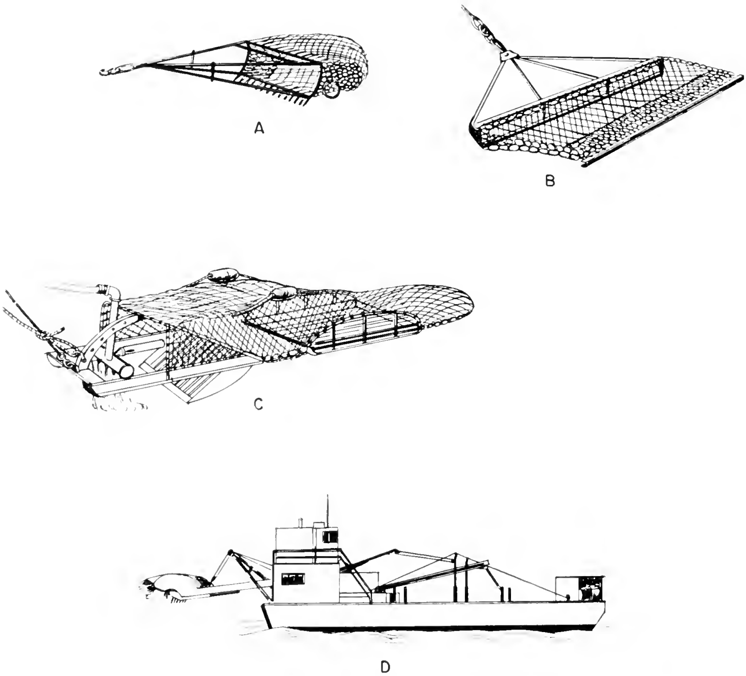

Figure 4.1. Dredges. *(Dumont and Sundstrom, U.S. Fish and Wildlife Service.)*

A. Oyster dredge
B. Scallop dredge
C. Hydraulic or jet dredge
D. Hydraulic oyster dredge

When removed from the bottom, the sponges or abalones are placed into baskets and hauled to the surface by fishermen aboard the tending boat.

Traps and Barriers

A wide variety of traps and pots is used to capture fishes. Capture generally depends upon attracting fish or shellfish to pots by means of bait or by leading fish into an enclosure. Pots are used in the West Coast Dungeness crab and shrimp fisheries and in the blue crab and lobster fisheries along the Atlantic seaboard (Figure 4.2). Pots are also used in

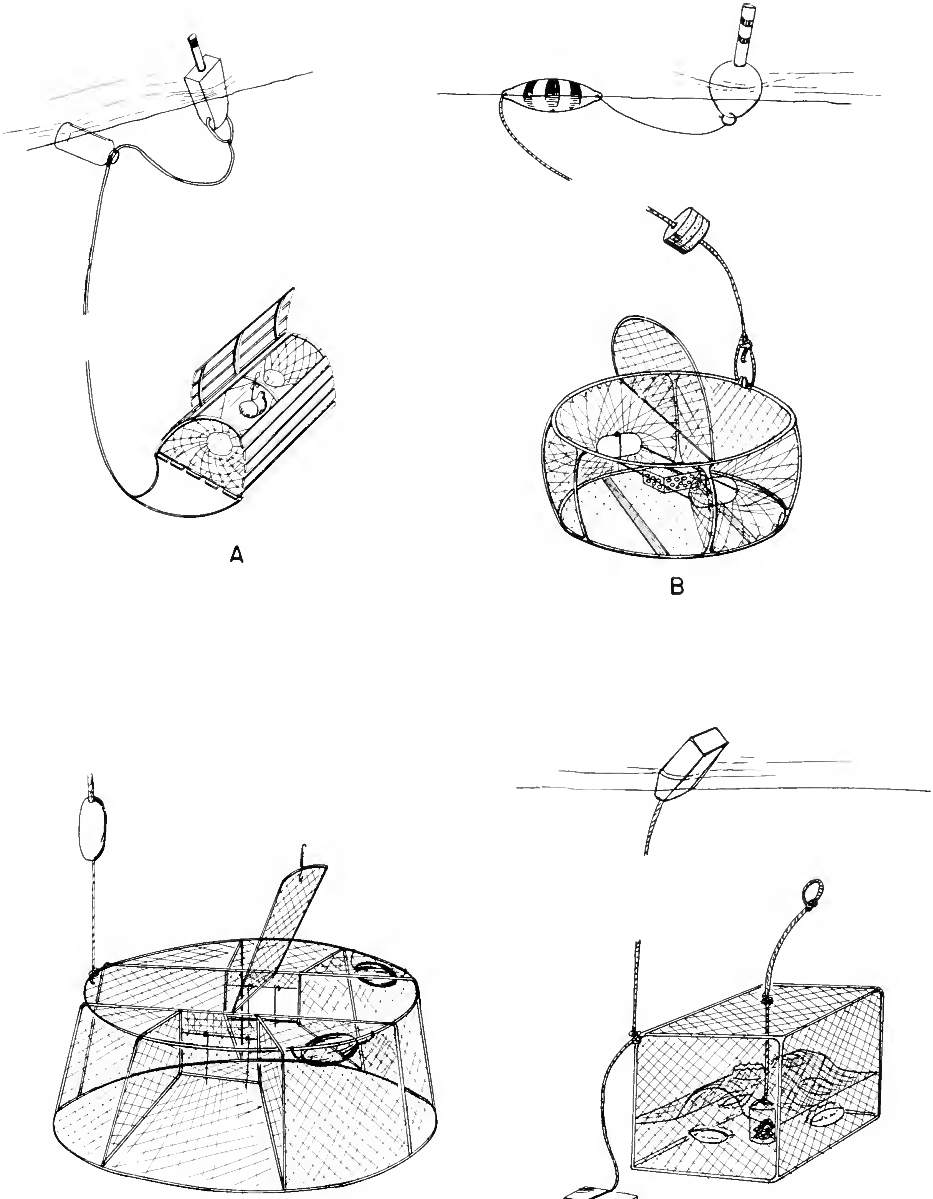

Figure 4.2. Fishing pots. (*Dumont and Sundstrom, U.S. Fish and Wildlife Service.*)

A. Atlantic coast lobster pot
B. Pacific coast dungeness crab pot
C. Pacific coast king crab pot
D. Atlantic hard crab pot

the United States to catch eels, sea bass, crawfish, and octopus. The most common pot used along the West Coast is circular in shape (Dungeness pot), has a metal frame, and is covered with a wire mesh. Two cone-shaped tunnels are normally placed at opposite sides of the rounded surface of the pot. The lower flat portion of the pot is weighted so that

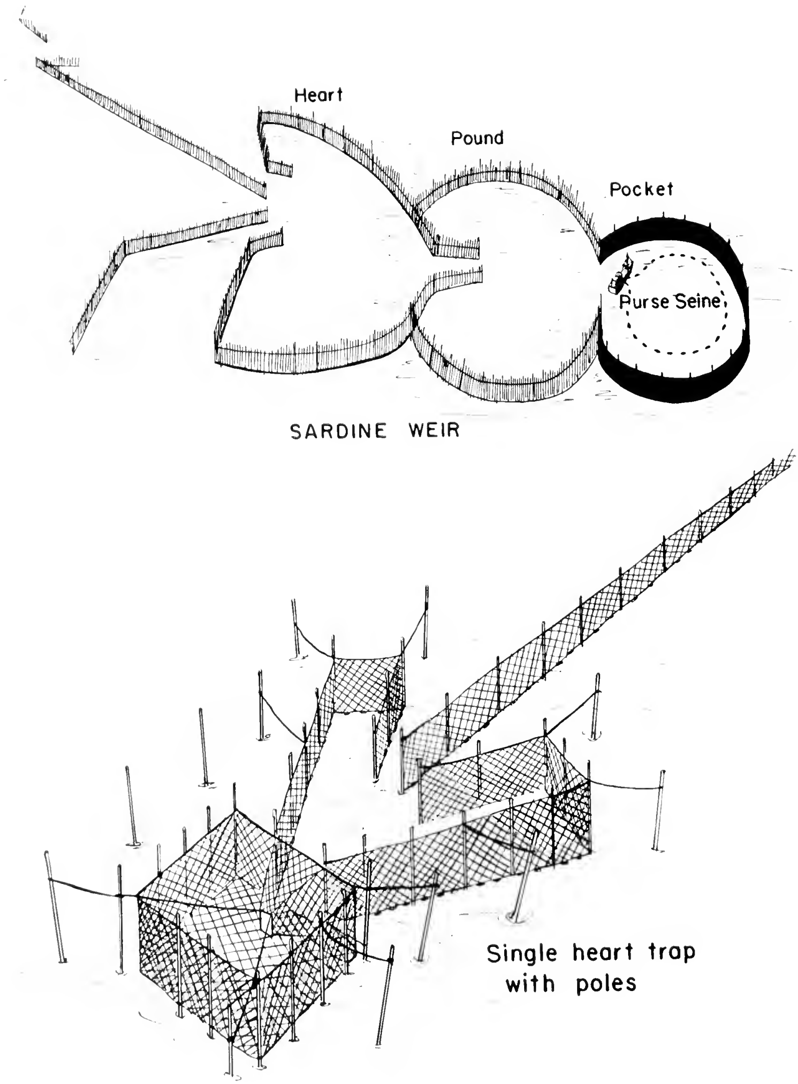

Figure 4.3. Traps. (*Dumont and Sundstrom, U.S. Fish and Wildlife Service.*)

when dropped into the water it will come to rest on the bottom. The Alaska king crab pots may be similar in design, only much larger, and they are also made rectangular. Lobster pots used off the East Coast of the United States are made of either wood or metal. The frames are often formed so that the top is domed or crescent-shaped. Wood lath or wire mesh is used to cover the frames.

When fishing, the position of the pot is marked with a float to which a line leading to the pot is attached. To keep the hauling line from fouling or chafing on the bottom, or against the pot, a small float is placed several feet above the pot on the haul line.

Fish traps have been used in the United States for many generations, and are still used to fish sardine, salmon, and other species. In a large fish trap a long lead is used to guide the fish through a series of progressively smaller tunnels and compartments. The basic design of fish traps (Figure 4.3) is similar in most areas of the United States, having a lead of webbing, wire mesh, poles, or laths to guide the fish into the outer heart chamber and finally into a pocket or bag from which the fish are removed. The fish may be brailed or seined from the trap pocket.

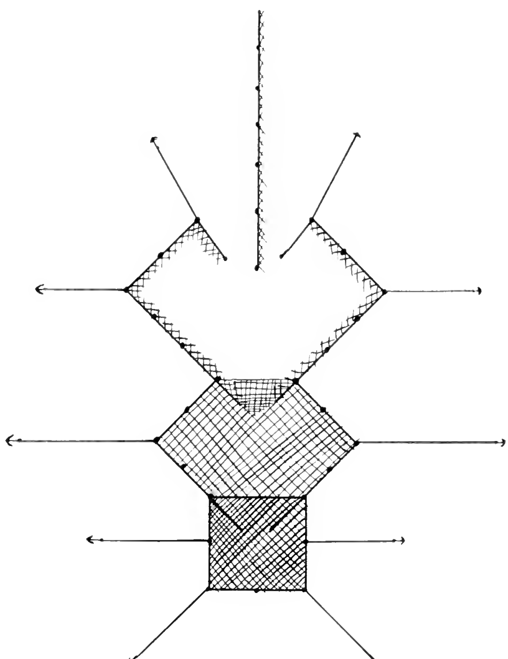

Figure 4.3 (*cont'd*)

In some traps several outer heart-shaped chambers are made. At times the outer hearts are referred to as "jiggers."

Hook and Line Techniques

Hook and line methods are used throughout the world. The objective of modern hook and line fishing is to orient fishing lines in such a manner as to obtain maximum geographic coverage by the hooks while at the same time minimizing the amount of effort required to handle the paraphernalia.

Hook and line fishing can be divided into four categories: (1) hand lines, (2) pole and lines, (3) troll-line fishing, and (4) long lines or set lines. In hand-line fishing the gear consists of a single line, sinker, and perhaps several hooks. In the United States this type of fishing is practiced commerically only in the Gulf of Mexico snapper fishery and in some of the smaller inshore fisheries.

The use of the pole and line in major commercial fisheries is most prominent in the exploiting of tuna and mackerel-like fishes. Basic gear for pole and line fishing of tuna consists of short bamboo poles ranging from 7 to 17 feet in length and fishing lines composed of several sections. In the California tuna fishery, the ends of the poles are laced with a linen or nylon loop to which a 2½- to 4-foot length of heavy cotton line is attached. From the cotton line a wire leader made up in two sections is added, with a barbless hook or feathered jig attached to the end of the leader. At times when extremely large fish are encountered two poles are joined to a single leader and one fish hauled from two poles. The length of the poles and leaders is determined by the size and behavior of the fish. In the United States yellowfin, skipjack, and albacore tuna are the principal species harvested by this method.

Troll fishing adds motion to the bait or lure being used. Simple trolling may be conducted by one line. However, in modern trolling, such as in the Pacific salmon fisheries, as many lines as possible are used. To achieve spatial distribution of the lines, outriggers or spreader poles are used. The fishing lines are attached to tag lines which are tied to the trolling poles. At the end of the trolling line heavy "cannon ball" weights are placed which may weigh from 18 to 50 pounds. Four or five lures or baited hooks, spaced approximately 6 feet apart, are fished from the end of the main line to which the cannon ball weight is attached. The number of lines which may be fished from a trolling vessel is, in some areas, governed by conservation laws. During fishing, the vessel moves forward slowly (the speed dependent on the fish sought) giving action to the lures.

In the more advanced line fisheries, long lines are used. The general design of the longline is rather simple, being constructed of a main line with a number of droppers (gangens or offshoots) to which baited hooks are attached (Figure 4.4C). Longlines may be fished on the bottom, at intermediate depths, or near the surface. The advantage of the longline method of fishing is that it allows fewer men to handle a large number of hooks which can be fished over a wide area. The halibut fishery of the Pacific Northwest is a good example of one of the world's principal longline fisheries. The basic unit of gear in this fishery is a skate which consists of a groundline usually made up by joining six 50-fathom lengths of hemp line. The hooks are attached to 5- or 6-foot long gangens which are spaced along the groundline at intervals of 13 to 18 feet. Each skate containing 100 to 120 hooks is coiled and baited prior to fishing. When the gear is ready to set, a flag marker, buoy keg, and anchor are thrown overboard 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 fished or "soaked," one end of the longline is picked up and the gear retrieved using a power gurdy controlled by a fisherman at the rail of the vessel. As the fish are brought to the surface they are gaffed and lifted aboard. During the process the lines are recoiled, baited, and made ready for another set.

Pelagic (floating) longline gear which is used in many areas of the world is similar to that described for halibut; however, the gear is suspended from a number of floats and the droppers spaced a considerable distance apart (approximately 15 fathoms). The basic unit of gear in the Japanese floating longline is the basket which contains a main line to which are attached approximately 12 to 14 hooks, each spaced 15 fathoms apart. Prior to setting, the main lines from each basket are knotted together so that the desired number of baskets may be fished in a string. Floats are attached to the gear as it is being set, and as in the halibut fishery, markers are set at each end of the string. A special line hauler is used to haul and coil the gear.

Nets

Many types of nets are used to exploit fishes, the most important of which include encircling nets, trawls, and drift nets.

Encircling nets are the most important type used to capture fish. The most advanced encircling net is the purse seine (Figure 4.4A). The purse seine is a wall or modified wall of net which is used to encircle a school of fish. The top of the net is fitted with a number of floats, while the bottom of the net is weighted. A pursing cable threaded through rings under the net allows the fisherman to close off or pouch the bottom of the net,

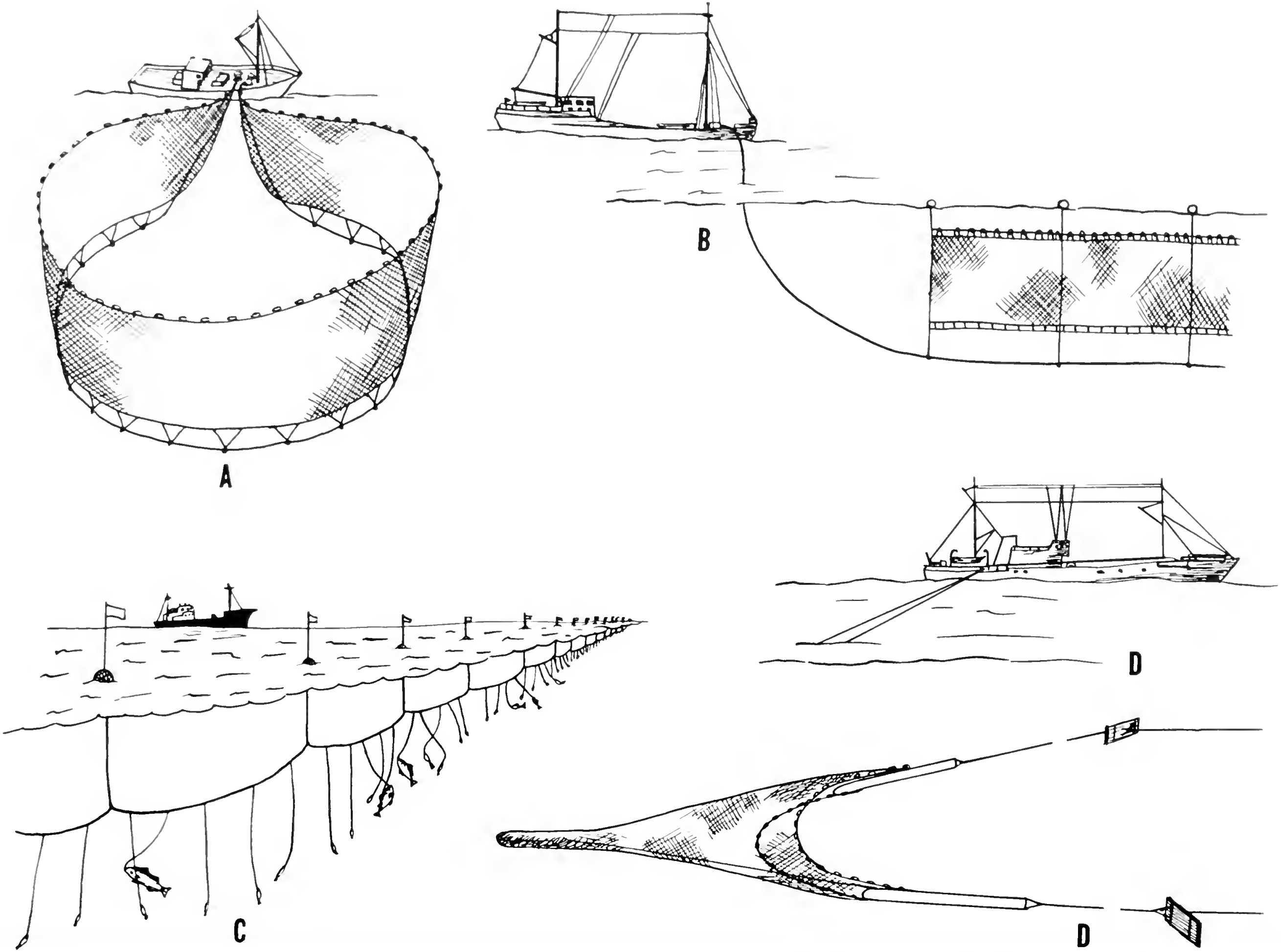

Figure 4.4. Four methods of high-seas fishing: A. Purse seining; B. Drift or gillnetting; C. Long lining; D. Otter trawling.

thus trapping the fish in an inverted umbrella-shaped enclosure. The enclosed fish are then drawn to the vessel, and the fish subsequently brailed or pumped aboard.

There are essentially two techniques[6] used to set and haul purse seines throughout the world. The two-boat system is commonly used on the East Coast of the United States in the menhaden fisheries. This system utilizes two small seine boats (32 to 36 feet in length) to carry and set the gear. Each seine boat carries approximately one-half the net, and the boats run side by side until a school of fish is located. When the fish have been located, the two seine boats begin setting their respective ends of the net, running first in opposite directions and subsequently forming a large circle around the school of fish. Pursing is accomplished using a small winch in one of the two boats. The net is then hauled by hand from each end by crews in the small boats (or power blocks mounted in the small boats) until the fish are sufficiently raised and concentrated. A large vessel then comes alongside and removes the fish from the net with either a large brail or fish pump.

One-boat seining is generally practiced on the Pacific Coast of the United States in the salmon, herring, and tuna fisheries. Seines carried on the tuna vessels may be extremely large, ranging to 600 fathoms in length and 45 fathoms in depth[3]. The net is carried aboard the main fishing vessel. A small auxiliary boat called a skiff is used to facilitate the operation. When surrounding a school of fish, one end of the net is attached to the skiff which begins towing away from the seiner as the larger vessel encircles the fish. When the encircling operation has been completed, the net is pursed from the large fishing vessel, hauled aboard using a power block (or by strapping) until the fish are sufficiently concentrated, and then brailed or pumped into the hold.

Drum seining is peculiar to the Pacific Northwest. In hauling and setting, the operation is similar to that used in the one-boat operation described above. It differs only in having a large drum onto which the entire net is spooled during hauling. Most drums are hydraulically powered; however, some use mechanical shafting and gearing.

The lampera net differs from the purse seine in lacking rings and having a relatively large, simple bunt area and comparatively short wings. The mesh in the wings is generally large, while that in the bunt is quite small. This type of gear has been used extensively to take bait for use in the California pole and line tuna fisheries. The gear is set in a circular fashion, similar to that of the purse seine, and hauled by pulling both wings simultaneously.

Trawling is the most important fishing method used to harvest demersal fishes such as flounder, cod, etc., which normally inhabit waters near the sea bed. The trawl (Figure 4.4D) is a conical-shaped net which has a wide mouth and tapers to a sock-like end which is referred to as the "cod end." Trawls may be subdivided into several categories depending on the method used to spread the net. In the United States two trawling techniques are used, the beam trawl and the otter trawl. The beam trawl which is used in the Alaska and California shrimp fisheries uses a long, tapered wooden beam to spread the mouth of the net. To the ends of the beam "U"- or "D"-shaped runners are attached. The net is secured to the beam and runners. Unlike most trawls, the net is not always tapered to a cod end.

The mouth of the otter trawl is opened by boards (doors) which are kite-like devices which shear in a horizontal direction. In the United States two different techniques are used in operating otter-trawl gear. On the East Coast the towing davits are arranged on the same side of the fishing vessel and the net is shot and hauled from the side of the vessel. On the West Coast small multi-purpose vessels, when engaged in trawling, have a davit on each side of the stern. The net and boards are shot or set over the stern and retrieved over the starboard side aft.

Bull trawling or two-boat trawling is another method used to tow large trawls. One vessel has the towing warp attached to one wing of the net, while the other vessel has the towing warp attached to the other wing. This technique was used off California during the development of the early trawl fishery, but it has now been replaced by otter trawls. Two-boat trawling, however, is still extensively carried on by the Japanese.

Trawling is conducted in the shallow seas and on the continental shelf and slope to depths of about 500 fathoms.

Midwater trawling was initiated in commercial fisheries after World War II. An excellent review of midwater trawls has been made by Parrish[4]. The midwater trawl has the same sock-like shape as otter trawls. The trawl is generally cut so that the net is square in shape; that is, the side, top, and bottom of the net have similar shapes and dimensions. Various techniques are employed to open the mouth of the net, including two-boat or pair trawling, especially designed boards, depressors, and kites. These nets are used to harvest fish when they school in "mid depths" and have been effective for harvesting herring-like and cod-like fishes.

Driftnets, gillnets (Figure 4.4B), tanglenets, and trammel nets are merely vertical walls of webbing which are normally set out in a straight line. The capture of fish is based on their fortuitous encounter with the nets. Driftnets may be set at the surface or fished off the bottom (diver nets) or at intermediate depths. The top of the net is buoyed with floats and the bottom weighted with leads so as to keep the net in an upright position. Vessels handling gear of this type generally haul the nets over a powered roller rigged amidship.

Special Capture Methods

There are a number of fishing techniques which rely on physical-chemical stimuli such as light, electricity, and odors. Of these, lights are by far the most important. Lights are used in a wide variety of fisheries to attract fish into traps or to aggregate them so they may be netted. Lights are widely used to facilitate capture of bait fishes in the United States and are employed in large-scale commercial fisheries in Europe and Asia. Electricity for shocking or guiding fish has been used experimentally since the end of World War II. It has not yet, however, been extensively employed in marine fisheries. Experiments using electricity to aggregate fish into intakes of fish pumps have been conducted in the East Coast menhaden fishery. The fish, which have been previously captured by a seine, are drawn to the mouth of the pump by "electrotaxis." Guiding herring into nets or traps by use of a wall or stream of air bubbles has been experimented with and employed with some success in the northeastern part of the United States.

Fishing Vessels

Many types of fishing craft are used in the United States. The most common include the Pacific troller, Pacific combination vessel, halibut schooner, tuna clipper, Atlantic troller, gulf shrimper, and gulf snapper vessels[1].

Pacific Troller. The Pacific troller is the most common fishing craft operating in waters contiguous to the West Coast of the United States and Canada. These vessels which range from 25 to 60 feet in length are normally constructed of wood. They range from 5 to 26 tons and have a cruising speed of 6 to 10 knots. The most distinguishing characteristics of the Pacific troller are the paired outriggers or poles which are used to secure a number of "tag lines" from which the trolling lures are towed. When fishing, the outriggers are lowered to an angle of about 50 degrees from the water.

Combination Vessel. Pacific combination vessels (Figure 4.5) range from about 50 to 100 feet in length. They are referred to as the "seiner type" having the house forward and work area aft. These vessels operate in the halibut, salmon, herring, otter trawl, shrimp, and albacore-troll fisheries.

When rigged for purse seining, the seine table is fitted on the stern and the bulwarks cut away to allow the table to swing during fishing operations. A small purse winch is located just aft of the house. The large bulky net and corks are stacked on the seine table. The innovation of the power block has eliminated the necessity of the seine table, and many vessels now operate purse-seine gear without the table. Large seine skiffs are usually towed when on the fishing grounds or stowed atop the net when running to or from port.

If the combination or multipurpose vessel is operating in the line fisheries, the seine table may or may not be removed. A baiting table

Figure 4.5. Pacific combination vessel.

is built up normally on the port side. A small steel chute is mounted on the stern, a gurdy for hauling the line gear is placed aft of the house, and a roller is mounted on the guard rail.

When trawling, a pair of heavy gallows frames are secured, one on each side of the stern, and a large winch mounted just aft of the house. This winch may have paired drums facing the bulwarks and towing cables running first athwartships and then around blocks aft to the gallows frames. Others have the winch drums divided, one on each side of the vessel, with the towing cable leading directly aft to the blocks on the gallows frames.

In the past five years many Pacific Northwest "seiner-type" trawlers have been converted to "drum trawlers." The trawl doors, gallows frame, and winch which identify the typical "multipurpose trawler" are all used in drum trawling. The only addition is the drum mounted near the stern for spooling parts of the net.

Pacific Halibut Schooner. The Pacific halibut schooner (Figure 4.6) was one of the earliest U.S. deep-sea fishing craft operated in the Northwest. The vessels, which appeared on the fishing scene shortly following

Figure 4.6. Pacific halibut schooner.

1900, were designed as a cross between the Gloucester sailing craft and the Norwegian motor cutter.

Pacific halibut schooners range from about 50 to 100 feet in length. The house and engine are aft, with work space amidships. In most of the older craft the living quarters were forward in a raised forecastle. This area also included the galley. On some of the larger, more recent schooners, additional living quarters are provided aft, below decks. The typical halibut vessel is rigged with two masts, one at the forecastle break and one just forward of the house. A dory may be carried atop the house or on a support built alongside the house.

Tuna Clippers. The tuna clipper (Figure 4.7) is one of the few fishing craft operated in the United States that can be considered a design developed for a U.S. fishery. The modern U.S. tuna clipper is a large complex craft capable of operating thousands of miles from home port. Modern clippers are identified by the raised deck forward running aft past amidships. The main deck which is extremely low aft is awash much of the time. A number of raised wells or tanks used for carrying live bait are on the stern. A covered canopy is normally built over the three after wells.

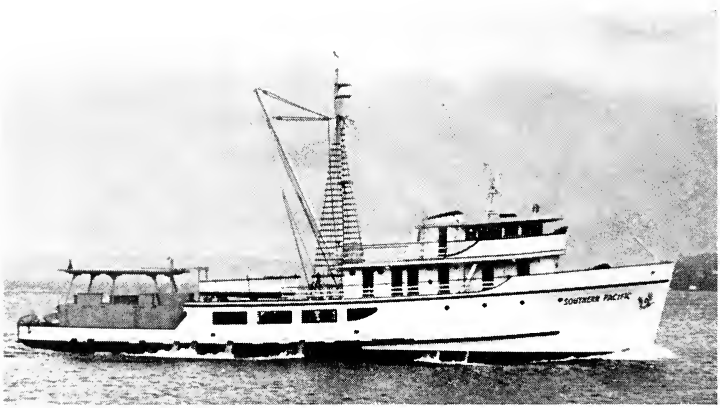

Figure 4.7. Tuna clipper.

Fishing is conducted from steel racks hung outboard over the main deck rail along the port side of the ship adjacent to the canopy and around the stern. During running, the steel racks are pulled inboard. The fishing paraphernalia consists of short bamboo poles from which feathered jigs or live bait are fished. The poles are stored in overhead racks built below the canopy top. Clippers range from about 80 to 170 feet in length and are constructed from wood or steel. They operate in waters from lower California to Chile, and in some summer months may work their way north along the Oregon and Washington coasts in pursuit of albacore tuna.

Tuna Seiners. In the past several years there has been a rapid conversion of pole-and-line clippers or bait boats to purse-seine boats[3]. To accommodate the large seine and accessory fishing equipment, the bait wells aft are removed and the stern area remodeled to accommodate a seine table or net platform. A large purse winch and new mast and boom are installed, and the vessel is equipped with a hydraulic-driven power block. The booms of the tuna seiner are probably the longest of any fishing vessel of this size. Although the forward parts of the vessels are unchanged, the vessels appear denuded in contrast with the clipper rigged for bait fishing.

Gulf-of-Mexico Shrimper. The Gulf shrimp trawlers (Figure 4.8) which range from about 30 to 90 feet in length are mostly of wood construction, although steel is used at times. The above-water lines of the ship are similar in many respects to the West Coast multipurpose seiners, having

Figure 4.8. Gulf shrimp trawler.

a low house forward and work space aft. Although Gulf shrimp vessels operate trawl gear, they do not normally utilize the gallows frames (stanchions and A-frames) which characterize West Coast and Atlantic bottom fish trawlers. The vessels may be identified by double towing booms that are secured to the main mast and a larger lifting boom. Towing booms which run athwartships are secured with stays running from their tips to a point on the bulwark and upper hull forward of the house. In the small, single-rigged vessels (fishes one net) the towing booms are short (contrasted with the main mast), while in the double-rigged Gulf shrimpers (fishes two nets simultaneously) the towing booms exceed the length of the main mast, and the lifting boom is modified by fitting a cross-tee at the terminal end. The lifting boom in the twin-rigged shrimper is secured to the stern by a boom backstay ratline structure and single block tackle running from the ends of the cross-tee athwartships to each side of the stern. The trawl winch is placed amidships between the main mast and the hatch.

In operation, the net is towed from warps (cables) which pass from the winch through a block at the tip of the towing boom. In single-rig towing the two warps pass through (usually starboard) the blocks on the same boom, and in double-rig towing a single warp passes to blocks at the end of each boom.

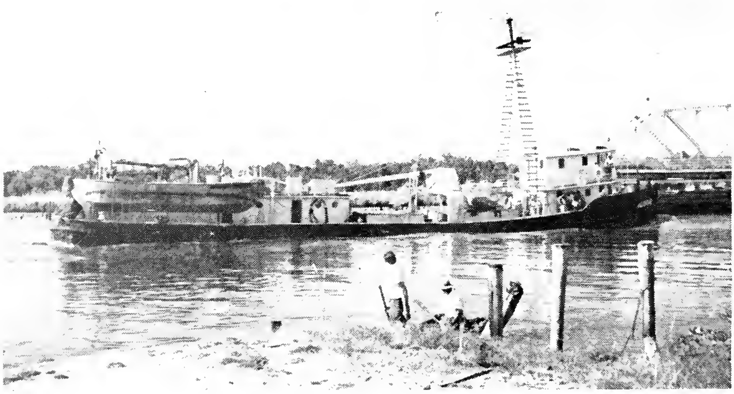

Figure 4.9. Menhaden purse seiner.

A few shrimpers (luggers) have the house aft and winch forward. The towing cables are led through blocks over the house. The luggers have a small platform area aft.

Gulf trawlers (often referred to as Florida trawlers) are found from North Carolina to Florida along the Atlantic Coast and throughout the Gulf of Mexico, and in recent years they have worked off the coasts of Central and South America. Some vessels of this type also fish in the Gulf of Panama.

Menhaden Purse Seiner. Menhaden purse seiners (Figure 4.9) should perhaps be classified as fish packers rather than catchers as they do not participate in the capture of fish, although they do assist in locating them. The typical menhaden purse seiner has a house forward, work space or pumping area amidships, and a house on the stern. The stack is brought through the aft house which is usually a trunk over the engine room. It is the only American fishing vessel with this particular superstructure arrangement.

Menhaden purse seiners range from 80 to 200 feet in length, are of rather narrow beam, and may be of wood or steel construction. The vessels operate along the Atlantic seaboard from Cape Cod to Florida and throughout most of the Gulf.

Snapper Schooner. The Gulf snapper vessel is a two-masted schooner normally rigged with sails fore and aft. One of the few U.S. offshore craft still using single-line fishing technique, the snapper schooner is

Figure 4.10. Atlantic trawler.

rigged with a number of hand-operated fishing reels. The reels are mounted along both the port and starboard bulwarks. Snapper schooners which range from about 35 to 100 feet in length carry a crew of 2 to 10 fishermen. The vessels, of wood construction, operate adjacent to the Gulf States and off Campeche, Mexico.

Atlantic Trawler. These vessels (Figure 4.10) range from about 40 to 140 feet in length and may be constructed of wood or steel. The house is aft, and on the larger vessels there is a raised forecastle deck forward. Large trawl winches are placed just forward of the house. The vessels have large gallows frames, one set just ahead of the forward mast and the other aft, alongside the house. Many of them carry davits on both sides. During running, the large trawl doors may be set inboard alongside the rail between the gallows and the bulwarks. When towing the net along the sea floor, the two towing cables are brought together near the stern of the vessel into a towing block.

The vessel's main area of operation is in the Atlantic Ocean from about Massachusetts north to the Grand Banks. Occasionally trips as far as Greenland are undertaken.

Scallop Boats. Scallop trawlers operating along the Atlantic Coast may be considered a conversion of the Atlantic trawler. The only changes necessary for scallop fishing are the addition of two booms which are secured to the forward mast and used for handling the heavy dredges. Shucking tanks for cleaning scallops are mounted along the rails on both sides of the vessel. The forward gallows frames found on the normal trawler are retained, although at times the aft frames may be removed.

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PART II

Description of Important Fisheries and Their Products

CHAPTER 5

The Bottom Fisheries

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The various terms bottom fish, ground fish, and demersal fish are used to describe the kinds of fish that live on or near the ocean bottom in a range ordinarily limited by the continental shelf. On the East Coast of the United States this range extends out in places over 200 miles, while the West Coast is characterized by a much narrower shelf extending only about 10 miles. On this relatively narrow strip of ocean floor live and breed the fish which together comprise one of the most lucrative fisheries of the United States. In New England, ocean perch, haddock, whiting, cod, pollock, and the various flounders and soles are the most important of New England's fisheries resources. These, plus the West Coast species such as halibut, rockfishes (including Pacific Ocean perch), Pacific cod, and the "soles" native to that coast, account for over 13 per cent of the fish landed in the United States with total landings of about 674 million pounds valued at 47 million dollars[13].

In the following sections the handling methods that are used aboard the vessel and ashore for these important species are described in detail.

Haddock

The haddock fishery is presently New England's most valuable ground fish resource. With landings of 112,629,000 pounds in 1959, this fishery nationally ranked 11th both in pounds landed and in value of the catch[13]. Landings have varied greatly in the past, ranging from a high of about 294 million pounds in 1929 to a low of 45 million in 1934. The growth rate of haddock is quite rapid with the young entering the fishery as scrod haddock weighing 1½ to 2½ pounds when only 2 to 3 years old[3].

Handling at Sea. The vast majority of haddock are caught by otter trawling; a small inshore fishery using line trawls or gill nets accounts for the remainder of the landings.

After the fish are dumped from the trawl net on the deck of the vessel, they are eviscerated (in hot weather the gills are also removed), washed, sorted (or culled) into size groups (see Table 5.1), and iced down in pens in the vessel's hold. The amount of ice used varies with the season of the year, but in general about one pound of ice is used for two pounds of fish. The average trip lasts for 10 days, and fishing goes on 24 hours a day while the vessel is on the banks.

Handling at the Wharf. On arrival at the Boston Fish Pier, the fish are sold at auction and unloading is begun. The typical unloading operation involves the following: The lumpers (stevedores hired by the crew) pitchfork the haddock from the vessel's pens into canvas baskets holding about 100 pounds of fish. The baskets are hoisted out of the hold by means of a winch mounted on the vessel's foredeck, swung over to the wharf, and dumped into tared weighing boxes. When 500 pounds have been dumped into the weigh-box, the fish are transferred by means of pitchforks to carts, barrels, or other boxes for transport to the processing plant, which may be located from a few yards to as much as half a mile from the unloading site. About 25 pounds of ice are added to each 100 pounds of fish to keep them cool while awaiting processing.

At other ports, where haddock is a minor part of the catch, mixed sizes of the fish plus some ice are dumped directly onto the wharf and sorted into wooden boxes on platform scales by means of pitchforks. The boxes, when full, contain 100 pounds of haddock plus about 25 pounds of ice and are shipped directly to the fresh-fish market.

Processing. Fresh (unfrozen) haddock fillets account for slightly more than half of the haddock production in New England. The remainder of the fillets are frozen, primarily in one-pound consumer packages.

In a typical processing plant, the scales are removed by passing the haddock on a conveyor belt under a series of revolving serrated disks or stiff brushes. In some plants, where haddock is of secondary importance to other species, they may be scaled by hand or in a rotating cylinder of expanded metal. After scaling, the fish are filleted and in some cases skinned either by hand or machine.

Packing. Fresh fillets are ordinarily packed in 10, 20, or 30-pound fillet cans. The cans are rectangular, measuring about 15¼ inches long by 10½ inches wide with the depth varying depending on capacity. The cans are either enamelled or tin-plated. Recently, wax-impregnated

TABLE 5.1. MARKET CLASSIFICATION FOR VARIOUS SPECIES OF BOTTOM FISH*

Species	Market Classification	Approximate Weight, size or number
Haddock	Large	Over 2½ lbs
	Scrod	1½ to 2½ lbs
	Snapper	Under 1½ lbs
Cod	Whale	Over 25 lbs
	Large	10 to 25 lbs
	Market	2½ to 10 lbs
	Scrod	1½ to 2½ lbs
	Snapper	Under 1½ lbs
Pollock	Large	Over 4 lbs
	Scrod	1½ to 4 lbs
Whiting	—	½ to 4 lbs
Ocean perch	Mixed	½ to 3 lbs
Flounders and soles, blackback	Large	¾ to 2½ lbs
	Small	Under ¾ lb
Dab	—	1 lb and over
Gray sole	Large	2 lbs and over
	Small	Under 2 lbs
Lemon sole	—	2½ lbs and over
Yellowtail	Large	1 lb and over
	Small	Under 1 lb
Dover sole	Large	24 to 30 in.
	Small	10 to 23 in.
English sole	Large	13 in. and over
	Small	11½ to 13 in.
Petrale sole	—	16 to 18 in.
Rex sole	—	11½ in. and over
Scup	Large	1 to 2 lbs
	Medium	½ to 1 lb
	Small	Under ½ lb
Rockfish	—	4 to 5 lbs
Snapper	—	2 to 20 lbs
Butterfish	Jumbo	½ lb and up
	Large	200 to 300 per 100 lbs
	Medium	300 to 350 per 100 lbs
	Small	Over 350 per 100 lbs
Sablefish	Large	5 lbs and over
	Small	Under 5 lbs
Sea bass	Large	1¼ lbs and up
	Medium	¾ to 1 lb
	Small	Under ½ lb
Lingcod	—	5 lbs and over
Grouper	—	5 to 15 lbs

* Adapted from "Fresh and Frozen Fish Buying Manual," Circular 20, U.S. Department of the Interior, Fish and Wildlife Service, 1954.

corrugated or fiberboard fillet cartons have been introduced which cost significantly less than the fillet cans and have sufficient strength and moisture resistance to be suitable for the purpose intended. The fillets may be layer-packed in the cans or $\frac{3}{4}$ to 1 pound of fillets are wrapped in cellophane and then packed in the cans. The filled cans are then iced down in wooden boxes or barrels for shipment to market.

Fillets to be frozen are generally brine-dipped after filleting and before going to the packing line. The brine used ranges in concentration from 10 to 45° salinometer and the immersion time varies from 3 to 15 seconds. An escalator conveyor removes the fillets from the brine tank and dumps them either onto a conveyor or into a shallow bin. The conveyor takes the brined fillets to the one-pound packing line where each woman packer has a scale on which she packs, then weighs, the filled carton and adjusts the weight if necessary by adding or subtracting small pieces of fish cut from larger fillets. Experienced packers rarely need to use the scales, and on some packing lines no scales are used, the cartons being only spot-checked for weight before going to the overwrap machine.

The cartons used measure $1\frac{3}{16} \times 3 \times 8\frac{1}{2}$ inches and are typically of one-piece construction made from waxed paperboard. Waxed, bleached sulfite paper is applied to the cartons by standard overwrapping machines. The wrapped packages are placed in trays and frozen in plate freezers. When frozen, the packages are transferred to corrugated master cartons containing 12 or 24 packages and put in cold storage.

When 5 and 10-pound packages are to be filled, the fillets are scooped from the shallow bin, weighed out in 5 or 10-pound lots, dumped into the bottom half of a two-piece waxed carton, and conveyed to the packing line. The women packers wrap $\frac{3}{4}$ to 1 pound of fillets in cellophane and place the packs in another bottom half of the two-piece carton. When filled, the cartons are covered and conveyed to the end of the packing line where they are placed in trays for freezing in either sharp or plate freezers, or occasionally they are placed in racks for blast freezing. After freezing, the packages are put in master cartons containing five 10-pound or ten 5-pound packages and transferred to cold storage.

Quality Considerations. There is considerable variation in quality of the haddock unloaded from the typical Georges Bank trawler. Usually the best quality "last-caught" fish are used for the fresh fish trade while the "first-caught" are frozen "before they get any worse." Quality loss may also occur during unloading and processing. Chief reasons for these losses are as follows:

Pitchfork. The two-tined forks customarily used are responsible not only for physical damage to the flesh, but the holes produced provide easy access for bacteria present in large numbers on the skin of the fish.

Temperature of Fish and Fillets. The time interval between unloading and processing may vary from a few minutes to many hours when, during glut periods, fish have to be held overnight. Often the quantity of ice used is not sufficient to keep the fish at or near 32°F, and spoilage bacteria have a chance to multiply very rapidly. Temperatures as high as 50°F have been observed in haddock fillets as they are being packed into fillet boxes for shipment. Cooling tests at the Gloucester laboratory, U.S. Bureau of Commercial Fisheries, have shown that 48 hours are required to cool 20-pound fillet boxes packed in ice from 50°F to 32°F. During this period considerable bacterial growth can occur with resulting quality loss.

Sanitation Storage boxes, conveyor belts, cutting boards, and other surfaces in contact with the fish pick up scales, slime, and fish juice and, if not cleaned frequently and thoroughly, provide excellent growing places for bacteria. Brining solutions are generally changed every two hours, but even in this short period large quantities of bacteria will accumulate in the solution and may heavily contaminate relatively clean fillets.

Cod and Pollock

These species account for only 1.7 per cent of total United States' landings of fish, despite the relative abundance of the fish on the grounds.

Handling methods aboard the vessel and ashore are practically identical with those for haddock except that the larger sizes of cod may be cut transversely into steaks rather than be filleted.

Whiting

The whiting or silver hake is a very abundant species, but only in recent years has it been fished extensively. Since 1933, when less than 9 million pounds were reported, the fishery has increased quite steadily to over 115 million pounds in 1959. Although landings of whiting were 2½ million pounds higher than those of haddock in 1959, the value of the whiting catch was less than ¼ that of the haddock[13]. In addition to great differences in value, the handling and marketing methods used for these closely related species are also vastly different.

Handling at Sea. As with other ground fish, the majority of the catch is made by otter trawling. Pound nets and traps account for most of the remainder[1].

Most whiting are landed in the round and are not sorted by size at sea. However, at some ports, notably Provincetown, Massachusetts, the whiting are headed and gutted at sea by the fishermen.

Handling at the Wharf. In Gloucester, Massachusetts, whiting may be weighed in the unloading baskets, such as are used for haddock, or dumped from the baskets directly onto a conveyor and carried to a weighing station where they are weighed in 500-pound lots. In other cases, the conveyor deposits them in a dump truck for transport to a more distant processing plant.

Processing. In the plant the whiting may be processed immediately or held for periods up to 18 hours in storage pens made of wood, steel, or concrete block.

In contrast to haddock more than 99 per cent of the whiting catch is sold frozen[13], and the great majority of the frozen product is marketed in the headed and gutted (H&G) form.

Heading and Gutting. For the production of H&G whiting, the fish are conveyed by belt or sluice to a heading machine where workers place the fish in a V-slotted belt. The belt carries the fish to a circular knife which removes the heads. The headed fish then pass through a rotary scaler where the scales and much of the viscera are removed. From the scaler, the fish go to an inspection table where they are checked for complete removal of the viscera.

Filleting. The large fish are culled out at the heading machine belt and conveyed or carried in boxes to the filleting line. The fillets are cut, brined, and packaged as described for haddock.

Packing H&G Whiting. Typically H&G whiting are packed in 1½, 5, and 10-pound containers. Window-style cartons are often used for the 1½-pound packs while the larger sizes are usually packed in two-piece telescoping cartons.

Each packer fills and weighs the 1½-pound size packs as in packing fillets. The fish are packed alternately thick end to thin end and considerable choosing and rejecting of individual fish may be required before the desired weight is reached. For the larger sizes, the fish may be preweighed and conveyed to the packers (as is done with the fillets) or "volume packing" may be used where each packer fills the box to approximately the correct weight with final adjustment to exact weight being made by one or two checkers at the end of the packing line.

Few processors of whiting have their own freezers so the filled cartons are placed in trays or racks for trucking to a commercial freezer and cold storage warehouse.

Quality Considerations. Aboard the larger vessels in the whiting fishery no shelving is used in the fish pens. The piles of whiting exceed 10 feet in height and the pressure on the bottom layer of fish is well over 850 pounds per square foot. In addition, ice is applied sparingly as the fish are stowed in the pens, resulting in serious loss of quality, particularly during the warm months of the year when whiting landings are greatest.

At the shore plant when fish are to be held in pens before processing, the small quantity of ice unloaded with the fish is depended on to keep the fish cool.

Several hours may elapse before the filled packages are put in the freezer. It is not unusual for the bottom of the packages to become completely water-soaked during this waiting period. In addition, no ice or mechanical refrigeration is used to cool the fish during this period.

Ocean Perch

The ocean perch fishery showed a spectacular increase in importance between 1930 and 1941. During this period landings jumped from 118,000 pounds to 145,000,000 pounds, making this species second only to haddock in volume landed in New England.[1,13] Since 1941 landings have fluctuated somewhat. In 1959 136,703,000 pounds of ocean perch were landed, and nationally this species ranked 8th in volume and 13th in value. All of this catch was landed at New England ports, with 55 per cent going to Maine and the remainder to Massachusetts. Ocean perch grow quite slowly, reaching maturity in about 11 years as contrasted with 3 years for haddock.

Handling at Sea. Otter trawling accounts for all but a very insignificant fraction of the ocean perch landed. Fishing is carried on only during the day since the fish rise off the bottom at night and are impossible to catch with ordinary gear.

The fish are occasionally sorted by size aboard the vessel and are stowed round (uneviscerated) in ice in the vessel's pens, with about one pound of ice being used for two pounds of fish. As fish become scarcer close to New England, the ocean perch vessels have had to make longer trips. Trips of 21 days' duration are not unusual, and 6 days of this period are spent in voyaging to and from the fishing grounds.

Handling at the Wharf. Unloading methods vary considerably at different processing plants, but in general the fish are shoveled by the lumpers from the vessel's pens into unloading baskets, hoisted out of the hold, and swung over to the wharf. Here they may be weighed in 500-pound lots and conveyed directly into the processing plant, or they may be loaded into a dump truck, the truck-load weighed, and taken to a more distant plant.

Processing. Most ocean perch are processed the day they are unloaded from the vessel, but occasional gluts will make it necessary for the processor to store the fish in pens at the plant for as long as 18 hours.

Over 98 per cent of the ocean perch landed is filleted and frozen; the remainder enters the fresh fish trade. Prior to filleting, the fish pass through a rotary scaler and then to a conveyor which carries them to the filleting line. Recently some plants have installed filleting machines for the small fish, but all the large fish and most of the small are hand filleted. Only rarely are the skins removed from ocean perch fillets.

Packing. From the filleting line the fish are conveyed to the brining tank and then to the packing line (Figure 5.2). Fish from some areas may be parasite infested, the fillets from these fish being inspected by candling.

Figure 5.1. Ocean perch iced in pen prior to filleting. (*F. T. Piskur, U.S. Fish and Wildlife Service.*)

A specially constructed table is used for this procedure. Usually a conveyor belt carries the fillets along the center of a wide table. On each side transluscent glass or plastic panels are set into the surface of the bench and illuminated from underneath by incandescent or fluorescent lamps. The candlers inspect each fillet and cut all parasites out of the flesh with scissors. The fillets then go to the brine tank where they are dipped in a salt brine. The concentration varies with different plants but is usually 10° salinometer.

The one-pound retail packages of fillets are filled, overwrapped, and and frozen as described for haddock. In packing the 5 and 10-pound cartons of ocean perch fillets, the fillets may be "volume packed" and check weighed at the end of the packing line or, more often, preweighed at the beginning of the line as described under packing H&G whiting. The large packages are not generally overwrapped but are stacked on

Figure 5.2. Escalator conveyor carrying ocean perch fillets out of brine tank. (*F. T. Piskur, U.S. Fish and Wildlife Service.*)

pallets for transfer to a central freezing plant where they are frozen in shelf coil (sharp) freezers or blast freezers.

Quality Considerations. Aboard the vessels quality may be lost when insufficient ice is used on the fish to cool them to 32°F and maintain them at this temperature for the duration of the trip. Occasionally, vessels have to lay-to during stormy weather. When fishing is resumed, much of the ice on the first-caught fish may have disappeared, and there is insufficient ice aboard to properly preserve the last-caught fish. Thus, both the first and last-caught fish may be of low quality when landed.

Ashore, the ocean perch may be held overnight in pens, piled 5 to 6 feet high. Generally, the fish are not washed before going into the pens to remove the bacteria accumulated on the surface during storage in the vessel, and while liberal quantities of ice may be used to cover the pile of fish, the ice is not mixed into the pile. In such a mass of fish no significant cooling will occur; instead, the fish may warm up as result of bacterial growth and enzyme activity.

As in other filleting operations, the brine may be changed as often as every two hours, but large numbers of bacteria will accumulate in the tank during this period.

In the plants having no freezing facilities of their own, the packaged fish may be exposed to room temperature for several hours before freezing. Considerable quality loss can occur during this period.

Flounders and Soles

In 1959 the United States' catch of flounders and soles amounted to 121,566,000 pounds valued at $12,631,000. The catch, comprised principally of 9 species of flatfish, ranked 9th in volume and 8th in value. New Bedford, Massachusetts alone accounted for 28 per cent of the landings, representing 35 per cent of the total value[13].

Table 5.2. Species of Flounders and Soles of Major Commercial Importance

Atlantic Coast	
Yellowtail	(*Limanda ferruginea*)
Lemon sole and blackback	(*Pseudopleuronectes americanus*)*
Fluke	(*Paralichthys* species)
Dab	(*Hippoglossoides platessoides*)
Gray sole	(*Glyptocephalus cynoglossus*)
Pacific Coast	
Dover sole	(*Microstomus pacificus*)
English sole	(*Parophrys vetulus*)
Petrale sole	(*Eopsetta jordani*)
Rex sole	(*Glyptocephalus zachirus*)

* Lemon sole weigh over 2½ pounds, blackbacks weigh less than 2½ pounds.

The important species of flatfish are listed in Table 5.2. The 9 species shown are caught and processed in much the same manner on both coasts.

Handling at Sea. Otter trawling is the principal method used for catching flounder and sole. Only small amounts are taken with pound nets, gill nets, hand lines, and long lines.

Largely as a result of the higher price paid for flatfish in comparison with ocean perch and whiting, greater care is taken by the fishermen in icing and stowing the catch aboard the vessel. The pens are shelved at about four-foot intervals, and the ratio of ice to fish closely approaches the 1 to 2 figure necessary to cool fish to, and maintain them at, the temperature of melting ice.

Handling at the Wharf. Unloading operations are similar to those used for other species of fish. At some plants the fish are iced in boxes for holding prior to processing while in other plants storage pens may be used.

Processing. Large quantities of the flounders landed on the Atlantic Coast are shipped whole in ice to the fresh fish markets. The only processing involved in this operation is that of shoveling about 25 pounds of ice and 100 pounds of fish into wooden boxes and nailing on the cover.

All filleting is done by hand as no machine has yet been developed capable of doing this job. Scaling machines are not generally used since the majority of plants skin the fillets from both the dark and light sides of the fish. Previous to the adoption of efficient skinning machines many packers skinned only the dark side of the fish.

About 75 per cent of the flounder fillets produced on the Atlantic Coast are marketed in the unfrozen state. Packing procedures are essentially the same as for fresh haddock fillets described above. On the Pacific Coast, only 45 per cent of the fillets are marketed unfrozen.

On the Atlantic Coast, fillets to be frozen are brine-dipped before packing. Some processors claim that varying sensitivity to salt in the fillets is found in different market areas with the result that they vary the brine strength slightly in the range of 10 to 14° salinometer to suit a particular market. On the Pacific Coast, brining is ordinarily omitted.

Packing procedures are very similar to those described for haddock. For the 5 and 10-pound sizes, some packers use a volume pack as is described for whiting. Freezing and storage procedures are also very similar to those used for haddock.

Quality Considerations. There appear to be no quality considerations peculiar only to the flounder and sole fishery, with exception of the occurrence of a jellied condition found in the fillets of soles taken from certain deep water areas off the Pacific Coast and sporadically from various areas on the Atlantic Coast. The individual packers are relied on to cull out the jellied fillets.

Miscellaneous

There are numerous other species of bottom-dwelling fish, the most important of these being listed in order of decreasing economic importance in Table 5.3. With the exception of lingcod, most of the catch of

TABLE 5.3. MISCELLANEOUS SPECIES OF BOTTOM FISH

Species		Area	Principal gear
Scup or porgy	(*Calamus* and *Stenotomus* species)	Atlantic	Otter trawls
Rockfishes	(*Sebastodes* species)	Pacific	Otter trawls
Snappers	(Principally *Lutjanus* species)	Gulf	Hand lines
Butterfish	(*Poronotus triacanthus*)	Atlantic	Otter trawls
Sablefish	(*Anoplopoma fimbria*)	Pacific	Otter trawls
Sea bass	(*Centropristes striatus*)	Atlantic	Otter trawls
Lingcod	(*Ophiodon elongatus*)	Pacific	Otter trawls
Groupers	(*Epinephelus and Mycteroporca* species)	Gulf	Hand lines

these species enters the fresh fish trade whole, dressed, or as fillets. Handling methods are very similar to those described in detail for the other species and there do not appear to be any major problems peculiar to these species alone.

Fish Sticks

A relatively new type of product which has been increasing rapidly in usage during recent years is the breaded fish sticks and the related fish portion. Since these products are manufactured from groundfish such as cod and haddock, their production and manufacturing methods will be discussed here.

Fish sticks are rectangular, frozen portions of fish flesh that have been sawed or cut from blocks of frozen fish fillets, coated with batter, breaded, and then usually precooked before being refrozen. Fish sticks were the first such product to be developed, and their United States production has reached a fairly stable quantity of the order of 60 million pounds or so per year. Fish portions are uniformly shaped, frequently square, pieces of boneless fish flesh cut from a frozen block of fillets, battered, breaded, and usually marketed uncooked. These fish portions, because of their uniform size, are much in demand for use in restaurants and institutions. Breaded portions are a more recent development than fish sticks, and their annual production in the United States is still rapidly increasing. From 1958 to 1961, United States fish portion production increased from 22 million pounds to 60 million pounds. Production of various forms of breaded fish sticks and fish portions is shown in Table 5.4.

The largest production of fish sticks takes place in the Atlantic Coast states, particularly in Massachusetts where the groundfish industry is centered. However, an increasing proportion of the manufacturing of these products is now located in other areas, with several plants, for example, now operating in the Midwest and in California. Most of the frozen fish blocks from which the sticks and portions are prepared are imported from Canada, Iceland, or elsewhere.

Table 5.4. Production of Breaded Fish Sticks and Fish Portions in the United States in 1961

Commodity	Production	
	Millions of pounds	Millions of dollars
Cooked fish sticks	65.1	27.8
Raw fish sticks	4.8	1.7
Total cooked and raw fish sticks	69.9	29.5
Cooked fish portions	11.3	4.6
Raw fish portions	46.9	15.8
Total cooked and raw fish portions	58.2	20.4

In the following sections the steps used in the manufacture of fish sticks will be described. These include (1) the freezing of fillet blocks, (2) cutting of sticks from the frozen blocks, (3) breading and battering of the fish sticks, (4) cooking of the coated sticks, and (5) packaging and refreezing of the sticks. Fish portion production is carried out in a fairly similar manner. When raw sticks, a minor item, are prepared step (4) is omitted.

Freezing of Fillet Blocks. Since fish sticks are cut to a stipulated dimension and a certain number placed in a package to give a predetermined weight, it is vital that the frozen block of fillets from which the sticks are cut be of uniform density to insure equal volumes having equal weights. This requires the fillets to be packed together evenly without air spaces and to be frozen under pressure. The fillets are carefully hand-packed into waxed paperboard boxes with a uniform arrangement of fillets lined up to avoid air spaces. For freezing, two blocks are put into a metal tray and then loaded into a plate freezer. The boxes are slightly over-filled with fish so that, when freezing under pressure takes place, all corners of the box are uniformly filled. The dimensions of the box vary according to the specifications of the purchaser, but slabs or blocks in the range of 14 to 15 pounds are common. Four blocks are ordinarily boxed together in one master carton.

Cutting of Sticks. The sticks are cut while the block is still frozen and shortly after it has been removed from cold storage. Cutting is in three stages. Band or gang saws are used in the first two stages to produce thin slabs of frozen fillets. In the final stage, the slabs are cut into sticks using saws or guillotine-type cutting machines. The latter avoid the loss of sawdust, which results when saws are employed, but give less satisfactory sticks in other respects, with such defects as chipping and cracking sometimes occurring.

Battering and Breading Materials. Numerous commercial varieties of batter mixes and breadings are available for use in fish stick manufacture. A typical batter may contain corn meal, grained corn flour, and non-fat dry-milk solids. Breadings may contain, either alone or in combinations, some of the following: ground, soft, winter wheat cereals; cracker meal; potato or soy flour; dried bread crumbs; and more recently, starch or hydrolyzed flour. The color of the cooked fish stick is determined, in part, by the choice of breading. Corn meal breadings tend, for example, to give light yellow shades to the final stick, as compared to the more golden brown shade resulting when wheat cereal types are used. The batter mixture varies greatly but is generally prepared with two parts of dry ingredient to three parts of water. Some processors dust the sticks initially with a thin coat of dry batter mix to aid the main liquid batter in adhering to the stick.

Coating of Fish Sticks. In operations employing fully automatic breading and battering equipment, the fish sticks are conveyed from the cutting stage to an unscrambling device where they are separated into equally spaced rows. They then pass along a belt beneath a manifold from which the batter flows down in the form of a curtain over the sticks, which are moving at right angles to the batter flow. Some excess batter collects in a depression beneath the belt and coats the lower side of the sticks as they move ahead. The rest drains into a tank from which it is pumped back to the manifold.

A similar operation then takes place in the breading machine, where the dry breading compound is applied to all surfaces. Mechanical devices such as rollers or a series of ascending and descending flexible rings may press against the sticks to aid in getting a firm adhesion of the breading compound to the surface of the sticks. Excess breading is usually removed by passing the sticks across a vibrating screen. The sticks may be inspected at this point to remove any apparent signs of defects. Sticks to be packed raw pass from this point directly to the packing line; otherwise, they move on to the cooker.

Cooking of Fish Sticks. Fish sticks are cooked in either continuous or batch cookers. In a typical continuous cooking operation, the sticks from the breader travel on a conveyor through the cooker which may be about 5 feet wide and 30 feet long and which may have a capacity of 250 gallons of oil. The sticks pass through the cooker in 25 to 35 seconds; the oil is generally held at temperatures close to 400°F. In such an operation about 2000 pounds of fish sticks can be processed per hour.

Either a melted hydrogenated fat or a liquid vegetable oil is employed for the cooking, and each possesses some advantages and disadvantages. The liquid vegetable oils, for example, provide a very uniform coating with less tendency for solidifying into irregular patches than may occur with hydrogenated fat. On the other hand, use of liquid vegetable oils results in somewhat shorter storage life than is obtained with hydrogenated oils. There is sometimes a slight flavor preference initially when the liquid vegetable oil is employed. Liquid vegetable oils are used in most installations.

The oil is heated either indirectly in a heat exchanger or directly by oil or gas flame under the cooking chamber. In a properly designed system, the oil volume in the cooker is kept low in relation to the input of fish sticks. Oil losses, through adsorption on the sticks, are great enough so that a complete oil change takes place about twice a day. Thus, no significant breakdown of the oil occurs and only rarely is it necessary to discard oil.

As has been mentioned, the choice of breading compound, in part, determines the color of the cooked stick. Another variable influencing color is the length of the cook—longer cooking time resulting in darker colors.

During the cooking of fish sticks a loss in moisture content takes place, yet the sticks do not lose as much weight as that of the moisture which is lost. This is caused by a pick-up of some oil during the cooking. The quantity of oil adsorbed depends both upon the length of the cook and upon the characteristics (porosity, size of crumbs, and composition) of the breading compound. Thus, the yield is an empirical matter controlled by several factors which must be worked out for each individual operation.

Considerable breading may be shaken loose from the sticks as they pass through the cooker. These crumbs soon darken and, unless promptly removed by continuous filtration, will adhere to other sticks, giving an undesirable appearance and, in time, promoting hydrolysis of the oil.

Packing and Freezing. Before packaging cooked fish sticks, it is necessary to cool them to a temperature between 90 and 100°F; otherwise, quality will be impaired. In batch operations the sticks may simply remain on trays in moving currents of air until the desired temperature is reached. Use is made in continuous operations of more elaborate cooling involving conveyer belts passing through tunnels through which refrigerated air is circulated. Fish sticks are packaged by hand into cartons which, if for consumer markets, generally contain eight or ten one-ounce sticks. The cartons are often given an overwrap, and the contents are then promptly sent to the freezer to be refrozen.

In some newer plants, the fish sticks go directly from the cooker to a continuous-blast freezer. The frozen sticks are then machine-packed into end-loading cartons which are glue-sealed. No overwrap is used in this method.

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CHAPTER 6

Lake and River Fisheries

HARRY L. SEAGRAN

The commercial fisheries of the central United States historically have been the only significant domestic source of fresh-water fishery products. Although these fisheries have contributed only a small percentage—less than 0.2 per cent—of the basic protein food consumed annually in the United States and about 3.4 per cent of the total domestic fish catch[9], they have been the sole source of such highly prized fish as whitefish, lake trout, walleye, and blue pike. These fisheries, which have changed little for years (until the last decade), have been basically of the fresh-fish type; few fish have been taken for animal food or industrial markets or stored for subsequent sale. Thus, daily trips by small boats yielded relatively small catches of comparatively high-value fish which, for the most part, were rushed to the fresh markets in large cities of the highly industrialized Midwest. Considerable quantities were sold in local fresh-fish markets, often operated in conjunction with the water-front fishing facility. Seldom were fish frozen; seldom did processing go beyond evisceration. Traditional markets for such products—lake trout, whitefish, walleye, blue pike, suckers, large chub, carp, and smoked and cured fish—had long existed.

The Traditional Fisheries

The significant commercial fresh-water fisheries of the United States may readily be grouped into three systems: the Great Lakes; the inland lakes, such as the Red Lakes and the Boundary Lakes of Minnesota; and the Mississippi River and its tributaries. The U.S. waters of the Great Lakes, which for years have produced at an annual rate in excess of 70 million pounds[8], have provided—in addition to those species previously mentioned—yellow perch, ciscoe, lake herring, and sheepshead. The fisheries of the inland lakes, which have had an annual production of about 20 million pounds[8], produce essentially tullibee (a variety of lake herring), suckers, burbot, walleye, and various rough fish. The Mississippi River system has produced at an annual rate of about 50 million pounds of fish[8]; the catch has consisted primarily of carp, buffalo, sheepshead, catfish, and bullheads.

Traditional Production Methods

Of the various gear employed, the gill net has accounted for at least half the total catch in the Great Lakes and Boundary Lakes. Trap nets, pound nets, haul seines, and other gear[10] have also been extensively used in the fishery. Generally, most of the species caught were of sufficiently high value to warrant the high labor costs of such fishing methods. Fishing vessels were small and possessed limited storage facilities; refrigeration systems for holding the catch were unheard of, and handling methods were strictly by hand labor.

Fishing methods of the river fisheries have been relatively primitive, and although gill nets and haul seines were generally used for rough fish, the high-value species usually have been taken by set or snag lines. Such fish frequently have been kept in live-boxes prior to local marketing.

Shore facilities were little more than sheds for sorting, hand-dressing, and boxing the catch, and for repair and storage of gear. Ice was generally used on the high-value fish for rail shipment or trucking to distant cities. Mechanical refrigeration systems for freezing fish were uncommon. Some species were smoked for market. Most fishermen had at their shore facility a small smokehouse where large chub and some trout and whitefish were smoked for eastern and midwest markets.

Prior to World War II, therefore, these traditional fisheries were relatively stable and simple operations with little capital investment in vessels and equipment or processing facilities and with little flexibility in fishing or production methods. Further, market outlets, although well-defined, were relatively local and dependent upon specific population groups. Perhaps most important, the products of this fishery had limited shelf-life, and markets suffered frequent saturation due to periodic glut production with resultant price-breaks. The industry up to the 1940's could best be described as static and traditional.

Decline of the Traditional Great Lakes Fishery

In the early 1940's, the lake trout, long the backbone of the Great Lakes industry, suddenly began to decline[6]. The annual trout catch in Lake Huron, for example, dropped from over 5 million pounds before 1940 to about 300,000 pounds in 1953. The same fate began to overtake Lake Michigan's trout in 1946, and the catch there fell from over 6 million pounds to a mere 402 pounds in 1953. Lake Superior, which has provided the last remaining U.S. lake trout fishery, normally producing about 4½ million pounds of lake trout annually, started declining in 1947 and by 1959, the take was only 870,000 pounds.

The rapid disappearance of these highly-prized lake trout stocks has been attributed solely to the invasion of the Great Lakes by the sea lamprey[2], a parasitic eel-like fish which is equipped with a sucker-like mouth, sharp teeth, and a file-like tongue. By attaching itself to an unwary victim by its mouth, it quickly rasps a hole in the body of the fish and feeds on the blood and tissue fluids. The sea lamprey almost certainly entered the Great Lakes above Niagara Falls through the Welland navigation canal; the first specimen was identified from Lake Erie in 1921. Once it had made its way across the unfavorable environment of Lake Erie into Huron, it spread rapidly and developed tremendous stocks.

Species of fish that were not originally major targets of lamprey predation are in serious peril following depletion of trout stocks[6]. Two species of large chub are almost extinct; other large chub have been reduced markedly. Whitefish have been reduced until the stocks are very low. There is evidence of rather serious predation on walleyes and suckers in several localities. Selective fishing against the higher-priced species, progressive changes in environmental conditions in Lake Erie, and pollution in shallow bays of the other Lakes near industrial centers have also taken their toll of the once-valued fish stocks of the Great Lakes. In an attempt to control the lamprey, the new primary predator of the Lakes, the U.S. Fish and Wildlife Service, the states bordering the Great Lakes, and the Province of Ontario in 1950 initiated an intensive research program[2]. Successful control of the sea lamprey and re-establishment of lake trout in the Great Lakes will prove a tremendous undertaking. Only time will reveal the relative success of this program.

To make problems of the Lakes fishery even more complex, the invasion of the sea lamprey was preceded or followed by the introduction of other marine species—the smelt and the alewife—much smaller, lower-valued, and frequently unmarketable fish. Furthermore, the disappearance of lake trout triggered a population explosion of small chub species, the major forage-fish of the trout. This transition in fish stocks occurring in recent years in the Great Lakes (Figure 6.1) has dramatically lessened the abundance of the large, higher-valued species while many of the small, lower-valued species have become excessively plentiful. The true extent of these under-utilized fish available for exploitation is not known,

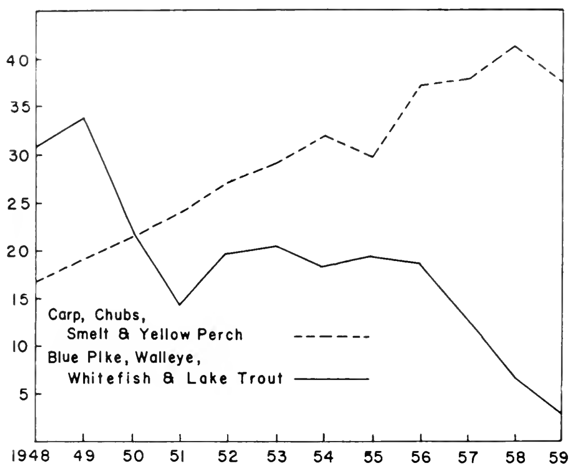

Figure 6.1. Great Lakes fish production by groups of species, in millions of pounds from 1948 through 1959[3].

but the potential output of the Lakes, which once was fairly stable at an annual rate of 70 to 80 million pounds, now may run into hundreds of millions of pounds[5]. This sudden change of the fish stocks has severe impact on the commercial fisheries, which will be described briefly later in this chapter.

Changes in Other Fresh Water Fisheries

Changes in other domestic, fresh-water fisheries in recent years have been far less drastic than those in the Great Lakes. Several significantly new fisheries, currently in the process of development, are worthy of mention, however.

The possibilities of fish-rearing in rice ponds of the southern United States were first sensed in the early 1950's from observations of the growth of fish introduced inadvertently with the water supplies. Subsequently, a number of rice farmers undertook seriously the rearing of fish. Although this industry is still in its infancy (less than 25 thousand acres are being farmed for fish—Figure 6.2), the rice ponds of Arkansas, the auxilliary water reservoirs, and the extensive bottom-land areas of the lower Mississippi offer an enormous potential for the production of fish[7,9], the true extent of which is difficult to judge at this time. In excess of 2 million acres of bottom-land, estimated conservatively to be capable of yielding 400 pounds of fish per acre, can be called upon to produce fish as needed. Principal species currently harvested in the ponds include buffalo, carp, catfish, bait minnows, and some game fish. Few modern harvesting and processing facilities for this fishery have developed, and

Figure 6.2. Buffalofish seined from an Arkansas rice pond.

the fish farmers have been handicapped by lack of technical information and skills in all phases of the operation. Given sound management, however, this new fishery could reach a significant level in a short period of time.

Of interest also is the rapidly expanding flood-control reservoir system on the Mississippi and its tributaries. Biological studies[9] on such reservoirs have demonstrated the presence of huge resources of fish usable as food or for industrial products. Development of this resource is yet insignificant, although several of the states along the Missouri River have a strong interest in the development of a full-scale commercial fishery.

Several states, too, have expanded their programs for removal of rough fish from large inland lakes as part of state sport-fishery development. This fishery, rapidly expanding and employing more efficient harvesting methods such as trawling, is quickly reaching significant proportions. The bulk of the catches—sheepshead, carp, and tullibee—are marketed as animal food, primarily for mink, in the northern states.

Technological Status of the Industry

The changes of fish stock that brought the commercial fishery of the Great Lakes to its present critical condition came about abruptly. The fishery, reasonably healthy in 1945 and geared for large, high-valued species such as lake trout and whitefish, within a decade was faced with the almost complete replacement of former stocks by a tremendous abundance of small, low-value fish such as small chub, smelt, and alewives. These factors combined to make traditional gill net fishing in the Lakes a marginal or even a losing operation. The small fish tangle readily in gill nets and are difficult to remove from the net, usually seriously damaging the fish. Generally, the returns were far too small to cover the cost of clearing the nets. The logical conversion to more effective fishing methods was hampered, however, by highly restrictive and complicated state fishery codes that detailed gear specifications, seasons, grounds, size limits, ... Conservatism in modifying these codes and the resistance of sport fishery groups to changes lessened motivation for experimentation in more effective fishing methods by the industry.

Furthermore, the small scattered plants of the traditional fishery were ill-equipped to make a sudden change. Lack of suitable handling, processing, and storage facilities made it difficult to take and sell even top-quality fish at a profit. Peak periods of production, typical of the seasonal glut of the fishery, saturated markets to the breaking point. Few cold-storage warehouses were available to smooth out production and maintain a stable market.

Still other marketing problems developed. Increasing quantities of lake trout, and whitefish, produced from the interior lakes of Canada, and domestic and imported marine fishery products, therefore, entered midwest and eastern markets. Consumer tastes had been traditional, but in recent years these tastes gradually shifted farther towards highly processed, convenience-type products.

Progress has been made by the industry, however, in making this technological transition. In the last few years, special permits have been issued by several of the Great Lakes states to authorize the use of otter trawls[4] in the capture of these small deep-water fish. An extensive Canadian trawl fishery for smelt also has been developed in recent years on Lake Erie. Yet, improvements in the taking and handling of these small fish have been limited. Vessels that were designed for gill-netting (Figure 6.3) are only moderately successful in trawl fishing. Lack of adequate power for effective trawling speeds, limited storage space, poor facilities for cooling the catch, and inadequate transfer systems have hampered this phase of the fishery.

An increasing number of convenience products such as breaded fillets from yellow perch, smelt, and small chub, and small smoked chub are entering the market. The industry is gradually acquiring semi-automatic processing machinery to fillet or dress small fish[1], thus eliminating costly

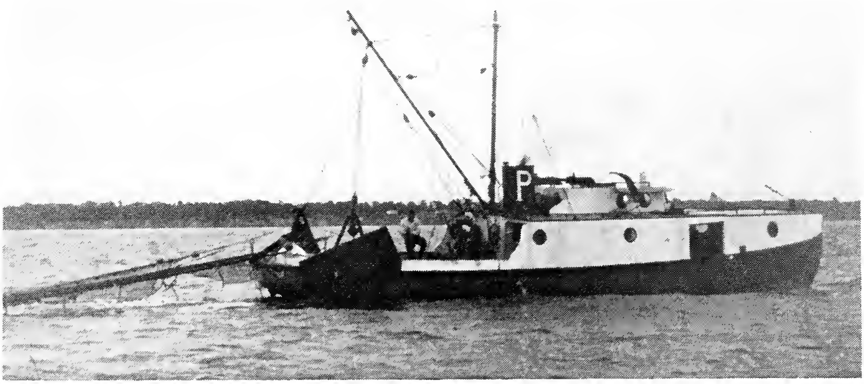

Figure 6.3. Stern-type trawler, typical of several that have been developed from traditional gill net tugs.

hand labor. Good possibilities exist for broadening the use of fresh-water fish in the manufacture of pet foods and food for fur-bearing animals, particularly mink[5]. Mink ranchers of the Midwest currently use about 50 million pounds of fresh-water fish annually. Economical and efficient harvesting and processing methods and, particularly, the ability to handle a large quantity of fish in a short period of time, are the keys to the further development of this market. There still exists a great shortage of adequate and modern sharp-freezing and cold-storage facilities, however, to handle the large stocks of fish available for human foods as well as for industrial purposes.

The fresh-water fishery of the United States is no longer static. Tremendous and abrupt changes of fish stocks and the unsuitability of old gears and techniques for exploitation of the enormously abundant new stocks have forced many industry members out of business. Those remaining, by painful and slow technological transition to new methods of harvesting, processing, and marketing, may yet survive and prosper. Their efforts are being gradually facilitated by new legislation and consumer acceptance of their products. They are slowly developing a new industry, quite unlike the old, traditional fishery.

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CHAPTER 7

The Tuna Industry

ROLAND FINCH

The Development of Tuna Canning in the United States

Accounts of the origin of the tuna industry are somewhat conflicting[4,3,27], but it is generally agreed that the initial stimulus was provided in 1903 by the failure of the sardine run in the San Pedro, California area. This led Mr. A. P. Halfhill to experiment with alternative fish, including albacore, in order to maintain his canning operation.

By 1912, when 75,900 cases were packed, the industry was firmly established at the beginning of a continuous upward trend which has continued until nearly 150 times the 1912 amount is packed in the United States today. As the demand for fish increased, canners who had used only albacore at first began processing yellowfin, skipjack, and later bluefin. This in turn widened the search for tuna, forcing the fleet to fish even further south. In 1922 nearly 4000 tons were caught off Latin America, and in 1927 catches from this area exceeded those from United States waters for the first time. Eventually as fish were sought off Central America, and even further from the home ports, average trips had grown to as much as two to three months' duration. The changing nature of the operation led to larger, better equipped, and better insulated vessels, but nevertheless the amount of spoilage mounted. It was estimated that in 1935 about 5 per cent of the total catch was lost to the industry through spoilage[20].

As a result of the growing concern about the situation, work was carried out by the George Williams Hooper Foundation in San Francisco which laid the basis for the development of a practical brine freezing system. Although this system is far from perfect, its general adoption by the American fleet in the following years caused a dramatic drop in the level of rejects.

The supply of tuna landed by the American fleet has for many years now been augmented by frozen imported fish. This has consisted mainly of "round" albacore, "gilled and gutted" yellowfin, plus smaller amounts of skipjack, and raw fillets. Recently a smaller amount of precooked and cleaned frozen tuna has also been imported, mostly in the forms of "loins" but some shaped into can-size "discs." Total imports were relatively small until after World War II when the increase was spectacular, supplying almost the whole of the additional fish needed to meet the growing requirements of the United States canners. Thus, while imported fish accounted for only 1.4 per cent of the total United States supply in 1948, by 1958 the proportion had grown to 35.9 per cent. Most of this tuna has come from the Japanese fleet, much of the remainder from Peru, the latter being mainly produced by United States operations.

The intense competition of Japanese imports drove fish prices down in 1955 below the level required for profitable operation. The resultant attrition in the United States tuna fleet continued for some years, but the position was reversed starting in 1959 by the conversion of a large part of the bait boat fleet to a purse seining rig. The development of the Puretic power block and nylon nets made deep-water seining a better proposition than it had been formerly. The result was a dramatic reduction in the trip time, and the corresponding increase in annual yield and profit enabled the domestic fleet to meet the competition offered by imports and put it into a strong selling position. This vigorous tuna seining activity has recently led to a depletion of the Pacific yellowfin resource with a consequent decline in the catch per unit effort.

The principal center of the tuna canning industry has remained in Southern California (Terminal Island and San Diego), with some production in the Pacific Northwest (chiefly at Astoria, Oregon). The continued shift of fishing centers further south and to Atlantic waters has resulted in the building of plants by some of the United States canners nearer to these productive areas. Puerto Rico is the largest such center, strategically placed to receive fish from both Atlantic and Pacific oceans and to ship to United States markets on both coasts. Other American plants are located in Samoa, Hawaii, Peru, and Ecuador.

The Tunas

Canned tuna is mostly prepared in the United States from four species. These are: albacore, yellowfin, skipjack, and bluefin, although the commercial bluefin may consist of more than one species. A fifth species, little tuna, has been taken in some years but in amounts of less than 1 per cent of the whole catch.

The tunas are pelagic, fast-swimming fish of compact, rounded, but streamlined appearance. They are distinguished, apart from their general shape, by a number of small finlets along the dorsal and ventral lines posterior to the second dorsal and anal fins. Their anatomy is described in some detail by Kishinouye[17], Godsil[11], Godsil *et al.*[12], and more briefly by Nakamura[25]. The taxonomy of the tunas is still a matter of some dispute, and in consequence, alternative systematic names are often used by different writers for each species. Although virtually only the four species mentioned are used for canning in the United States, several others are known, and the United States Federal Standard of Identity for Canned Tuna[5] lists additional species which may be used. However, these do not include the yellowtail and bonito which are generally classified as "tuna-like" fishes and may not be identified as "tuna." It does not distinguish the big-eyed tuna (*Parathunnus sibi*), which is similar to yellowfin in appearance and is, in fact, caught and included with yellowfin in commercial catch records.

The tunas are carnivorous and consume a widely-varied diet, the composition of which appears to be largely influenced by availability[1,2]. They are found in the mixed warm upper layers of water which cover much of the surface of the temperate and tropical oceans. These layers which run down to the thermocline or region of abrupt temperature lowering are mostly fairly shallow in the Eastern Pacific and Eastern Atlantic but as deep as 200 fathoms in the Western Ocean areas. The different species are located and harvested in their characteristic fashions, and so each will be separately described below.

Albacore (*Thunnus germo*). Albacore is a large tuna distinguished by a long pectoral fin. It is regarded by the consumer as a premium fish owing to the light color of the cooked flesh. The American fishery located on the Pacific Coast is seasonal, operating from June to October, and the catch is quite variable from year to year. Trolling and live-bait fishing methods are used to catch albacore, although recently seiners have had some success. The Japanese albacore fishery is mostly a long-line operation, except seasonally around the home islands. Long-liners which freeze their own catches and mothership-catchers units which range into the South Pacific, Indian, and South Atlantic areas account for the greater part of the production. Much of the fish from these is sold locally or transhipped for United States canneries.

Yellowfin (*Neothunnus macropterus*). This fish derives its name from the bright irridescent color seen on the fins and finlets of the live or freshly caught fish. The species has a fairly long pectoral fin, although shorter than albacore. After albacore it gives the lightest color cooked meat and so receives a higher price at the cannery than skipjack or bluefin. Yellowfin is the largest volume species canned in the United States.

Skipjack (***Katsuwonus pelamis***). Skipjack is the smallest of the commercial species and is distinguished by four or five broad, dark horizontal stripes running along the lower part of the body. Individuals weigh up to 20 pounds, the legal limit in California being 4 pounds. This species is mainly supplied to United States canneries by the American fleet, being fished off Central and South America. The recent conversion of many bait boats to seiners resulted at first in a considerable drop in the amount of skipjack landed, although Eastern Pacific stocks appear to be large and relatively little exploited. Skipjack, being darker fleshed, stronger flavored, and as a rule oiler than yellowfin, is less valuable than other species.

Bluefin. The name bluefin is applied to more than one species of the genus *Thunnus*[13], which are distinguished in external appearance from other tunas by a short pectoral fin which does not extend as far as the insertion of the second dorsal fin. The Pacific bluefin is purse-seined and can be as heavy as 250 pounds. A small amount is caught commercially on the East Coast of the United States where it is also much sought as a game fish. The flesh is generally dark, especially in the larger fish, which is, therefore, of less value to the canner than albacore or yellowfin.

Fishing Operation

The considerable range of the United States tuna fishing operation has had a profound effect on vessel design. Most of the large boats now in use were designed for sustained live bait operation and so were equipped to handle considerable amounts of fuel and live bait and to freeze and hold large tonnages of tuna. Excellent descriptions of tuna boat refrigeration equipment are given by Lassen and Rawlings[23] and Hendrickson[14].

The larger boats or clippers which comprise the greater part of the American fleet are 120 to 130 feet long and carry 300 to 350 tons of tuna. They are generally equipped with radar, D.F., radio telephone, fathometers, etc. The crew consists of about 12 men who are usually paid on a "share" principle. The engine room lies forward, and aft of this the insulated wells which are used in turn for fuel, bait, and frozen fish are set in pairs, one either side of the shaft alley. A typical bait boat may have 10 wells and 3 refrigerated bait boxes set on the main deck at the stern. The refrigerant used is ammonia which is fed from one of the three compressors through a sea water condensor, a liquid manifold, and expansion valves to the steel coils which line the wells. The suction side of each set of well coils is similarly connected to a return manifold. Each well also has a separate system for circulating brine or sea water. The liquid is pumped into the top of the well by the coaming *via* a gooseneck and passes out at the bottom through a bait screen. The separate brine systems for the various wells are connected to common headers through valves. Thus by suitable switching, brine may be circulated or transferred from one well to another as required, or sea water may be pumped from a sea-chest through the well or bait boxes for storing live bait. This arrangement is very flexible to meet the many different situations which arise at sea.

A few boats use a brine spray system in which brine is pumped over a head exchanger using ammonia or "Freon," projected as a spray over the fish, and then drawn off for recirculation. There is a good deal of argument as to the relative merits of the two systems, neither being strikingly superior, at least as presently used.

For bait boat fishing, anchoveta (*Centergraulis mysticetus*) or some similar small anchovies or herrings are caught using a small mesh seine net and brailed alive into the live bait tanks and available wells. When tuna are sighted, the live bait or "chum" is thrown into the water causing the fish to develop a "biting frenzy." The crew fish from racks let down over the side and stern of the boat near the waterline using bamboo poles, some 8 feet in length. The biting fish take the hook and are pulled inboard behind the crew. When large fish are encountered, 2 and even 3 lines are joined to one leader, and the 2 or 3 fishermen work in unison to haul them in—a spectacular and highly skilled operation.

The procedure described above has now given way in large measure to purse seining. The bait boats are mostly converted by removing the bait tanks, racks, and part of the amidships deck on the port side, so as to clear the afterdeck for the installation of the net, turntable, winches, booms, controls, etc. The storage wells and refrigeration equipment are generally unchanged. An excellent description of modern tuna seining gear and its operation has been given by McNeeley[24].

Albacore is largely trolled by jig boats, mostly operated in the short summer season only. These boats have a 2- to 20-ton capacity, and, being out for short trips only, carry little or no refrigeration. Some albacore is also landed by bait boats and seiners.

Storage and Transport. The Atlantic bluefin seining is a day operation and no ice is used. The freezing process used by the Pacific fleet is subject to so many operating variants that it is far from standard, but the following is a typical procedure.

Usually two wells are filled with sea water chilled to 30 to 32°F before fishing commences. Tuna is allowed to accumulate on deck during a bait boat operation until a school is lost or the "rail is full." Then it is thrown, slid down troughs, or flumed into the wells. When seining, fish is brailed directly into hoppers from which it runs by troughs into wells. Fish temperatures may be 65 to 90°F, causing a temporary warming of the circulating sea water, but this then usually cools to 30 to 32°F in 24 hours under refrigeration.

Tuna is buoyant in sea water, and when the well is apparently filled, it can still accept another 20 to 25 per cent of fish. Water from the circulating system is therefore discharged overboard or to another well, causing the level of sea water and fish to sink and allowing more fish to be packed under the well overhead. When this operation is completed, a wooden grating is lodged at the bottom of the coaming to hold down the fish when the denser freezing brine is circulated.

While it is economically important to stow a maximum of fish in a well, pumping too low or forcing too much fish into the top puts excess weight on the still soft fish below which distorts and flattens it. Pressing it together reduces the exposed surfaces through which heat may be extracted and, at the same time, closes up the structure of the load, greatly impeding the flow of brine. This is especially true with the softer and smaller skipjack. The result is to slow the cooling, which may then permit bacterial spoilage and heavy salt penetration. At the thawing stage, the slower passage of brine through over-packed wells can cause complete icing with considerable loss and delay.

When the well has cooled to 30 to 35°F, it is "brined." Cold brine may be transferred from another well, or the salt content of the water in the well may be increased as required by pouring salt into the coaming where it is dissolved by circulating liquid. Enough salt is generally added to give a brine freezing about 5°F below the temperature at which it is intended to hold the fish. Thus a 13 per cent brine freezing at 15.7°F might be used to cool to 20°F, at which temperature approximately 90 per cent of the water in the tuna would be frozen.

It is important to lower the temperature of the water before the salt is added. Lang and Farber[19] demonstrated that salt penetrates much more rapidly into the fish muscle at higher temperatures, and an excessive salt level in the fish results from prolonged contact with brine above freezing.

When the brine is first circulated, the fish temperature drops slowly while most of the water in the tuna is being frozen, then more rapidly. After about three days, the well is "dried up" by pumping the brine overboard or to another well. This not only reduces salt penetration, which would result from continued contact of brine with the fish, but lightens the vessel load. The refrigeration is usually left on in the coils, and the fish temperature falls very slowly. Brine is not usually used more than twice owing to the accumulation of blood and slime from the fish. Sometimes when boats intend to unload tuna without thawing, e.g., when transhipping at sea or to a freezer plant, the wells are not "dried up," but the cold brine is left on the tuna and subsequently pumped off prior to unloading the wells. However, most of the tuna is brought direct to the cannery and thawed by a reverse process of adding brine and circulating without refrigeration until the temperature has risen sufficiently when the well is pumped dry for unloading. The aim is to remove the tuna at about 28°F, when it is soft enough to eviscerate, but firm enough to handle.

This freezing system is a practical compromise arranged to be applied in a wide variety of operating circumstances. As such it is far from ideal. The operating margin is often critical so that many boats lose some fish at times through spoilage, especially where big sets are made. Freezing is fairly slow and holding temperatures high so that tuna received at the plant deteriorates a good deal in quality as compared with the fresh fish. Salt penetration is influenced considerably by a number of factors, making it impossible to produce a truly consistent flavor in the end product. Some objections might be overcome by the use of alternative freezing methods or media[22], but, so far, apart from local ice boats, brine freezing remains the practice in American vessels.

Imported tuna is received in several forms, but most commonly as frozen "round" and "gilled and gutted." Before processing, this is thawed in the plant using water sprays or tanks holding several tons each. The temperature of the tuna is gradually raised by vigorous circulation of sea or fresh water, until it is ready for unloading.

The Canning Operation

Preparation. The following account is only general in nature and practices and equipment vary somewhat from one operation to another.

On arrival at the plant, the thawed fish is transferred by buggy, conveyors, or flumes to be weighed (Figure 7.2) and then to the butchering table, which is a conveyor belt surfaced with 1 by 4-inch pine slats. There the tuna are aligned on either side at a 45° angle to present them conveniently to the butchers who, with two deft strokes, open the belly wall and remove the viscera. The fish pass on under a rinse spray to an inspector who removes any spoiled fish (Figure 7.3) and then to rackers who place them according to size on galvanized wire mesh baskets which are stacked in wheeled frame racks. The tray or basket size is typically 15 $\times$ 30 inches with 3-inch high sides. To prevent sticking and to reduce the accumulation of fish particles on the wire mesh, the basket is lined with a disposable perforated kraft paper sheet before filling. Tuna are racked and cooked by species and size, being known as "aces," "deuces," "sixes," "eights," etc., according to the number put in a basket. The average weight of fish in a basket is fifty pounds, and the angle iron frame racks hold some fourteen baskets. Fish over about 60 pounds each

Figure 7.1. Unloading skipjack tuna from a storage well. Fish on the deck were taken out to clear the well head. (*Westgate-California Corporation.*)

("big aces") usually have their tails sawed off. In some cases when very large, they may be split laterally to reduce cooking time.

Precooking. When sufficient racks of one size are collected to fill a cooker, which may hold from 12 to 30 racks, they are wheeled into position, generally in 2 rows (Figure 7.4). The cookers are box-shaped and typically made of quarter-inch steel plate reinforced with channel iron. They may have doors at one or both ends and are fitted with steam spreaders which usually run along the floors, steam vents, and outlet valves for running off the cooker or "stick" water while cooking. Some cookers are fitted with temperature recorders, most with pressure gauges and thermometers. When full, the cookers are closed, except for vents, and steam is turned on to raise the temperature over a period of 15 to 30 minutes to 215 to 220°F.

Cooking time increases with the size of fish and varies with the technique preferred at each plant. "Eights" weighing some 6 to 10 pounds

Figure 7.2. Tuna being conveyed from the boat to the weigh house. (*Westgate-California Corporation.*)

are cooked for 105 minutes and so on up to fish of 100 pounds which require 8 hours or more.

Cooling. Tuna is normally cooled overnight to firm it and bring the temperature down to a point at which cleaners may handle it. This is usually done by standing in a cooling room in still air. Lassen[21] has shown that the bacterial count, reduced almost to zero in the precook, rises little for 24 hours although forced circulation of the air adds to the increase. Some drying and oxidation and polymerization of the oily surface layer occurs in the cooking and drying, but this is usually superficial and may be removed during the cleaning operation.

Cleaning. The cooked, cooled fish is dumped from the baskets onto stainless steel cleaning tables which are now mostly provided with various conveyor belt systems. In the more elaborate systems, fish is conveyed to the cleaners while cleaned loins, blood meat, and scrap are conveyed away separately. A typical cleaning sequence is as follows: The head is

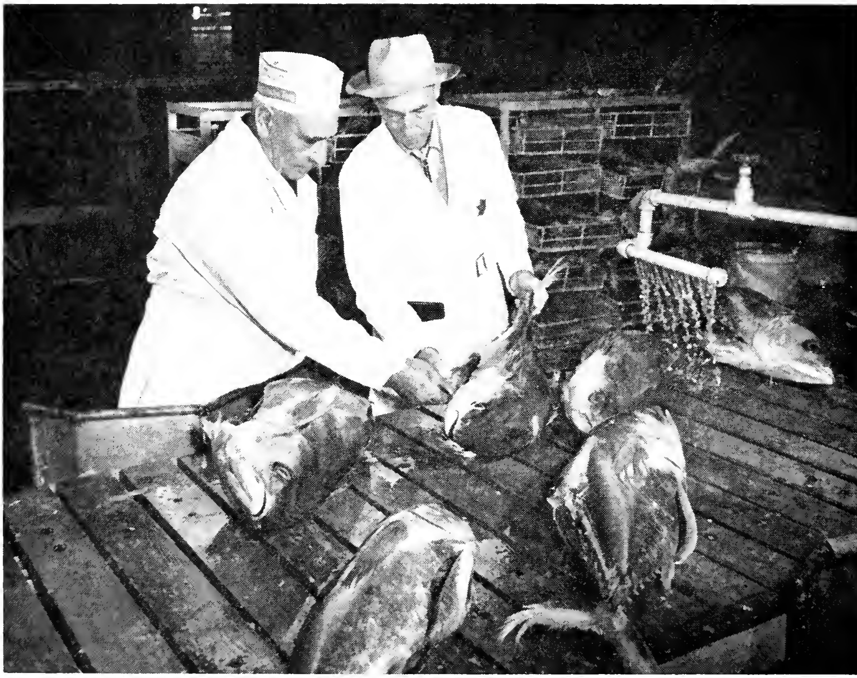

Figure 7.3. California State Inspector checking eviscerated yellowfin tuna. (*Westgate-California Corporation.*)

removed; the fish is skinned and split. The backbone and tail are removed and pushed onto a scrap conveyor. The halves are split into quarters or "loins" along the median lines. The red meat is cut and scraped from each piece. Finally the loins are "polished" by rubbing loose flake from the outside.

Packing. Formerly, filling was a hand operation; now it is almost entirely carried out by machines. The solid or "fancy" pack is filled on a Carruther's "Pak-shaper." The loins are laid in careful order on a narrow belt flanked on either side by vertical belts with semicircular cross section links facing inward which gradually converge to form a hollow cylinder. The stream of fish is thus gently squeezed to form a cylindrical shape as it progresses so that when it reaches the head of the shaper, it is extruded from the end into a waiting can which it fits neatly. A circular knife then cuts it off at the open end. The cake is pushed down snugly into the can which then drops down the track. The knife

Figure 7.4. A rack of raw tuna being wheeled into the cooker. (*Westgate-California Corporation.*)

returns and another empty can drops into place ready for the cycle to recommence.

To pack in chunk form, the loins are first cut on the belt by vertical reciprocating cutter blades which may be in a straight, diamond, star, or other form, then filled with an adjustable pocket filler at a rate of about 240 cans per minute. Grated tuna, which is made by disintegrating broken loins and flake, is filled with the same type of equipment. On some lines, continuous weighers are used to assist the filling machine operator. Reject mechanisms may also be used to eliminate low weights.

The filled cans pass under salters, then optionally under a vegetable broth feed (Figure 7.7), and finally under one or more oil feeds. The oil used presently is soya bean or corn oil and is heated to about 180°F. Its addition in the case of solid pack is often made over a long run of line to give the oil time to penetrate the fish before sealing. Solid pack cans may pass over "tippers" to remove excess oil. Either vacuum or steam flow exhaust seamers are used to seal the cans which are then passed through detergent and water washers to remove surface oil.

In the United States, most tuna is packed in California where all canning is under state inspection. Cans must be coded and retorted for a prescribed time in approved and tested retorts fitted with recorders. Records of each lot are examined for conformity by a state inspector who also scrutinizes fish quality and general plant sanitation.

Data on five sizes of pack in common use are listed below, by far the most popular being the half.

Size	Style	Can Dimension	Retort Time (Minutes)		Usual Net (Ounces)	Required* Press Weight (Ounces)
			240°F	250°F		
¼	Solid	211 × 109	65	40	3.5	2.25
	Chunk		"	"	3.25	1.98
½	Solid	307 × 113†	75	55	7.0	4.47
	Chunk		"	"	6.5	3.92
	Grated		"	"	6.0	3.96
¾	Chunk	303 × 212	100	75	9.25	5.56
1 lb	Solid	401 × 206	95	80	13.0	8.76
	Chunk		"	"	12.5	7.68
4 lb	Chunk	603 × 408	230	190	60.0	37.9

* Federal Standard of Identity for canned tuna fish[5].
† Up to 1920, a 307 × 200 can was used.

By Products. Most larger tuna canneries process ground entrails, cooker water, and scrap from the cleaning operation to give meal, oil, and fish solubles. These operations, for the most part, employ conventional cookers, screw presses, and steam tube dryers for meal production; centrifuges or settling tanks for oil separation; and evaporators for concentrating solubles. Tuna meal as sold contains 55 to 62 per cent crude protein and around 22 per cent ash which consists mainly of calcium and phosphorus from the high bone inclusion. Viscera, cooker water, and press water from the meal press may be acid or enzyme digested before concentration to finished solubles containing 50 per cent solids. Sulfuric acid is also added at some stage, sometimes to assist in the digestion process, but also to reduce the pH of the finished solubles to a stable level. Oil is removed by centrifuge at one or more stages in varying degrees of purity and is sold both crude and refined.

The red meat or "blood meat" was at one time collected with the cleaning scrap for reduction but now is almost invariably canned for pet food. It is collected from the cleaning tables, inspected, disintegrated, or ground, and filled into cans sometimes with the addition of vitamins, minerals, and other supplements. Sufficient hot water (20 to 30 per cent) and sometimes smoke flavoring are added to give a desirable moist texture to the finished product, and the cans are closed, washed, and retorted.

Figure 7.5. Cleaning tuna. (*Westgate-California Corporation.*)

Federal Standard of Identity. All canned tuna sold in the United States must comply with a Federal Standard of Identity[5]. Section 37.1 of this Standard defines and regulates the nature and quality of the pack. It lists the species of fish which may be canned as tuna and defines the optional forms of pack—solid, chunk, and grated. It specifies the size of the pieces for each style and the method of test by screening. Four color designations are given in terms of Munsell values. These are white (for which only albacore may be used), light, dark, and blended. An official test method based on visual comparison with suitable matte reflectance standards is described. Three optional packing media are permitted. Most tuna was originally put up in cottonseed oil, but soya bean and corn oils are now used almost exclusively. Most imported tuna is packed in water and sometimes has a firmer texture than the oil packs.

Optional flavorings and seasonings are listed. Of these, the most generally used is a vegetable broth which is usually prepared by the hot-water extraction of dehydrated vegetables.

Section 37.3 refers to the standard of fill for various size cans. In the case of tuna, the drained weight provides an unreliable index of the

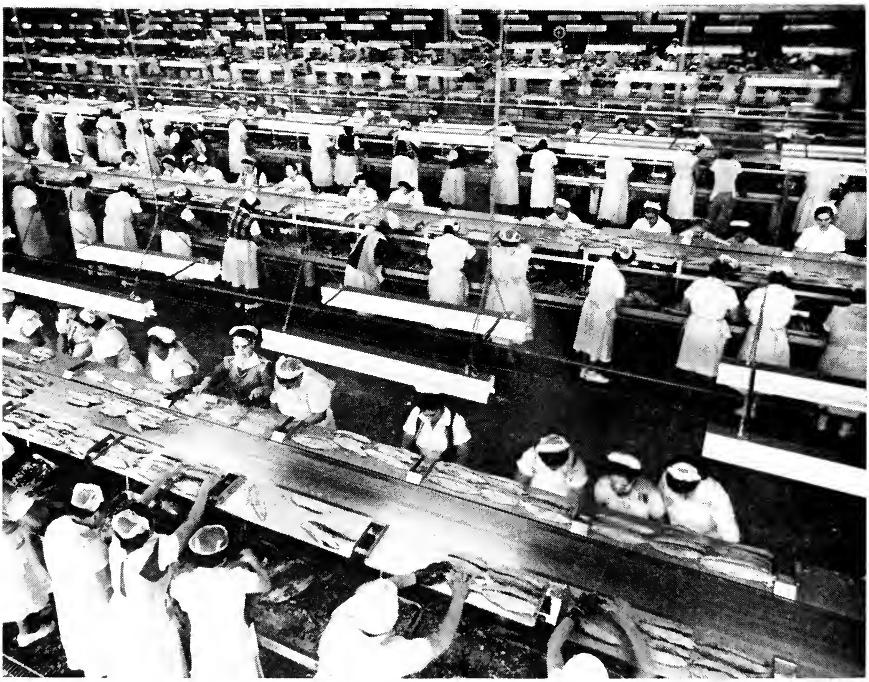

Figure 7.6. Tuna cleaning operation. (*Westgate-California Corporation.*)

original fish fill, and so the official test uses pressed weight. The method consists of pressing the contents of each of 24 cans of the lot under test to remove "free" liquid. A special hydraulic press, plunger, and cup are used, following a carefully defined routine. The press cakes so formed are weighed, and the average must not fall below a minimum specified for the particular can size and pack form being examined.

Tuna Products. Various tuna products have been marketed from time to time, but none have been highly successful. Only a few, such as canned tuna and noodles and frozen tuna pies, have maintained a high enough

Figure 7.7. Regulating vegetable broth addition to filled cans. Solenoid valve cuts flow when line is stopped. (*Westgate-California Corporation.*)

sale to justify their continued production. The amount of tuna sold in these forms represents only a small proportion of all production.

Spoilage in Tuna

The particular circumstances of tuna fishing tend to lead readily to bacterial and autolytic spoilage, and considerable care has to be exercised, therefore, to avoid heavy loss. Most tuna is fished in water temperatures which run from 65 to 90°F and in air temperatures which are often higher. When fishing with live bait, all other effort is subordinated to landing the fish since there is no way of knowing when the school may be lost. Consequently, the fish may lie on deck for some hours before it is put down even into cool water. When a tuna seiner makes a big set, many fish die in the net and may start to spoil in the warm water even before they are landed. Often a large tonnage of fish may be brought aboard in a short space of time, throwing a heavy load on the refrigeration system so that the fish may be cooled more slowly than is desirable. When bacterial spoilage occurs, it follows a similar pattern to that in other fish and shows up as the raw fish are first examined on the butchering table. "Sour," "stinking," and badly-broken fish are rejected at this point, and being already included in the landed weight, they are reweighed and charged back against the boat.

Lengthy on-deck time also leads to "honeycomb" formation which is generally believed due to enzyme action. This condition only becomes apparent when the cooked fish is cleaned and consists, as its name implies, of areas of pitted, spongy-looking muscle tissue, often localized towards the head. Otsu[26], in a series of experiments with Hawaiian skipjack, found the extent of honeycombing to increase with the on-deck time and with higher fish temperatures.

Honeycombed tissue has not been shown to be toxic as such, but is believed at times to be associated with the formation of histamine which has been shown by many workers to occur under conditions of advanced spoilage[16]. Honeycombed fish is rejected at the cleaning stage, and there is no record of significant amounts of histamine occurring in tuna canned commercially in the United States.

Another undesirable characteristic occurring in some individual tuna, which only becomes evident at the cleaning stage, is the so-called "green" or "greening." This appears as a green to green-tan tint in the cooked loins. It is often accompanied by an unpleasant urine-like odor, especially if the color is marked, and appears to be more prevalent in large fish. There is no evidence that green tuna muscle is toxic, the objections being primarily aesthetic. Brown *et al.*,[8] conclude that the color is mainly a hemichrome, probably resulting from oxidation of the natural hemochrome which forms during cooking from myoglobin, the normal muscle pigment. They were unable to connect its occurrence with any known circumstance subsequent to capture. Various tests have been proposed to detect this condition in the raw fish. Some of these have been critically examined by Dollar *et al.*[9] They found that certain factors, such as color of kidney suspension, total heme pigments, oxidation state of the iron, peroxide in fat, tended to vary with "greenness," but that the ranges from fish to fish were so great that no one of these or other measurements examined could be used as the basis of a practical test routine.

Struvite (magnesium ammonium phosphate hexahydrate) forms in some cans made from long-lined fish, especially where the muscle has a pH greater than 7.2. The crystals are fairly soft and dissolve in the digestive juices, but their glass-like appearance is alarming to consumers. Their formation can be reduced or eliminated by the addition of small amounts of harmless additives to the can before closing which appear to sequester the magnesium ion.

Another undesirable condition in raw tuna is excessive salt content. Bad handling practices, especially the use of strong freezing brine at too high temperatures and slow thawing, may lead to salt levels as high as 4 per cent in the outer layers of tuna. This makes accurate control of the salt level in the final product virtually impossible. Low quality salt containing excessive iron or copper may result in a gray "metal stain" forming on some pieces of fish after canning, as may contact with copper or brass during processing.

Prolonged storage of the raw fish, especially in the case of skipjack, may lead to dehydration and oxidation of subcutaneous fat, which shows itself as a yellow to orange coating on the surface of the cooked loin. This appears to be an insoluble complex of oxidized oil and protein. It is costly and wasteful to remove entirely, but if particles remain in the fish, they give a poor appearance and strong, bitter taste to the canned tuna.

Chemical methods for the measurement of spoilage, in particular, the volatile reducible solids (V.R.S.)[10] and volatile acids[15], have been proposed for tuna. They have never gained a wide acceptance as processing controls, mainly owing to their relatively lengthy nature, but might be developed as referee methods.

In practice, most spoilage and quality assessments, especially on the production line, are organoleptic, relying on the skilled judgments of trained personnel.

Quality in Tuna

The quality of the raw tuna as received is probably by far the biggest single factor influencing the final quality in the can. Efforts to predict the quality of the canned fish from its raw appearance have met with little success so that it is not feasible at present for a processor to select and buy only premium fish. In any case, canneries have to buy the entire load of a boat, good or bad, except for spoiled fish, and so must often accept very variable material.

The result is an end product which, in spite of all leveling processes, varies widely in color and texture and, to a somewhat lesser extent, in taste and odor. It is, therefore, necessary to separate canned tuna into grades of quality corresponding to different market outlets, each demanding a constant product within its own established style-price-quality field. For this reason the grading procedures used are of great importance. Each cannery has its own method of evaluation and standards. Among commercial requirements color is commonly regarded as being most important, but texture, particle size, flavor, general appearance, and other factors are also judged.

Development and Outlook

The basic outline of the tuna canning operation has remained unchanged from that of early days. The only important advances have been the elimination of exhaust boxes, the use of mechanical conveying, filling, and more efficient use of by-products.

Various alternatives have been proposed to improve the product and the process. Borg[7] describes a canning method in which cans containing pieces of edible portions of the raw fish are immersed in hot water to coagulate the protein, followed by cold water before pressing or centrifuging to remove the excess liquor. The cans are then oiled and processed as usual. Lang[18] proposed a precooking method in which the fish is sprayed with recirculated cooking liquor during cooking and then cooled in a humid atmosphere to reduce surface drying and oxidation. The "Pauley Process"[28] was used on a limited scale for some time, but for various reasons was discontinued. This method comprised preparing cleaned skinless, boneless fillets of tuna, precooking to a center temperature of 130°F, then cooling with water sprays prior to cutting to size and packing. The patent authors claim that their method reduces time, loss, and waste. Perhaps the main problem involved in this and similar processes is lack of a mechanical device which will fillet raw tuna cleanly and yet avoid waste. The present precooking system allows a quicker and more exact separation. However, Anderson *et al.*,[6] recently proposed a method of separating raw fish into four fillets. Steam is applied through rows of hollow needles along the planes of natural cleavage to beheaded, eviscerated fish. This softens the fish at these points only so that the four quarter fillets can be broken away from the backbone. The skin may then be removed from the fillets with superheated steam before cooking.

There can be little doubt that, in spite of the present high level of efficiency, much can be done to improve many phases of handling and processing tuna, both at sea and in the plant, which would result in a higher and more uniform quality product. It is probable also that ultimately it will be possible to automate processing with a corresponding cost reduction. Meantime the steady per capita increase of consumption, which has been sustained for many years, indicates a continued healthy and prosperous growth for this important fishery, provided that the handling of the resource itself can be correspondingly developed to yield a sustained supply of raw tuna at a reasonable price.

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CHAPTER 8

The Salmon Fisheries

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Salmon has long been used as a food by man, as evidenced by wall carvings found in caves in France which date back to 12,000 years ago. This salmon was probably the "Atlantic" salmon (*Salmo salar*) which is prized as a game fish in western Europe and the eastern United States today. The "Atlantic" salmon also was the first salmon used in commerce in western Europe and the eastern United States as fresh, salted, and smoked salmon. In 1839 small amounts of this species of salmon were canned in New Brunswick, Canada.

The potential of the United States salmon industry was first recognized in 1852 when William Hume started fishing for salmon in the Sacramento River in California. George and William Hume established the first salmon cannery on the West Coast of the United States on the Sacramento River in 1864, and in 1866 the first cannery was built on the Columbia River at Astoria, Oregon. The first salmon cannery was established in Alaska at Klawock in 1872.

Commercial Species of Salmon

There are five species of salmon occurring on the Pacific Coast of the United States, Canada, and Alaska. These, and a sixth species, occur in eastern Russia and northern Japan. These areas constitute the major fishing for commercial salmon in the world. These salmon are all of the genus *Oncorhynchus* which are hatched from eggs in streams or lakes and migrate to and live their adult lives in the ocean, returning to the same stream in which they were hatched to spawn.

The adult mature salmon spawn usually in small streams which empty into rivers and finally into the ocean. They start their spawning migration from the sea during the early summer and continue in large numbers throughout the summer. The salmon return to the headwaters of their native stream and the females deposit their eggs in the gravel of the stream beds where the eggs are fertilized by the males, following which the spawned-out adults die. The eggs develop during the winter and hatch during the early spring of the following year. The salmon fry then begin their downstream migration to the sea where they grow to adult salmon and spend from two to five years before they return to the stream, in which they were hatched, to spawn and die. The only variation in this cycle occurs with the *Oncorhynchus nerka* which spends part of its early life in lakes during its downstream migration.

Chinook Salmon. *Oncorhynchus tschawytscha,* also known as king or spring salmon, is the largest of the salmon, averaging 20 pounds in weight. The flesh of this species varies from a deep red to white and is used for curing, canning, and the fresh and frozen market. The chinook salmon is caught commercially by purse seine, trolling, gill netting, and by traps.

Sockeye Salmon. *Oncorhynchus nerka,* also known as red, blueback, and quinalt salmon, averages about 6½ pounds in weight and is used chiefly for canning. This species has flesh which is a deep orange-red color. The bulk of the sockeye salmon catch is made with gill nets and purse seines.

Silver Salmon. *Oncorhynchus kisutch* is also commercially known as coho and medium red salmon. This salmon averages about 8 pounds in weight and has light red-colored flesh. The silver salmon is caught commercially by trolling, seining, and gill netting. This species is primarily used for the fresh and frozen markets, and a smaller portion of the catch is canned.

Pink Salmon. *Oncorhynchus gorbuscha,* also known as humpback salmon, is primarily a canning fish and accounts for about one-third of the canned salmon pack of the United States. This species has light pink-colored flesh with a delicate flavor and has an average size of approximately 4 pounds. The majority of the commercial pink salmon are caught in seines and gill nets with a small quantity taken by trollers and traps.

Chum Salmon. *Oncorhynchus keta* is sometimes called dog salmon. This salmon averages about 8 pounds in size and has deep pink to nearly white-colored flesh. The bulk of the catch of chum salmon is canned, though a substantial amount is sold on the fresh and frozen market. This species is taken for market commercially by seines, gill nets, and traps.

Quality of Salmon

During their life at sea, salmon increase in size and immediately prior to and during the early part of their spawning migration the fish are in prime condition for use by the consumer. As the salmon approach their spawning streams, they cease to eat and continue their migration using their body oils for energy. This change is also accompanied by changes in the protein composition of the fish[1]. There are also physical changes which occur. The color of the flesh becomes pale and the skin loses its bright silver color and takes on a discoloration called "watermarking."

Regulations of the Fisheries

The American salmon industry is an inshore fishery, subject to the regulations of the states of Alaska, Washington, Oregon, and California and the Province of British Columbia, Canada. The Federal government in the United States and the government of the Dominion of Canada also play an advisory role in the administration of these fisheries. The red and pink salmon fishery of the Fraser River are under regulations by an International Commission by treaty between the United States and Canada. These various official agencies collect data, analyze probable runs, provide for escapement for spawning, promulgate fishing regulations, and enforce these regulations.

Commercial Salmon Fishing Districts

The Yukon River. The Yukon River is the most northerly of the North American salmon fishery districts. The chinook salmon constitutes the bulk of the commercial fishery in this river. There are also runs of chum and coho salmon which are used by the natives for personal use and dog food. The chinook production is canned, mild cured, and hard salted for shipment to Washington and Oregon for distribution.

Gill netting is the principal method used in taking the catch in this fishery. Two types of gear are used. The bulk of the catch is taken with set nets and the balance of the production from drift nets. The fishing grounds in the Yukon River district are close to the processing plants and fish are delivered to the canneries and stations with a minimum of delay from the time of catch.

The mild cured and salted salmon from this district are of good quality. The canned salmon has an attractive color and is very rich in oil. This unusually high oil content causes a slight softness in texture of the canned product. Almost all of the canned production from this area is put up in one-half pound cans.

Bristol Bay. The Bristol Bay area produces a major portion of the United States pack of canned red salmon. A very small pack of canned chinook, chum, pink, and coho salmon is also made, incidental to the red salmon pack. A very small amount of king salmon from this district is also mild cured, and both red and king salmon are salted in a small-scale operation. The natives of this district also take a considerable number of fish for personal use and for dog food. The Bristol Bay canned salmon pack is of good quality with good color and the fish are rich in oil. There are some variations in quality in the fishing districts in this Bay due to the races of salmon going into different river systems to spawn.

Bristol Bay is a very large, shallow and open fishing area with characteristically turbid water. For this reason the commercial fish are taken by gill nets. The major portion of the catch is taken by drift gill nets with a small part of the catch made by set nets along the shore. The typical operation is for the gill net boats to play out their net and drift until a catch is made. Following the drift, the fish are delivered to cannery tenders and power scows for delivery from the fishing grounds to the canneries. The canneries in this district are close to the fishing ground so that delivery is not a problem. The difficulty occurs in this fishery when a large run of salmon enter Bristol Bay and the catch exceeds the cannery capacities. When this situation arises, the canners put the fishing boats on limits and use chilled brine and refrigerated sea water to maintain the quality of the raw salmon.

A small part of the Bristol Bay catch is delivered to freezer boats in a mother-ship operation. These boats usually have brine freezers similar to those used in the tuna industry, although there are ships which air freeze the salmon. This frozen salmon is delivered to canneries in Alaska or in Washington and Oregon for processing. Salmon has highly unsaturated oils, and for this reason this freezing operation presents some serious problems from the standpoint of oxidation of these oils during frozen storage prior to canning. The very heavy landings during the season in this district make the protective glazing of the fish with ice almost impossible; also the brine freezing makes it impracticable to apply a protective coating to the salmon in frozen storage.

When these frozen fish arrive at the cannery, they are thawed by air, water sprays, or by immersion in water, and they are then canned in the normal manner. The pack from this district is put up in one-pound and half-pound cans with a small four-pound production developing in the area.

The pack from this part of Alaska is shipped by steamship to Washington and Oregon for distribution. One of the problems in the southward movement of the canned pack arises from the fact that the pack must be lightered from the canneries to the steamers anchored out in deeper waters of the bay. Storms and rainy weather make this operation difficult and hazardous.

Alaska Peninsula. The fishery in this geographical area is of mixed species with the predominant runs being red, chum, and pink salmon. Almost all of the catch from this part of the fishery is canned.

The fishing gear used consists of purse seines and gill nets, although the production from the latter type of gear is small.

The fishery is located some distance from the canneries and transportation from the fishing grounds to the plants is usually accomplished with cannery tenders and power scows using refrigerated sea water, chilled brine, or ice.

The many river and stream systems in this area produce some variation in the quality of the canned salmon. Generally, the red and chum salmon packs are good while the pink salmon pack, though slightly pale in color, is also of good quality. The pack from this area is generally made in one-pound tall and half-pound cans with a small production in one-quarter-pound cans.

Kodiak Island. This production district provides all five species of salmon, the bulk of which is canned. The salmon are taken primarily by purse seines and are usually delivered to cannery tenders or power scows for transportation to the canneries. The chinook and coho species are of minor importance and the major production is canned pink salmon with chum and red salmon making up the significant balance of the commercial pack.

The production from this area varies in quality because of the many river and stream systems with the resulting numerous races of salmon arriving in the fishery. The pack from this part of Alaska is usually put up in one-pound tall and half-pound cans with a small part of the production in four-pound cans.

Cook Inlet. The catch from this production area is usually made with gill nets and purse seines. The gill net fishery is composed of both drift gill nets and set nets. The fishing effort in this part of Alaska is widely scattered and deliveries are made by the fishing boats and shore gear to cannery tenders and power scows for transportation to the canneries. These tenders and scows use refrigerated brine, chilled sea water, and ice for transportation of the salmon in good condition to the canneries. In recent years the fishing season in this district has been curtailed to allow only a few days per week of fishing so the canners here also put in extensive shore installations for holding salmon in chilled sea water or refrigerated brine prior to canning.

The pack in this district is put up in one-pound tall, half-pound, and quarter-pound cans. A small part of the production is also mild cured and salted.

The quality of the fish in this production district is interesting. The color of the reds, chinooks, and chum salmon is very good, while the oil level is below that of most other districts producing these species of prime quality. The quality of the pink salmon from this area is slightly below normal for the species, but the fish are usually rich in oil. The major part of the chinook salmon pack from Cook Inlet is put up in the early season and has very good color characteristics.

Prince William Sound and Copper River. This production area has two distinct fishing seasons. In late May and early June there is a run of chinook and red salmon into the Copper River which produces a very high quality canned pack for the market. The red salmon has a good color and is very rich in oil. The chinook salmon is usually slightly pale in color but has high oil content and a very good flavor. This pack is taken by gill nets, and as the canneries are close to the fishery, the problem of transportation to the canneries is not difficult.

The second fish production period in this area during July is primarily a pink and chum salmon run with the other three species being taken incidental to these two major species. There is also a small coho salmon pack in the fall in this district. This second catch is made with purse seines and gill nets. This catch is wide spread in the Sound and typical fish packers, scows, and tenders are used to transport the salmon from the boats to the canneries. These boats and scows use chilled brine, refrigerated sea water, and ice to preserve the quality of the raw salmon.

The production from this area is usually canned in one-pound tall and half-pound cans.

Southeastern Alaska. All five species of salmon are fished commercially in this production district. Purse seines account for the greater part of the catch, and the balance is taken by fish traps, gill nets, and by trolling. The pink salmon constitutes the major species in numbers in this area with chum salmon also taken in fairly large quantities. Red, coho, and chinook salmon make up the remaining portion of this fishery.

The southeastern area is a large geographical district, so the transportation of the catch to the canneries is the major consideration.

British Columbia. The salmon fishery in the northern part of the province of British Columbia is very similar to that of southeastern Alaska. The predominance of the species is the same. The biggest difference is that in this fishing area the canneries are few and the problem of the transportation of the salmon is more difficult.

The southern portion of British Columbia has salmon runs which are primarily based on the spawning grounds of the Fraser River system and which are of primary importance. Red salmon runs have been rebuilt under the International Sockeye Commission into substantial productions. Pink salmon in this area are taken in considerable quantities on odd-numbered years while the even-numbered years produce very small productions. A considerable number of chum salmon are also taken in this district on the west coast of Vancouver Island and from Johnston Straits. These areas are fished by seine and gill nets and are usually of very good quality during the peak of the runs.

There is a good troll fishery for king and silver salmon along the coast of British Columbia and also in the straits behind the coastal islands.

Puget Sound. Puget Sound has a salmon fishery very similar to the southern part of British Columbia. It is dependent largely on a part of the Fraser River runs for red and pink salmon and is consequently under regulation of the International Commission. The waters of Puget Sound and its river systems also produce some pink and chum salmon.

Fishing in this area is carried out primarily with purse seines, gill nets, and reef nets.

Washington Coast. The Washington Coast produces its best quality commercial fish as troll fish taken the entire length of the coast. There are small fisheries for chum and silver salmon by gill nets in Grays Harbor and Willapa Harbor. The Quinalt River has a small commercial run of sockeye salmon, a large part of which goes on the fresh market and the balance is canned. This run is of high quality and is characterized by small fish with deep color and large amounts of free oil.

Columbia River. The Columbia River fishery is a gill net commercial fishery in the river which produces primarily chinook salmon. This fishery has one of the longest yearly seasons, lasting from May into October with closed period to allow for escape of spawners. The early catches from this river system are very high quality and are canned and handled for the fresh and frozen markets.

Oregon Coast. The Oregon Coast produces primarily chinook and silver salmon which are taken by trollers, and the major portion of this catch is used in the fresh and frozen market. During heavy production periods, a part of this catch is canned.

California Coast. This area from the Oregon border to San Francisco Bay is also a chinook and silver salmon producing fishery. The salmon are taken by trollers and the catch is used in the fresh and frozen market. There is very little salmon canned in California.

Preservation of the Catch

Three periods are important in the preservation of salmon after they are caught by the commercial fisherman and until the fish are processed: (1) while the fish are in the hands of the fisherman, (2) while they are being transported to the cannery, and (3) while they are in the cannery before being canned.

The first of these is the handling by the fisherman, and the care given the salmon is dependent to a considerable extent upon the type of fishing which produces the salmon. Trolling boats wash and eviscerate their catch immediately after taking the salmon aboard the boat and ice the fish down in the hold. These salmon are layer-iced, with ice also being placed in the belly cavity. The holds in these boats have bins and usually horizontal pen boards to prevent excessive pressure throughout the load. The usual procedure is to floor-ice the hold and then build up alternate layers of fish and ice, maintaining a layer of ice next to the skin of the hold. Some trollers operate as day boats and use no ice or only small amounts of ice. Also, a few trollers employ refrigerated sea water or brine holding-tanks as described below for the seine fishery.

The gill net fishery operating from boats deliver to the cannery tenders or pick-up boats on each tide and do not ice their catch aboard the boat. The catch from gill nets worked as set nets from the shore is boxed on the beach when the nets are picked each tide, and the boxed fish are transferred to pick-up boats or trucks for transportation to the processing plant. These fish are not iced.

Seine boats use several methods of handling the catch from the fishery to the cannery or pick-up boats. Some seiners operate as day boats and do not use any or, at most, very little ice. A number of seiners ice the fish as they come aboard the boat. In this case, the round fish are put away in the hold with floor and skin ice, and the fish are either layer-iced or the ice is mixed with the salmon.

A number of seine boats have recently installed chilled brine or refrigerated sea water systems to provide a better storage medium for fish aboard the boats. These systems are generally of three types and are all developments based upon the chilled brine system originated in California in the middle 1920's.

At present, the most popular is the refrigerated sea water or brine system. This method is very good if properly engineered and utilized at its optimum capabilities, both for loading and storage time. The method uses tanks of circulating sea water or brine at approximately the 3½ per cent level which is cooled mechanically to a temperature of 28 to 30°F to preserve the catch aboard the boat.

The second system, employing chilled brine or sea water, is used on some seine boats for preservation of the catch. This system does not use mechanical refrigeration but is dependent upon the use of ice in the tanks to produce the cooling necessary for the preservation of the salmon aboard the boat. In this case it is of the utmost importance that an excess of ice be maintained in the tanks at all times to insure proper cooling. This type of preservation is also limited by loading capacities and storage time as is the mechanically refrigerated system, and the chilled brine installation must have mechanical circulation systems to be fully effective. Attention must also be given to maintaining the proper salt level in this system as the melting ice dilutes the brine.

The third refrigeration method in general use aboard the vessel is a combination of the mechanical refrigeration method and the chilled brine method using mechanically refrigerated sea water or brine with the addition of ice, especially at the time of heavy loading of the tank with fish.

Fish taken in traps are usually moved aboard tenders to the processing plants without ice as they are kept alive in the traps until needed at the plants and arrive in good condition because the trap locations are near the processing plants.

The second important period in the handling and preservation of the salmon is aboard the tender or scow which will take the fish to the plant. A number of the plants are a considerable distance from the fishing grounds and, as the fishing boats would lose too much time from the grounds if they made this run, all of the processors operate tenders to bring the salmon into the plants. These tenders are large boats, power scows, or towed scows which are equipped to handle salmon from a number of fishing boats and deliver them to the processing plants. These tenders either use ice or, more generally, one of the three systems of pre-cooled sea water.

The third important period in handling salmon to the processing plant is at the plant itself. The fish which is received at the plant is processed as soon as possible after being received from the tenders and day boats. If there is going to be a delay in processing, the fish are iced in bins at the cannery or held in shore tanks with refrigerated brine or chilled sea water.

The refrigerated sea water or chilled brine systems are a recent innovation in the salmon industry and have contributed a great deal to the success of the industry. In past years with fewer canneries and processing plants operating, use of such systems has made it possible to transport salmon in good condition over greater distances. Their use has also made it possible for tenders to stay on the grounds longer so that the runs to the plants could be made with full loads. These systems allow for the transportation of the fish to the plants without the weight of fish in iced or dry loads causing a loss in yield through pressure drip. At the plant these systems have allowed the operator to even out the operating day to bring about the most effective and economical production.

The refrigerated sea water and chilled brine systems may be abused by overloading the system when picking up fish so that the systems are not able to return to proper holding temperatures soon enough to preserve the fish. Overloading of the system during holding periods also makes it impossible to achieve optimum storage temperatures and consequently sub-standard fish will result. Excessive holding times in these systems will result in chemical changes in salmon, such as oxidation of the oil.

Processing of Salmon

Canned Salmon. The major portion of the salmon catch is processed by canning. This is especially true of the sockeye, pink, and chum salmon which are landed in such large quantities during the peak of their runs in the various fishing districts that canning is the only practical and rapid method of preservation.

At the typical salmon cannery the salmon are unloaded from the holds of tenders by elevator to the docks and by conveyor to the fish bins of the canneries. While the fish are being conveyed to the bins they are sorted by species by skilled inspectors. If the fish are to be canned immediately, they are put into bins for direct delivery to the canning line. If they are to be held because of an excess of fish at the plant, they are iced down or placed in chilled brine or refrigerated sea water.

From the fish bins the salmon are conveyed to the butchering machines or "iron chinks" which remove the head, fins, and viscera from the salmon. Some plants hand-butcher chinook salmon and some other species for recovery of eggs for caviar and bait.

The salmon are next conveyed to the sliming tables from the "iron chink." Sliming consists of the removal of fins, bits of viscera, blood, etc., not removed by the "iron chinks." In some plants this work is done by hand or with machines, and in some instances a combination of both is used. During the sliming operation the fish are thoroughly washed and inspected for bruises and other defects.

From the sliming tables the butchered and cleaned fish are conveyed to a fish cutter where they are cut into can-size lengths for delivery to the filling machines. The newer filling machines include the fish cutter and filler in one machine. The filling machine is a volume filler which fills the can with the salmon and also bottom-salts the individual cans or delivers the cans to a salter immediately behind the filler. Salmon is usually salted at the level of 1.25 to 1.65 per cent.

From the filling machine the filled cans pass through a mechanical weighing machine which separates the underweight cans so they may be filled to the proper net contents. Some of the smaller plants check-weigh cans by hand.

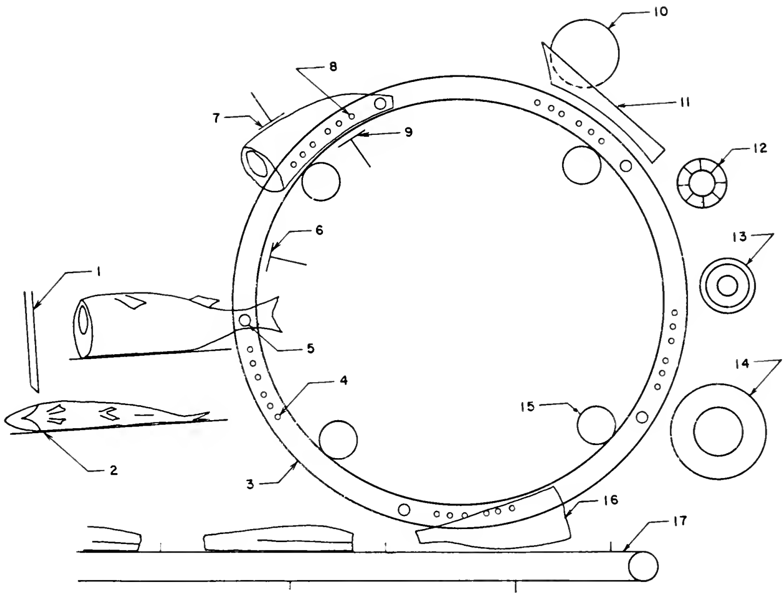

Figure 8.1. Iron chink for dressing salmon. (*L. G. McKee.*)

1. Header knife
2. Fish in position for heading
3. Bull ring which carries fish through the machine
4. Back pincers
5. Tail pincers advanced and grasping fish
6. Tail cut-off saw
7. Belly finning knife
8. Back pincers advanced and grasping fish
9. Back finning knife
10. Belly slitting saw
11. Guide to open belly flaps for gutting reel
12. Gutting reel to remove viscera
13. Knife and reel to slit kidney membrane and to remove kidney
14. Brush to remove blood and membranes
15. Roller to support bull ring
16. Fish released as back and tail pincers retract
17. Conveyor to remove butchered fish

Following the weighing procedure, the cans pass through a clincher which loosely rolls the cover on the can. As the cover is fed onto the can, a set of metal dies embosses a code on the cover so the packer will be able to identify his product. From the clincher the can passes into the vacuum closing machine which hermetically seals the cover under a partial vacuum. Some closing machines in use in the industry subject the can to a flow of steam across the open top and immediately complete the top seam to obtain a vacuum.

The filled and sealed cans are then discharged from the closing machine through a can washer to remove any particles of fish from the outside of the can. From the washer the cans are filled into retort baskets or flat metal strap or rod trays which are placed in the retorts for processing.

Machine filling is used for the one-pound tall, half-pound, and quarter-pound cans. All four-pound cans, some half-pound, and a considerable number of one quarter-pound cans are packed by hand.

Following processing, the cans are water-cooled by flooding the retorts or by cold water sprays. If sufficient water is not available, the cans are air cooled. When the cans are adequately cooled they are usually cased bright or may be labelled and cased for shipment from the canneries to the prime distribution centers of the Pacific Coast.

Collapsed cans are used to a large extent in Alaska to save on the cost of shipping cans from Washington and Oregon to Alaska. These collapsed cans are actually flattened can bodies which are reformed at the canneries in Alaska to their round shape and the bottom attached prior to filling.

Fresh and Frozen Salmon. Chinook, silver, and some chum salmon are taken from the troll and gill net fisheries and are dressed and shipped in ice to the various large metropolitan areas on the Pacific Coast and into the Midwest for use in the local fresh fish markets. These same species are also frozen at shore plants and shipped to these same markets and on to the East coast. These species are also packaged as steaks and fillets in both portion and institutional sizes for convenient use in the frozen form.

Mild Cured Salmon. Mild cured salmon is a salmon which is butchered and split to remove the backbone, and the sides are packed in tierces, wooden barrels which hold about 825 pounds, with a light salt added.

Chinook salmon is generally used for this pack, and the very best quality red oily chinook are most desirable.

The salmon are split, slimed, and dipped in a fine grain pure salt and packed skin down in the tierces. The tierces are headed and filled with 100° salinometer brine. This pack is held at temperatures of 35 to 40°F to preserve the pack and prevent oil loss.

After 30 days the mild cured tierces are repacked; the sides are given a close inspection for color, size, and defects and are repacked in a uniform quality for shipment to markets in the East and Europe for smoking and kippering.

Hard Salted Salmon. A small portion of the salmon catch is hard salted for shipment to the Orient. Silver salmon is generally used for this purpose. Good quality fish, free from defects, are split, the backbone removed, and the sides slimed and inspected.

The sides are packed in 100-pound barrels with alternate layers of salt and fish. Following 12 to 18 days of curing the sides are graded and repacked with light salt, and the barrels are filled with 100° salinometer brine. This product does not need refrigeration unless it is shipped to a warm climate.

Smoked Salmon. Chinook and silver salmon are usually used for smoking. Red salmon makes a fine smoked product and some chum salmon is also used.

Two types of smoked salmon are generally produced by the industry—the low-temperature smoke and the high-temperature smoke. Low-temperature smoke is produced by fresh water soaking of salted salmon sides, then draining and drying in a smoke house, followed by smoking in hardwood smokers at temperatures below 90°F. High-temperature smoked salmon is produced by freshening salted salmon sides, draining and drying in a smoke house, followed by smoking at high temperatures of approximately 175°F.

The degree of smoking is dependent upon the requirements of particular markets and may be varied in individual plants.

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CHAPTER 9

The Halibut Fisheries

JOHN A. DASSOW

Halibut (*Hippoglossus hippoglossus*, the Atlantic species, and *H. stenolepsis*, the Pacific species) have been a major food fish since ancient times for populations of the northern Atlantic and Pacific areas. The Vikings from Scandinavia, Celtic fishermen from Scotland, the native peoples from Greenland, and the Indians of the northwest coast of America fished halibut from the earliest years of the Christian Era.

During the first decades of the twentieth century the increasing exploitation of halibut in both the Atlantic and the Pacific brought about a serious decline in the annual landings. Conservation measures and modern fishery management (see Chaper 2 for additional discussion) restored the North Pacific halibut fishery to the status of a major fishery with a controlled annual yield of around 65 to 70 million pounds. The North Atlantic halibut fishery contributes currently a much smaller annual yield, around 8 to 12 million pounds.

Fishing Operations

The halibut, largest member of the flounder family (Figure 9.1), lives near the bottom in the colder northern waters at depths from 10 to over 100 fathoms. It feeds on squid, octopus, herring, crabs, and other marine life. Commercially, fish to 700 pounds have been caught but those from 20 to 80 pounds comprise the bulk of the current landings. Halibut has long been esteemed for the excellent keeping qualities of the fresh and frozen fish, the snow-white color of the flesh, and the mild flavor and firm, flaky texture after being cooked. The female fish live longer and grow larger than the males; a male may live as long as 25 years and be only 40 pounds, whereas a large female may live 35 years and be 400 pounds.

Fishing for halibut is conducted almost exclusively by means of the baited long line or set line laid along the bottom while the boat is running (see Chapter 4 for additional information on fishing gear). Most boats in the Pacific halibut fishery are 50 to 80 feet in length and hold 30 to 50 tons of iced halibut. The season starts in April or May and continues to October each year, depending upon the season and quota set by the International Halibut Commission. The larger boats, with a crew of 7 to 9 fishermen, head out to the fishing grounds with fuel, ice, bait, and

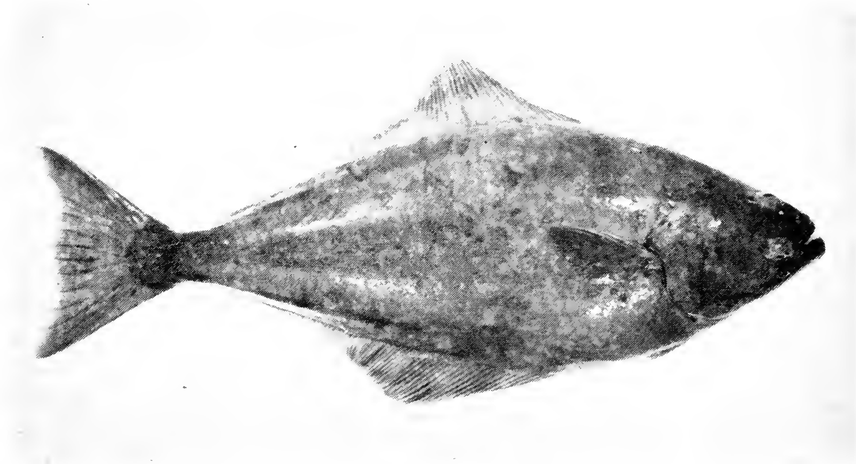

Figure 9.1. Halibut.

groceries for several weeks' fishing. The fishing grounds are 3 to 6 days away at an 8 knot cruising speed; therefore, time on the outgoing trip is used for preparing and baiting the gear. Everything is ready to go as soon as the grounds are reached. Frozen herring, about 200 to 300 pounds of it per ton of halibut to be caught, is a common bait but is interspersed with other frozen fish and, in recent years, with frozen octopus. Octopus is more efficient as a lure and has a staying power on the hook which makes it worth the extra cost to the fisherman.

After the long line has been on the bottom several hours, the buoy line is retrieved and a fisherman takes the position at the starboard rail for hauling the ground line to the surface. During the subsequent operation, when the ground line is hauled in, the fisherman at the rail and four others on the deck must work smoothly and efficiently at a most arduous task—that of recovering the gear smoothly and removing the fish while the boat runs alongside the gear. The handling and care of the halibut during these operations are most important to its subsequent quality.

Preservation of Halibut at Sea

Of all the world's fisheries, the halibut is second to none in the many problems of insuring high quality fish for delivery at the dock. The distance from port and the value of halibut make careful handling and preserving methods essential. Even in the catching process the halibut may be damaged physically, in some cases by factors outside the fishermen's control.

If there are undue delays in recovering the gear, because of stormy weather, for example, the fish may be damaged by attacks from sand fleas. On some grounds, attacks from predator sharks or sea lions may be a problem and can result in serious physical damage or complete loss of many fish. In bringing the fish over the rail and in shaking it from the hook, it is important not to bruise the fish or mar the skin since these may result in a lower price grade.

Handling on Deck. As the ground line comes over the roller on the starboard rail, the fisherman clears the gangion line so it drops below the power gurdy, gaffs the halibut, and clears the fish so it drops from the hook to the deck. All this is done swiftly and almost with one motion by an experienced fisherman. Large fish must be anticipated so they may be pulled over the rail by hand or with the gaff. In case of very large fish or snags in the line which can't be cleared readily, the fisherman can stop the gurdy; however, no time is wasted and the fish soon begin to pile up on deck during good fishing.

The halibut is a very active fish and, in the case of 40-pound fish and larger, exceedingly vigorous and must be dispatched promptly with a sharp blow between the eyes. Fish are then thrown in the checkers on the deck. Another fisherman quickly removes the gills and viscera, scrapes the abdominal cavity clean of excess blood and kidney, and passes the fish down the hold for icing. The halibut livers are separated during this operation and stored in 5-gallon cans for sale to plants recovering the high potency vitamin A oil. The halibut are not washed at this time; however, it is important that the gut cavity is cleaned properly and that no bits of viscera are left; otherwise early spoilage or "souring" may occur.

Icing. Ice is packed in both the belly and gill cavities, then the fish is laid on a bed of ice in the bin so the water from the melting ice will flow around and away from the fish. It is important that the fish be laid so any water in the belly cavity drains away and does not form a pool of blood and slime along the dorsal part (near the backbone) of the cavity.

Otherwise the gut cavity or "poke" soon develops sour off-odors during storage. Ample ice is placed around the halibut, with care being taken to provide extra ice adjacent to the sides of the vessel and the bin partitions. This practice avoids exposure of the halibut to the air as the ice melts and the development of "bilgy" spoilage in the flesh next to the wood.

As discussed earlier, a major portion of the North Pacific halibut is taken from grounds which are 3 to 6 days' voyage from the landing port. When this distance is added to the vagaries of weather and fish distribution, it can be readily seen why halibut are landed commonly from 8 to 16 days after catching. Fish from the earlier catches may still be of reasonably good quality, but must be used promptly or frozen.

The careful handling and icing by the fishermen are most important in assuring the maximum retention of quality and, within a limited sense, are more important than the time factor. Data from one group of landings show little direct relation between the icing period for the oldest halibut and per cent of the fish graded second quality because of soft, sour, and yellow fish[8].

Refrigerated Sea Water. Experimental tests[7] have indicated that fish held in refrigerated sea water (RSW) at 31°F are somewhat fresher than comparable fish held in crushed ice for the same period. Both the extensive experiments and commercial trials with bottom fish and halibut, however, have brought out disadvantages of the RSW method. Objectionable factors have been the large build-up of blood and slime in the brine, loss of slime from the skin, difficulty in later handling, increased salt content of flesh, weight gain of fish because of water absorption, softer texture, changes in appearance, problem of segregating fish of varying ages in a few large tanks, and reluctance of buyers and graders to handle the RSW fish. In view of these problems, little expectation is held that the RSW method provides the solution to the basic problem of extending the keeping quality of halibut from distant fishing grounds aboard the fishing vessel. Rather, the RSW system should be considered primarily for use in fisheries close to port with emphasis on the flexibility and labor-saving aspects of the system.

Improved Preservation Methods. In studying the extension of keeping quality for chilled halibut, the use of preservatives in the ice or in refrigerated sea water has been considered experimentally[10]. Of various preservatives, antibiotics, particularly chlorotetracycline, have shown the most promise. Halibut, as with fresh fish generally, reflects a modest improvement in quality or storage life if held in antibiotic ice under experimental conditions. Experience with preservative ice formulas in the last two decades has shown repeatedly, however, that the value of the preservative is easily canceled by over-long fishing trips and careless practices in icing and sanitation.

Actually, a review of handling and icing methods has indicated that more can be gained without use of preservatives if the level of practice throughout the fishing fleet can be raised. To this end, the National

Quality Improvement Guidelines
for
HALIBUT FISHING VESSELS

Handling of Catch

1. Carry a full crew—never leave port undermanned.
2. Gaff fish only in head.
3. Never release hook by striking halibut across checker. Avoid bruising fish.
4. Stun fish quickly to prevent deck thrashing. Club fish in head only and avoid striking body.
5. Gut and clean fish thoroughly. Leave no part of gut to start spoilage.
6. Remove all "sweet meat" and blood by scraping with a water-flushing scraper.
7. Put dressed fish below deck for icing immediately. (If delay is necessary, place fish black side down in checkers and cover with wet sacks.)

Icing

8. Prepare a smooth bed of ice from 8 to 12 inches deep in bottom of pens.
9. Use enough ice to cool fish rapidly. Use thermometer. Keep fish temperature below 35° F.
10. Build ice bank along all sides of pen from 4 to 6 inches thick and from 6 to 8 inches thick against skin of boat. Keep this bank higher than the iced fish at all times.
11. Pack fine ice into poke of fish.
12. Place black side down on ice, tail to tail (heads pointing forward and aft).
13. Use shelving when iced fish reaches a depth of 3 to 4 feet.
14. Cover shelving with bed of ice at least 2 inches thick.
15. Ice heavily on the top layer of fish—extra heavily at points where ice melts the fastest.

Sanitation

16. Remove all pen boards from stanchion grooves after every trip. Equip all pen boards with eye holes for easy removal.
17. Use metal or solid, smooth, painted wooden pen boards. Discard old and worn out pen boards.
18. Scrub deck, pen boards, stanchions and all surfaces of the hold, using clean water, a detergent and a stiff bristle broom.
19. Rinse scrubbed surfaces with a strong chlorine solution.
20. Use the Halibut Score Sheets to grade yourself. A score of 90 or more is Grade "A".

Figure 9.2. Quality improvement guidelines for halibut fishing vessels.

Fisheries Institute in cooperation with the halibut industry and the U.S. Bureau of Commercial Fisheries prepared and distributed to the fleet during 1959 "Quality Improvement Guidelines" for halibut fishing vessels. These guidelines (Figure 9.2) summarize good practice aboard the vessel and can be used conveniently by the fishermen in the form of a check list. Linda and Slavin[4] have pointed out that chlorinated sea water can easily be provided aboard fishing trawlers. Tests in which sea water with 50 to 60 ppm free chlorine was used aboard a trawler showed that slime and blood were easily removed, pen boards were easier to wash than with plain sea water, and fewer bilgy and spoiled fish were landed.

Freezing Halibut at Sea. An obvious solution to the limited storage life of the chilled fish is to freeze it at sea. Such frozen fish are most apt to be frozen whole for later processing. If thawed ashore for filleting and packaging, the fish may have to be refrozen. Studies on bottom fish[9,5,6] indicate that fish frozen at sea within a few hours of their capture show little adverse quality defects from freezing, thawing for processing, and finally refreezing. Any changes caused by refreezing were far outweighed by the obvious gain in over-all quality.

In considering the freezing of halibut within a few hours of capture, pretreatment to allow the fish to pass through *rigor mortis* may be desirable, since the halibut would probably be cut into steaks while frozen. Studies in freezing cod at sea aboard the trawler *Northern Wave* by the Torry Research Station[1] suggested that "No fish be frozen sooner than 6 hours after catching, preferably not until 12 hours." Later research on cod at Torry[2,3] indicate, for example, that undesirable texture can result, such as loss of juiciness, if fish are frozen prior to rigor. It was concluded, however, that under practical conditions the freezing of pre-rigor fish would not produce an unacceptable product. With halibut the enzymatic action in the skin leading to substantial slime formation is normally completed during the icing stage; subsequently, the slime is easily washed off prior to freezing. If frozen within a few hours after capture, such halibut may show an undesirable formation of slime during later thawing for use. Further research undoubtedly will clarify these problems.

Processing Fresh and Frozen Halibut

Most Pacific halibut vessels arrive at the landing port after a 3 to 4-week trip with a total catch from 50,000 to 80,000 pounds. A few larger boats have landed over 100,000-pound trips, and the recent developments in Canadian boat construction suggest that the larger capacity boats will become more common in halibut fishing. As a rule, the entire trip of halibut is posted on the board of the exchange and sold to the highest bidder.

Unloading and Grading the Fresh Halibut. Halibut are landed dressed (head on) and traditionally are sold on a heads off basis. The fishermen do the unloading and heading (Figure 9.3); a fish grader employed by the buyer grades the halibut for size and condition in accordance with set procedures. In recent years there is a trend toward purchase of the halibut with the heads on, in which case the weight is adjusted. A 12 per cent allowance for heads is accepted in several ports. A simple guillotine cutter is used for heading before freezing.

The grading procedures are notable in the selling of fresh halibut

Figure 9.3. Heading of halibut at the unloading platform.

because not only do they cover uniform size grades and allowances, but in addition they specify first and second quality classifications for the medium and large fish. The size classifications for dressed (heads off) halibut are: small, 5 to 10 pounds; medium, 10 to 60 pounds, and large, 60 pounds and over. The second quality classification includes discolored or mutilated fish as well as fish not of first quality because of poor cleaning, soft texture, sour odors, and other quality indicators.

Initial Processing. If the halibut are not to be processed immediately, they are re-iced in the fish house by placing a layer of ice on the floor, then the fish, and last a layer of ice over the fish. An improved procedure minimizing the handling of the fish is the use of large galvanized metal boxes suitable for stacking and handling with a fork lift. The halibut are placed in these after grading, then are transferred to the wash area for immediate processing, or are stacked with a topping of ice on each box for holding overnight.

Halibut are shipped fresh to markets by refrigerated truck or rail car in wood boxes holding 100 to 200 pounds of fish with an equal weight of finely crushed ice. Only the very freshest halibut is shipped in this manner, to assure that good quality fish is received and marketed.

A major portion of the medium size halibut is frozen in the dressed form within a few hours after landing and grading. Continuous belt washers with top and bottom sprays are used to wash the fish before freezing. The fish are loaded by hand onto the shelves of still air or sharp freezers and frozen overnight at −35 to −40°F. The frozen fish are dipped into water to provide an ice glaze to protect the fish from drying during storage. Formerly, the frozen halibut were stacked by hand in the large storage rooms; however, in modern practice large, heavy-duty baskets holding about 500 pounds of halibut each are used. These are convenient for glazing, storing, and transferring the frozen fish with the use of mechanical equipment.

Frozen halibut are stored at 0°F or colder and may be held, if wrapped or glazed properly, for over a year in good condition. Recognition of the importance of storage temperatures below 0°F for better retention of flavor and texture has brought about the increasing use of −15 to −20°F storage for halibut.

Halibut Fletches. Halibut fletches are boneless and skinless pieces produced from the fresh fish by cutting each side away from the backbone and trimming free of fins, nape, tail, belly section, and skin with the surface fat. This process divides the halibut into four or more trimmed meaty portions from 5 to 20 pounds, depending upon the size of the fish and the number of lateral cuts after splitting. The fletches are frozen and either glazed or packaged in a moisture vapor-proof wrap for shipment to restaurants and institutions, where the fletch is sliced conveniently into uniform-size serving portions with no trimming waste. The increasing demand for fletches and the ease of their production from large halibut has been a major factor in establishing a strong market and good prices for halibut 60 pounds and over.

Packaged Consumer Products. Throughout the year the frozen dressed halibut flows from the processor's refrigerated warehouse to the final processing room. There the still frozen halibut are trimmed with a band-saw to remove the tail, nape, belly, and excess bony portions, then sliced transversely into uniform steaks $3/4$ or $7/8$ inch thick. These are further trimmed to individual weights from 4 to 8 ounces and, in the case of portion control packs, are sorted automatically by machine into steaks of uniform weight to the nearest $1/2$ ounce. After inspection and ice

Figure 9.4. Fletching a large halibut at an Alaskan port. The fletches are trimmed and frozen for later shipment. (*U.S. Fish and WildLife Service.*)

glazing for protection from dehydration, the steaks are packaged in waxed cartons with a net weight of 12, 14, or 16 ounces and overwrapped. Also wholesale cartons of 5, 10, or 15 pounds are packed. A superior halibut steak pack for retail sale is produced by vacuum packaging the steaks with laminated plastic film, a process which is more expensive than glazing but provides unequaled protection against dehydration and oxidative loss of flavor in subsequent storage.

In addition to the production of packaged halibut steaks for retail frozen food cabinets, a large portion of the halibut steaks are prepared at central locations for the chain stores and packaged in the familiar tray carton and overwrapped with transparent film. These packages usually are placed in the self-service fresh fish cabinets where the fish thaws slowly and is ready for immediate use. Obviously, rapid turnover is essential to this service because if the thawed fish is not sold promptly, quality loss or spoilage may occur.

Other forms of fresh or frozen halibut are packaged fillets from small or chicken halibut, halibut roasts from the tail or nape sections, and breaded fillets or portions ready to cook. Recently halibut has been used as the main ingredient in TV dinners, including precooked broiled steaks, fried halibut sticks, and the deep fat fried halibut pieces. The meaty portion or cheeks from the sides of the large halibut heads have a mild flavor and a different texture liked by many; therefore, these are cut and frozen for both retail fish cabinets and the restaurants. The cheeks are cut, washed, and frozen in 1 and 5-pound cartons shortly after the halibut are landed.

Miscellaneous Halibut Products

The halibut is actually a most versatile food fish and lends itself to the preparation of several other products. Demand for halibut as frozen steaks, price, and competition from other foods have limited the production of other forms of halibut. Among these are: (1) canned halibut—a mild-flavored product with tender texture produced by precooking the fish and adding vegetable oil before heat processing, (2) kippered halibut—produced primarily by brining and hot smoking the tips and usable portions trimmed in preparation of steaks, (3) salted halibut—salted or brined halibut is produced mostly in coastal areas for home use. One other product should be mentioned: halibut liver oil—still produced for those markets in which a natural vitamin A is desired. Value and production of halibut liver oil declined drastically, as did other natural vitamin A sources in the U.S., when synthetic vitamin A was introduced at low prices after World War II.

Sablefish

Brief mention should be made of the relation and importance of the sablefish catch to the halibut fishery. The sablefish (*Anoplopoma fimbria*) or black cod is caught in substantial quantity by the halibut boats during the latter part of the season, at which time 1 pound of halibut may be taken for every 7 pounds of sablefish. The sablefish is a most desirable food fish and is valued particularly for its high oil content (12 to 14 per cent by weight in the edible flesh) and the firm, flaky white flesh that yields one of the best smoked fish products. The body is elongate, tapers into a rather long caudal peduncle, and tends toward a slate-black to greenish-gray coloration on dorsal surfaces. Sablefish have been caught on halibut banks down to 170 fathoms and up to 40 pounds in weight, although 5 to 10 pounds is a common weight range in commercial landings. Sablefish caught in the long-line fishery are dressed and iced similarly to halibut and sell at a premium price compared to sablefish landed in the round by the trawl fishery. The dressed fish are most commonly sold to markets as frozen dressed fish in the sizes: under 5 pounds, 5 to 8 pounds, and over 8 pounds. Steamed hot-smoked sablefish is a favorite menu item in many fine restaurants.

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CHAPTER 10

The Sardine, Mackerel, and Herring Fisheries

Sven Lassen

The Sardine Fisheries

The sardine industry of the United States is centered around the industrial utilization of two species of fish; namely, the pilchard (*Sardinops caerula*) and the small sea herring (*Clupea harengus*). The word "sardine," according to predominant and official views in this country, is a generic term identifying a canned product made from several species of the clupeoid family. This definition is not in conformity with that of several other nations. France and Portugal, for instance, claim that the term sardine is a proprietary name reserved exclusively for the species *Clupea pilchardus* (Walbaum).

This divergence of view which has been in existence on the international stage for almost a hundred years, and has resulted in several famous court cases, is still unresolved. Many hold the view that the word "sardine" has reference to a style of pack of certain species of small fish, rather than identifying the species themselves. Under the official U.S. interpretation, small herring, brisling sprats, and pilchards may be packed and sold as sardines because they all belong to the clupeoid family of fish. Anchovies, on the other hand, though available in commercial quantities and making an excellent canned product cannot be packed as sardines under this U.S. definition.

A survey made in 1954 revealed that 23 nations were packing sardine-like products from 14 different species of fish and labeling them sardines. The most distinguishing feature that these packs had in common was the style of pack, which seems to bear out that the word sardine may not be a taxonomic concept but one associated with its mode of preparation. The sardine canning industry of the United States is located mainly in California and Maine. The canning of Maine sardines is described in a subsequent section on the herring fisheries.

The California Sardine (Pilchard)

The California sardine (pilchard) has played an important role in the development of the California fishing industry, and at one time the landings of sardine exceeded in tonnage the combined catch of all other California fisheries. The sardine fisheries began to soar during the first World War and amounted to 150,000,000 pounds in 1918. From then on the sardine industry grew at a very fast rate and reached its peak in 1936 when 1,500,000,000 pounds were landed. By 1944 a rapid decline of the highly expanded sardine industry began, resulting in financial difficulties for fishermen as well as for canners, and this decline has continued since then. Today the California sardine industry is only a shadow of its former self.

Method of Fishing. The California sardine is now caught almost exclusively in purse seines. In the earlier years of the sardine canning industry on the West Coast, lampara nets, similar in nature but smaller than the original Italian lampara, were used in boats of 30 to 50 foot length with a carrying capacity of up to 50 tons. In 1925 the purse seine was introduced, after an earlier attempt at its use had proven unpopular. This time the use of this method of fishing for sardines proved successful, and since then purse seining has dominated the sardine fishing industry. Today the fishing for sardine is carried out in large diesel-engined vessels reaching up to 100 feet in length, using purse seines of 300 fathoms length or more, and made of nylon or some other synthetic rot-proof fiber. Vessels of this type naturally can operate over a much larger fishing area and, with modern navigational equipment and improved fishing gear at their disposal, the efficiency of the fleet has greatly improved.

The sardine is usually seined at night during complete darkness. This is because a school of sardine may conveniently be located in darkness by the phosphorescent glow produced by the movements of the sardines near the surface. It has become customary for the fishermen not to go sardine fishing the last two days before full moon and the first two days after, as these moonlit nights usually do not provide a long enough period of darkness for the fishermen to locate the sardine schools.

The sardine fishing season is set by an act of legislature and usually starts in Southern California in September, while the Monterey area usually starts a month earlier. By the end of January the sardine season usually comes to a close but may, under certain circumstances, be extended beyond this limit.

The fishing areas for sardine in Southern California are usually only some few hours' run from the cannery. The sardines arriving at the dockside are, therefore, generally in a very good condition.

Methods of Processing. The methods used for the unloading of the sardine catch varies some in various localities but is usually uniform in any one packing area. At Terminal Island the sardine boats tie up at the elevator piers jutting out from the dockside, and the sardines are either bailed out of the hold of the boat onto the elevator which transports the sardines into the cannery or pumped through a 9-inch tubular hose by a Yoeman pump from the hold onto the elevator and then into the cannery. A somewhat different arrangement is used in Monterey, where an 8-inch pipe extends along the bottom of the bay to a rectangular hopper float at the surface about 100 yards off shore into which the sardine boats discharge their cargo of sardines. The hopper is provided with an overflow so that sea water can flow into the hopper. A powerful pump located ashore sucks the sardines and the water into the cannery as the fishermen bail the sardines from the boat into the hopper.

At the cannery the sardines are weighed and flumed to the receiving tanks. The weighing is done by discharging the sardines from an overhead hopper into weighing buckets holding 500 pounds per bucket. The number of 500-pound buckets is recorded, and after weighing, the buckets are emptied and the sardines are flumed to the receiving tanks. An automatic weighing device which weighs the sardines continuously as they pass over a conveyor belt and registers the integrated weights has been in use in some sardine canneries. This method of recording the catch proved unpopular, and the simpler method of weighing the catch in 500-pound capacity buckets is now again in general use.

The receiving tanks, which receive the sardines after they have been weighed, are provided with refrigeration so that the sardines may be held there in chilled sea water until they are ready to be cut. By opening a sliding door located at the base of the receiving tanks, the sardines flow out on the cutting table where cannery workers place the sardines in a deeply slotted conveyor belt so arranged that the sardines, when placed in these slots, back up, this holds the fish firmly. The conveyor belt then carries the sardines past two revolving, circular knives which cut off the heads and tails and reduce the size of the sardine so that they will readily fit into the can size they are intended for. In a subsequent operation the fish passes a vacuum apparatus which removes the viscera by suction. The cleaned fish is then flumed into smaller holding tanks. From here the fish finally is conveyed to the packing table where cannery workers place the sardines into their requisite cans. In other instances, the fish is passed from the cutting table directly into fully automatic filling machines.

After the can is filled with sardines, it is conveyed to the exhaust box. The exhaust box consists of a slowly moving, broad, metallic conveyor belt surrounded by a hood into which live steam is injected. The speed of the conveyor belt is so regulated that the open, filled sardine cans are heated up to a temperature that will expell the trapped air in the can and coagulate and shrink the fish protein, thereby releasing some of the natural juices of the fish. Sometimes smoke is introduced into the exhaust box, thereby imparting a light, smoked flavor to the canned product. This is done, for instance, when the so-called 6-ounce tinapa sardines in tomato sauce are passed through the exhaust box. The temperature inside the exhaust box, being open to the atmosphere at both ends, can, of course, not exceed 212°F and often averages from 200 to 210°F depending upon circumstances. The speed at which the cans pass through the exhaust box determines their final exit temperature. The speed at which the conveyor takes the various can sizes through the box can, therefore, be regulated so that small cans of fish spend shorter time in the exhaust box than the larger cans do. The final temperature of the open can of fish upon leaving the exhaust box should be around 145°F.

After a stay of 10 to 25 minutes (depending upon size of cans) in the exhaust box, the cans move out on the line and are tilted to draw off the free natural juices of the fish. After this, brine, tomato sauce, mustard sauce, or oil is added to the can before it goes to the automatic seaming machine for sealing. From the sealing machine the cans move through a mechanical washer that removes any particles of fish or oil or sauce which may cling to the surface of the tin can. From the washer the cans drop into a steel cart of circular cross section made of perforated steel plate in which the sealed, washed cans are carried directly to the retorts for sterilization.

Styles of Packs. The styles for the processing of the California sardine have undergone many changes and simplifications during the past decades. The several steps used earlier by California sardine canners, involving brining, hot or cold smoking, and oil frying (processes which are still in use in other countries), have either been greatly modified or eliminated altogether. These changes in modes of processing, dictated in part by economic considerations, have resulted in a canned sardine product which naturally differs from imported sardines. At the moment, the California sardine is packed predominantly in one of the following styles and pack sizes:

1 pound ovals in mustard or tomato sauce
1 pound talls in brine or tomato sauce
6 ounce tinapa in tomato sauce
8 ounce talls in tomato sauce
8 ounce flats in oil or specialty sauce

Several efforts have been made by the California sardine canners to produce canned sardine specialty products rather than the relatively expensive standard products currently produced, but with one or two exceptions, such efforts have been unsuccessful. The exceptions are the packs containing filleted sardines packed in oil or special sauces. For these specialty products the headed and gutted sardine is passed through a locally developed filleting machine in which two rotating circular knives, set at a suitable angle, make two deep parallel cuts along the back of the sardine, thereby separating the spinal column from the two fillets. The fillets are usually not brined but filled into flat cans. When passed through the exhaust box, a considerable shrinkage of the fillets occurs which is compensated by cutting the fillet a little larger than can size. After passing through the exhaust box, the can is drained and oil or sauce and spices and condiments are added. Then the can is sealed, washed, and retorted in the usual manner.

The Mackerel Fisheries

The Pacific Mackerel Industry. The Pacific mackerel (*Pneumatophorous diego*) has for many years been caught in commercial quantities along the coast of California. Although this species of mackerel ranges from northwestern Alaska to Baudras Bay in Mexico, the center of its industrial utilization is in Southern California. Until 1928 mackerel was essentially a fresh market fish with only minor amounts being utilized for canning and salting. According to statistics, 600 000 pounds of fresh mackerel were delivered to the markets during 1928. Since then, its importance as a fresh market fish has declined. It was not until after 1928 that the landings of the Pacific mackerel were reported separate from the jack mackerel (*Trachurus symmetricus*) which is not considered a true mackerel. The statistical figures relative to the mackerel landings prior to that date are, therefore, unreliable, but it is believed that the major catch consisted of the Pacific mackerel. Since 1935, the take of mackerel in the waters of Southern California have been steadily declining.

Method of Fishing. When canning of mackerel started on a large scale in 1928, it was found necessary to use more efficient fishing methods.

A variety of fishing nets, such as the lampara net, various ring nets, purse seines, and dip nets, were put to use. This increased the tonnage landed, and in 1933, 70 million pounds of mackerel were brought in by the mackerel boats in California. The record year was 1935, when more than 147 million pounds were taken. Of this tonnage, the largest amount by far was delivered by the purse seine fleet. A new method of mackerel fishing, the so-called scoop fishing, was evolved by 1939. This method, a modification of striker fishing, consisted of alluring the fish with chum, but instead of catching the fish with artificial lures bearing barbless hooks, the fish was scooped on board with a scoop net or a brail. This method is still practiced to a limited extent, although more than 80 per cent of the total catch is accounted for by the purse seiners and lampara boats.

The bulk of the mackerel catch is canned and used for human consumption; some is canned and sold as pet food, and 5 to 10 per cent of the total catch is still sold unprocessed as fresh fish.

Methods of Processing. The processing methods in use for the Pacific mackerel are much like those employed for the sardine. When arriving at the dockside, the mackerel is either brailed or pumped onto the elevated conveyor which brings the fish into the cannery. Here the mackerel is weighed in weighing buckets holding about 500 pounds.

After weighing, the mackerel is flumed into the holding tanks where it is held, chilled in sea water, until enough has accumulated to begin the cutting. The cutting follows the same procedure as that employed for sardine (q.v.), and the fish are finally flumed onto the packing table where cannery workers fill the cans by hand. The machine which sometimes is used for filling sardines into 1-pound tall cans is also occasionally used for mackerel. After leaving the packing table, or packing machine, the filled, open cans go through the exhaust box where they are heated by live steam as they slowly move through the box.

The Jack Mackerel Industry. The jack mackerel (*Trachunus symmetricus*) has been fished commercially for many years since it was first reported in the commercial fish catch of California as early as 1888. Statistics on landings were, however, not available until 1926 when the jack mackerel and the Pacific mackerel were reported separately in the statistics kept by the California Fish and Game Division. The jack mackerel became of importance commercially toward the end of the thirties when the rapidly failing sardine and Pacific mackerel fisheries forced the industry to look for substitutes for these two fish species. The jack mackerel population is large and is distributed along the west coast of North America from British Columbia southward to Acapulco, Mexico. The center of fishing for jack mackerel is in Southern California, San Pedro in particular, with smaller landings at Monterey, Port Hueneme, and

Newport Beach. The jack mackerel is often found in large schools at or near the surface, in close proximity to the mainland shore or offshore banks. The commercial catch is made almost exclusively with purse seine and other round haul nets. The canning of jack mackerel was not begun on a large scale until 1947. The peak catch was made in 1950 when 134,000,000 pounds were taken. Jack mackerel has proved to be a very useful substitute for California sardines packed in 1-pound tall cans, which were sold in large quantities in the southern part of the United States before the decline of the California sardine catch. The method of packing is similar to the one used for the Pacific mackerel.

The Atlantic Coast Mackerel Industry. The Atlantic Coast mackerel (*Scomber scombrus*) is related to the Pacific mackerel and is the basis for the mackerel industry on the northeast coast of the United States. This industry is mainly located in Gloucester, Massachusetts and Portland, Maine, and has never approached in magnitude that of the Pacific Coast. The methods used in fishing for the eastern mackerel resemble those used on the West Coast. Purse seining is, therefore, the predominant method of fishing for mackerel on the East Coast. The mackerel, when hauled aboard the fishing boat, are usually iced down in the hold and have been out of the water only 24 to 36 hours when they arrive at the dockside. The mackerel season begins in July and continues until November.

The Atlantic Coast mackerel is largely consumed in the fresh state. The fish are small and have a relatively high oil content at the peak of the season. Since the skin of this fish is also quite fragile, special precautions are necessary in the way of careful handling to prevent ice from brusing this delicate species. In the past, considerable mackerel were salted in the New England area. In recent years the salt mackerel production has greatly declined.

Another species, the Spanish mackerel (*Scomberomorus maculatus*) is taken along the middle and south Atlantic Coast. It is marketed in the fresh state.

The Herring Fisheries

The Pacific Coast Herring Industry. The Pacific herring (*Clupea pallasii*) has a very wide distribution. It is found along the west coast of the United States and Canada, from San Diego to Nome, Alaska. Its wide distribution not withstanding, the Pacific herring has been of comparatively little economic importance to the three west coast states; only Alaska and British Columbia have developed a herring industry of commercial importance.

The California and Washington Herring Fishery. The herring fishing in California rarely exceeds a million pounds a year. In 1960, when the landings of herring were heavier than average, a small amount of the catch was canned. The technical problems involved in canning of herring, and the economic basis for such an industry, does not, at this moment, seem to have been solved in a satisfactory manner for the California herring product. The small amount of herring landed at various points on the California coast is, therefore, mainly used for bait. The reduction of whole herring into meal and oil is not permitted in the state of California. Purse seining is the conventional method used for catching the Pacific herring.

Similarly, in the Pacific Northwest small quantities of herring are taken largely for use as fish bait. In recent years attempts have been made in upper Puget Sound in Washington to establish a herring meal and oil operation, but market conditions for the products were not sufficiently favorable to encourage establishment of this potential operation on a continuing basis.

The Alaskan Herring Fishery. The herring fishery in Alaska is still important but has, during the past decades, seemed to be decreasing. Yearly landings of herring in Alaska from 1940 to 1950 averages 67,000 tons as compared with the 41,000 ton average of more recent years. Practically all of the herring landed is reduced into fish meal and oil. The salting and curing of herring, which formerly was done to a considerable extent in the Kodiak and Dutch Harbor area, has now ceased due, in part, to lack of suitable raw material, rising costs, a contracting market, and foreign competition.

The British Columbia Herring Fishery. This industry is concentrated mainly in the area around Vancouver and Prince Rupert. Several herring reduction plants located in these areas reduced, during the herring season, the following quantities of herring:

Season	*Quantity of Herring Landed, in tons*
1960–1961	172,053
1959–1960	185,153
1958–1959	229,634
1957–1958	84,334
1956–1957	179,943

Only an insignificant part of the above landings was used for purposes other than reduction. Much of the more than 30,000 tons of herring meal produced yearly is exported to the United States.

The Maine Sardine Industry. The raw material for the Maine sardine industry is, as already stated, the small sea herring (*Clupea harengus*) which is found in commercial quantities in the shallow waters along the Maine coast. Although the Maine sardine has been utilized industrially since 1875, the canned product in past years has not enjoyed the public favor to the extent that sardines from other localities or lands enjoyed. This situation has recently been changed by a very efficient research and advertising program initiated cooperatively by the twenty-five or more canners of the Maine sardine. The program, financed by a per-case tax and aided by a technological research laboratory and an organization to grade the entire sardine pack, has been highly successful and rewarding.

Fishing and Processing Methods. The methods formerly used for the harvesting of the Maine sardine were either to trap the fish in weirs or to trap and isolate the fish in coves with stop nets. Today the principal method of fishing for Maine sardine is purse seining. By leaving the fish in the net for roughly 24 hours, the digestive tract of the fish will have been cleared. The fish is transferred by means of suction pumps from the seine to the fishing boat or to the carrier boat. As the hold is filled with fish, salt is added, usually at the rate of 4 pounds per bushel of fish. At the dock-side, the fish is again pumped from the boats into flumes that lead to holding tanks in the cannery where the fish is resalted to replace salt lost during unloading and to get a suitable salt level in the canned product.

The importance of the addition of salt to fish in transit, as well as in the holding tanks at the cannery, has been the subject of much work at the Maine Research Laboratory and elsewhere. The work at Maine has shown that the addition of salt in proper quantities will protect the fish against bacterial decomposition long enough, under the conditions of the Maine fisheries, to provide a reasonable time for transporting and processing in the plant. The strong influence of temperature upon the protein nitrogen losses into the brine was thoroughly studied by the Maine workers, and this probably is one of the more important reasons why in-plant refrigeration, as well as carrier-boat refrigeration, is gradually gaining a foothold. The fishing boats seldom operate more than some few hours run from the cannery so no ice or refrigeration is used.

From the holding (brining) tanks, the fish are taken on a conveyor to the processing room where the sardines are placed on wire racks called "flakes." After they are stacked in layers on a special cart, the sardines are rolled into a steam box for precooking. Some canners precook the fish in steam, others bake them or fry them in oil, still others put the sardine into the cans raw and do the entire cooking process in the can. The dressing and trimming of the fish are usually done in a single operation as they are filled into the can. The cans then go to a sealing machine. Before sealing, oils or sauces are added. The oils used are soybean oil, peanut oil, or olive oil, and the sauces are usually either tomato or mustard sauce. After sealing, the cans are retorted to sterilize the content of the can and then cooled, labeled, and packed in cases.

Two million cases of Maine sardine is considered a normal pack, although the 1961–62 pack was below normal, amounting to only 675,000 cases.

Fish Meal, Fish Oil, and Condensed Fish Solubles from Sardine and Mackerel Cannery Waste

When edible fish like sardine or mackerel are processed for canning, a considerable part of the whole fish goes into trimmings and offal. In preparing the fish for canning, each individual fish must be butchered and parts of the anatomy, such as heads, tails, viscera, fins, etc., removed to comply with government regulations and to satisfy the aesthetic standards current in this part of the world. Cutting fish of variable sizes to fit into standard size cans also produces a considerable amount of trimmings, which further reduces the amount of the fish which actually goes into the can. The offal and trimmings from these operations constitute the raw material for the production of fish meal, fish oil, and condensed fish solubles by the fish canners. These by-products are of great economic significance to the canners and have, at times, sustained the industry during periods when profits from cannery operations were marginal.

The enormous expansion of the fish meal industry which has taken place in recent years, using menhaden of the East and Gulf Coasts of the United States, the North Atlantic or Pacific herring, or the small clupeoid fish so abundant along the west coast of South America, has created an international glut in fish meal and oil. This has decreased the price of these commodities to such an extent that the profits derived from the production of fish meal and oil by sardine and mackerel canners have become marginal. Efforts are, therefore, being made to find other outlets for the offal and trimmings of the fish canning industry. These efforts have up to now been only partially successful, but as the decreased market for fish meal and oil and solubles in all probability will persist for several years, increased activity to find new outlets for fish meal and oil or to create new products from the offal and trimmings will undoubtedly continue.

Manufacture of Meal and Oil. The methods in use for the production and manufacture of fish meal, fish oil, and condensed fish solubles from the offal and trimmings of the sardine and mackerel canneries are, in the main, the same as those used for the reduction of the whole fish.

Cooking. The offal and trimmings from the cannery operations may be accumulated in a suitable concrete pit. They are conveyed by a screw or drag conveyor, usually located overhead in the meal plant, to a cooker. The cooker consists essentially of a closed steel screw conveyor filled with steam jets. The speed of the screw conveyor is regulated so that the offal stays in the cooker 10 to 15 minutes. During this time the jets of steam cook the fish offal and thereby impart upon the fish pulp physical properties which are favorable for a separation by pressure of this cooked material into a liquid and a solid portion.

In other countries, particularly those with high fuel costs, the cookers are of a somewhat different design. The offal is cooked by indirect steam by introducing the steam into a jacket surrounding the cooker. This saves the cost of fuel by avoiding the removal, by evaporation, of the condensate which adds to the volume of the press water (see Condensed Fish Solubles).

Pressing. The cooked fish pulp upon leaving the cooker is fed into a press usually located directly below the cooker. The press is either a screw press or a disc press. The screw press is an expeller type of continuous press, and as the fish pulp is moved through the screw barrel, it is subjected to increasing pressure which causes the press water to seep through the apertures of the barrel while the pressed solids are discharged at the end of the press as a press cake. The press water, also called stickwater, contains an appreciable amount of fish oil, usually in a high state of dispersion. It is worth noting that the press, in fractionating the cooked fish pulp into a liquid press water (stickwater) and a solid press cake, does not accomplish a very complete separation. Upon emerging from the press, the press cake more often than not contains more than 50 per cent moisture, and the press water usually contains small amounts of solid protein in suspension plus roughly 3.5 per cent of water soluble proteins. The separation of the fish oil originally present in the cooked fish into one or the other of the two fractions is not very complete either. Depending upon circumstances, the press cake may contain as much as 10 to 20 per cent of the total oil, leaving the rest in a highly dispersed state in the stickwater.

The screw press has, in some instances, been replaced with the continuous conical disc press, also popularly called the P&L disc press. This press consists of two four-feet diameter press shells. The wheels rotate by means of ring and pinion gears. The face of each wheel is made up of six removable perforated cast steel plates covered with metal screen. The angle at which the press wheels are set on the hub provides a uniform, continuous pressing action from the intake side towards the discharge side, and when properly adjusted seems to work very well on fish pulp although this press is reputed to have been designed for the pressing of citrus pulp. Low upkeep costs and small space requirements are two other significant advantages that have gained the entry of this type of press into the fish meal industry which for so many years was dominated by the screw press.

Drying. From the press, the press cake is conveyed through a wet mill to the drier. The wet mill is a disintegrator type of a mill whose purpose is to break up the press cake into a granular material of uniform size, thereby insuring a better and more even drying in the subsequent drying operation.

There are several types of fish meal driers in use but two seem to predominate. One is the direct heat rotary drier where the granular press cake is introduced at the hot end of the kilns and as it slowly moves down the slightly inclined kiln tube, the press cake, in contact with the hot combustion gases of the burner, slowly loses its moisture to the gases, thereby cooling them. The burner is recessed in the kiln so that the wet press cake is not in direct contact with the flame.

Another type of drier in common use is the steam tube drier. In this rotary drier the drying of the press cake is accomplished by heat from the steam tubes which run the full length of the drier. By the rotary action, the press cake constantly drops over and around the steam tubes, thereby causing a gentle and efficient drying of the press cake. Both of the above mentioned kilns can give a very excellent fish meal free from any recognizable sign of thermal damage. It is, however, very important that the operator of the drying kiln maintains proper control of the drying at all times by constantly watching rates of input and output and, in particular, by keeping a close watch on the temperature of kiln gases, humidity of exhaust, and remaining moisture content of the dried fish meal.

A third type of fish meal drier recently introduced into the fish meal industry, here and abroad, is the airlift drier. In this type of drier, ascending hot combustion gases meet the descending wet press cake in a tower of proper design, and by carefully regulating the temperature and volume of the gas and the amount of press cake, the manufacturer claims that a fish meal of superior quality may be obtained at minimum cost. Steam jacketed batch driers once so popular in small fish meal operations and continuous fire tube rotary driers are not in use any more.

The dried press cake is removed at the end of the kiln by various simple devices, depending on circumstances. In the direct-fired rotary kiln, the separation of the large volume of combustion gases from the fluffy fish meal requires elaborate cyclone construction. This problem does not seem so difficult with the steam tube rotary drier where the volume of gases is less. In any event, the moisture-laden gases from the drying kiln are vented to the atmosphere through a cyclone arrangement while the dried meal discharging at the exit end of the kiln, together with that trapped in the cyclone system, go to a dry grinder, usually a hammer mill or a Rietz vertical disintegrator, where the dried meal is finally reduced to the particle size usual for fish meal. The meal is then carried in ducts to storage bins from where it is ultimately taken to be blended and sacked in 100-pound net weight paper or burlap bags or stored in hoppers for bulk shipments. The transportation of the fish meal in ducts, sometimes over distances of several hundred feet, cools the fish meal sufficiently so that excessive heating subsequent to storage or sacking is avoided.

Fish meal plants are often located in areas of relatively low population density. In California, however, a rapid increase in population and the peculiar atmospheric conditions of some of those areas have caused some fish meal manufacturers to install in their plants equipment to eliminate fishy odor that otherwise would escape into the atmosphere. Such equipment, consisting of scrubbers or after-burners, effectively eliminates odors from the relatively large volume of exhaust gases that usually are involved in fish meal operations. Such equipment is, however, costly and, therefore, adversely affects the production costs of a commodity which already is hard pressed in a falling market.

Separation of Oil and Stickwater. As mentioned above, the fish meal presses release from the cooked fish pulp a liquid called press water or stickwater. This liquid contains the major part of the oil in the sardine or mackerel which is, therefore, recovered by suitable treatment of the press water. The fish oil in the press water is usually in a highly dispersed state; this renders mechanical separation difficult. The tendency of the highly dispersed oil globules to be coated with a proteinaceous film not only prevents coalescence of the individual oil globules to larger ones, but gives to some of the globules a density equal to the surrounding aqueous medium and thus prevents their separation by gravitational means.

The usual procedure followed in the treatment of stickwater is to pump the warm stickwater from the fish meal press to an overhead tank from where it is fed by gravity into a centrifugal separator. The separator is usually a large bowl DeLavel or Sharples separator which divides the stickwater into three parts: (1) a fraction consisting predominantly of oil with a small part stickwater, (2) a stickwater fraction from which most of the oil has been removed, and (3) a sludge fraction consisting of a small part of stickwater containing most of the solid proteinaceous matter suspended in the press water as it comes from the fish meal press.

It is very important that the temperature of the stickwater is high when it is centrifuged, a temperature of 200 to 205°F being optimal for centrifugation. The fraction containing predominantly the oil is pumped to a tank where it is blended with hot water then passed through a so-called polishing centrifuge. In this centrifuge, water and suspended matter are separated from the oil and, when properly adjusted and operated, the oil appearing from this centrifuge is dry and clear and may be pumped directly to crude oil storage.

The stickwater leaving the centrifuges still contains, as pointed out above, small amounts of oil. This oil, amounting to from 0.5 to 0.9 per cent, is assumed to be so highly dispersed in the aqueous phase of the stickwater and so intimately tied up with proteinaceous material that it is not influenced by the gravitational gradient existing in the centrifuge. The stickwater is now pumped to the solubles plant where it often undergoes further treatment before it is concentrated, by vacuum evaporation, into condensed fish solubles.

Manufacture of Condensed Fish Solubles. Condensed fish solubles are comparative newcomers to the family of by-products from fish cannery operations. Until the late thirties, the stickwater, as soon as it had been freed of its fish oil content, was discarded and run into the harbor or adjoining waterways. This often caused some very unpleasant water polution problems.

Table 10.1. Typical Analysis of Condensed Fish Solubles

Total solids	50.43%
Sp. gr. at 20°C	1.20%
pH	4.5
Ash	8.86%
Fat	4.8%
Crude protein (N × 6.25)	33.85%

	Vitamin Analysis, micrograms/gm		*Mineral Analysis*
Thiamine	7.5	Calcium	0.087%
Riboflavin	21.3	Phosphorous	0.85%
Nicotinic acid	304.0	Potassium	1.95%
Pantothenic acid	40.0	Sodium	1.87%
Choline	4000.	Magnesium	0.0025%
Vitamin B_{12}	0.46	Copper	0.0026%
Folic acid	0.17	Iron	0.020%
Pyridoxin	12.5	Iodine	1 ppm

When it was found that stickwater was a rich source of the B complex vitamins and other growth-promoting factors, a method was developed for its recovery and preservation. This method involved a stabilization of the stickwater by proper pH adjustment and a concentration, by vacuum evaporation, of the dilute liquid into a brown semi-viscous liquid. In stabilizing the stickwater by pH adjustment, small amounts of coagulable proteins are precipitated, and a change in the colloidal properties of the remaining fish oil takes place so that a subsequent centrifugation often yields additional oil and makes the stickwater more suitable for the subsequent concentration in the vacuum pans. This procedure also makes the resultant condensed fish solubles more attractive to the feedstuff mills that use it since it mixes more readily with the other feed ingredients and produces a more stable end product.

The production of condensed fish solubles in the United States amounts to, at present, more than 200 million pounds a year. Of this total, the sardine and mackerel canners produce only a small percentage. Condensed fish solubles are usually sold in tank car lots of roughly forty tons. A typical analysis of condensed solubles is given in Table 10.1.

CHAPTER 11

The Menhaden Fishery

Fred C. June

Menhaden support the largest and one of the oldest fisheries in North America. When the first European colonists reached the New World, the coastal Indians already were exploiting this vast fishery resource in the western Atlantic Ocean. Although few people claim knowledge of what a menhaden is, almost every grammar school child in the United States learned how Squanto of the Massachusetts Tribe taught the Pilgrims to place the "munnawhatteaûg," or menhaden, in each hill of Indian corn. The extent to which menhaden were used for this purpose by the early settlers is unknown; however, memory of the practice led to the utilization of this fish when crops along the southern New England coast began to fail early in the 19th century. In 1801, Ezra L'Hommedieu, a wealthy land owner on Long Island, published the results of several experiments in which menhaden were applied successfully as a soil dressing. L'Hommedieu's claims held promise of increased wealth to farmers living along the seacoast, and soon a number of small companies were organized for the purpose of supplying menhaden for fertilizer[2]. These events marked the beginning of a commercial fishery which eventually was to become the largest in North America.

The Resource

Description and Distribution of Menhaden. Menhaden are small, oily fishes belonging to the herring family Clupeidae. They are similar in appearance to the alewife and shad but are distinguishable from these and other herrings by the fact that the exposed margin of the scales is nearly vertical and edged with comb-like teeth instead of being rounded and smooth. Menhaden are dark blue to blue-brown above and silvery along the sides, although freshly caught specimens show a brassy luster. There is a conspicuous dark shoulder spot on both sides of the body, just behind the head. A single fin is located about midlength on the back, and a row of sharp-edged bony plates occurs along the midline of the belly. Adult fish may range up to 18 inches in length and over 3 pounds in weight, but most of them are less than 12 inches long and under a pound in weight.

Four species of menhaden, genus *Brevoortia*, occur along the Atlantic Coast of North America, but only two, the Atlantic menhaden (*B. tyrannus*) and the Gulf menhaden (*B. patronus*), are of importance to the United States reduction industry[12]. These species are known by no less than 30 common names, but most often are called bunker, pogy, mossbunker, or shad. The Atlantic menhaden is a temperate species which occurs from Nova Scotia to the central east coast of Florida. The Gulf menhaden is a subtropical species which is distributed in the Gulf of Mexico from southern Florida to the Yucatan Peninsula[3,13].

Habits. Menhaden are migratory fishes which appear in dense schools in the open waters of larger bays and along the shore sometime in April or May. Along the Atlantic Coast, the schools appear earlier in southern waters than further northward. Through the summer, they generally occur in depths of less than 20 fathoms and are found in greatest concentrations in localities with extensive estuarine drainage systems, such as the Mississippi Delta area and Chesapeake Bay. The schools disappear from the surface, coastal waters sometime in September or October. Along the Atlantic Coast, however, large, migratory schools reappear off Cape Hatteras, North Carolina in November and disappear off Cape Fear, North Carolina in December. The fish seldom are seen in the inshore waters until the following April or May[5].

Menhaden fluctuate greatly in both abundance and availability. Often the catch in one locality differs markedly from that in adjacent localities, and seasons of abundance in certain parts of the range may be followed by several years of scarcity.

Variations in abundance seem to be due largely to varying survival of individual year broods of young menhaden. An unusually abundant or "dominant" year brood may result in excessive abundance of fish for a year or two in a particular locality, but as their numbers become reduced by fishing, migration, and natural factors, the catch declines. A succession of poor year broods means that recruitment to the populations will be below normal and reflected in the catch accordingly. These circumstances also result in changes in the size of fish caught each year in the same locality[5].

Although the effect of oceanographic factors on the availability of menhaden has not yet been clearly demonstrated, fishery scientists believe that the varying seasonal and geographical distribution of the schools depends upon prevailing hydrographic conditions. As a possible result, the fish may, in some seasons, change their habits or migratory pattern and thus may not be available on their customary grounds[6].

The Fishery

Since the inception of the large-scale menhaden reduction industry in about 1850, purse seines have been the principal means of supplying the huge quantities of fish required by the plants. This gear accounts for over 98 per cent of the total annual catch. The remainder is taken by pound nets in several localities along the Atlantic Coast[6,9].

The purse seine fishery is governed by the seasonal occurrence of schools in the surface waters along the shore. Over most of the range, the schools appear regularly from year to year so that preparations for fishing usually are made with reasonable assurance of a successful season. As noted previously, however, because of variations in abundance or changes in their migratory pattern the schools may not be available in their usual numbers and seasonal landings in a given locality may be substantially reduced.

Fishing Seasons and Areas. Along the Atlantic Coast, the purse seine fishery is conducted during two separate periods. The "summer" fishery begins in waters south of Cape Hatteras, North Carolina in April or early May and by late May or early June, extends from the central east coast of Florida northward to Cape Ann, Massachusetts. South of Cape Hatteras, the summer fishery is most productive in May or June, while from Chesapeake Bay northward, catches reach a peak in July or August. The summer fishery terminates in September or October when the schools disappear from the inshore waters. Their disappearance occurs earliest in northern waters and progressively later farther southward. The "fall" fishery is conducted on aggregations of spawning fish which appear along the North Carolina coast in November and December[7]. Approximately 50 per cent of the annual catch along the Atlantic Coast is landed in Delaware and New Jersey. Landings during the North Carolina fall fishery account for about 10 per cent of the total.

In 1961 there were 18 reduction plants along the Atlantic Coast which handled menhaden exclusively. These were distributed as follows: Florida, 1; North Carolina, 8; Virginia, 4; Delaware, 2; New Jersey, 3; and New York, 1. Reduction plants located in Rhode Island, Massachusetts, and Maine also utilize menhaden during seasons when the schools are abundant in New England waters, but rely mostly on other industrial fishes and cuttings from fish filleting plants[15].

In the Gulf of Mexico, the fishery is active from May to October, with a peak of seasonal abundance usually occurring in July or August. Fishing is conducted along a relatively short stretch of the northern Gulf Coast from Sabine Pass on the Texas and Louisiana border eastward to Alabama[13]. Legal restrictions preclude fishing for menhaden along the Texas and Alabama coasts: however, catches made in Louisiana waters may be landed and processed in Texas. Approximately three-fourths of the Gulf catch is taken east of the Mississippi River, between Breton Sound and Mississippi Sound; consequently, most of the reduction plants are located in this area. There were 11 menhaden reduction plants in operation in the Gulf of Mexico in 1961, including 3 in Texas, 5 in Louisiana, and 3 in Mississippi. In some years, menhaden occur in sufficient abundance along the central west coast of Florida to support a single plant at Apalachicola.

Fishing Vessels and Gear. A fleet of about 200 carrier vessels is employed in the purse seine fishery. These vessels transport the crew, gear, and the catch between the reduction plants and fishing grounds and serve as a base of operations at sea. Most of the vessels in the carrier fleet have been built specifically for these purposes, although otter trawlers, Navy minesweepers, and various other craft also have been converted for use as carriers.

The design of the carrier vessels has remained essentially unchanged since the early days of the industry. Basically, these vessels are laid out with a high bow, a low stern, a large fish hold amidships, and two houses, one forward and one aft of the fish hold. The forward housing includes a galley on the main deck and pilot house and officers' quarters above. Crew's quarters are below deck, beneath the forward house. The after housing encloses the main engine and auxiliary power equipment. A mast, with its conspicuous crow's nest and boom, is located just aft of the forward housing.

Carrier vessels range in length from less than 75 to 195 feet, with those between 120 and 135 feet being most common. They vary from about 75 to 650 gross tons in weight and average around 200 gross tons. These vessels are powered by a single diesel engine which ranges from about 250 to 1280 horsepower, with the majority between 400 and 600 horsepower. Older vessels are of wooden construction, but those built since World War II are of steel. Most vessels are equipped with a "ship-to-ship" and a "ship-to-shore" radio telephone, a recording depth indicator, and a radar unit. In addition to the crew, each vessel carries two purse boats, a small skiff, and a purse seine.

The purse boats are shallow draft, open boats of heavy-duty construction. Most of the newer boats are made of aluminum and vary from 32 to 36 feet in length, with a 7- to 9-foot beam. Each is powered by a gasoline engine and equipped with a power-driven block for hauling the seine. During trips to and from the fishing grounds, the purse boats are hung from davits, one on each side of the after house near the stern.

Menhaden purse seines average 200 fathoms in length and 10 fathoms in depth. They are made of 1¾-inch webbing, with a reinforced bunt located in the upper center portion of the seine. During the past several years, cotton or linen seines have largely been replaced with those made of nylon.

Depending on the size, a new modern carrier, with its purse boats and seine, costs from $500,000 to $1,000,000.

Most of the carrier vessels, purse boats, and seines are owned by the reduction companies or their subsidiaries. The number of vessels operated by the individual plants varies according to the processing capacity of the plant. Most of the larger plants employ from 10 to 12 carriers, while the smaller plants generally use no fewer than 3 or 4 vessels. During the North Carolina fall fishery, however, as many as 20 or more vessels deliver their catches to a single plant.

Spotter Aircraft. The menhaden industry employs approximately 50 light aircraft for the purpose of locating concentrations of fish and directing the fishing operations of the purse seine fleet. Some reduction companies maintain their own aircraft and hire the pilots for the fishing season at a flat rate. In other cases, the aircraft and pilot are chartered, either at a fixed rate or on a catch-share basis[16]. It has been estimated that the use of the aircraft has increased the efficiency, hence the catch, of the purse seine fleet by at least one-third.

Fishing Methods. The method of purse seining for menhaden differs from that employed in the Pacific herring, tuna, and salmon fisheries in that the seine is operated from the two open seine boats with the assistance of a spotter aircraft pilot.

On the fishing grounds, the purse boats are lashed side by side, with half the seine carried in each boat, and towed behind the carrier. When a school has been selected for capture, the fishing captain and crew enter the purse boats and start out in the direction of the school. The spotter pilot keeps the captain informed of the movements of the school by radio contact and, at the appropriate moment, directs the two boats to separate. The seine is payed out as each boat completes a half circle to enclose the school. As soon as the two purse boats meet, the ends of the purse line are made fast and run through two snatch blocks attached to a heavy, lead weight called a tom. The tom is thrown overboard and closes the seine as it rides to the bottom. After pursing has been completed and the tom retrieved, the wings of the seine are hauled aboard by means of the power-driven blocks mounted in the purse boats (Figure 11.1). The fish are gradually concentrated in the bunt between the two purse boats. A small skiff, called the striker boat, is sometimes used to support the corkline, particularly when a heavy catch has been made. After the carrier vessel is brought alongside, a flexible suction hose is lowered into the net, and the fish are pumped into the hold. A number of carrier vessels are equipped with an electrical shocking device which attracts and immobilizes the fish around the end of the suction hose. Use of this gear not only increases the efficiency of the pumping operation, but

Figure 11.1. Menhaden purse seine in operation. The wings of the siene are being hauled aboard the two purse boats by power-driven blocks. After the fish have been concentrated in the bunt, the carrier vessel will move along side for transfer of the catch into the hold.

minimizes the loss of large sets in which the fish cannot be raised because of their heavy weight[8].

Menhaden fishing is conducted only during daylight hours. The carrier vessels usually arrive on the fishing grounds about dawn so as to reach, in the shortest possible time, any concentrations of fish reported by the spotter pilots. Vessels from a given plant frequently operate as a fleet in nearby waters, but when fish are scarce, vessels may disperse and range 100 miles or more from their home plant.

Catch. Because of the large quantities in which the fish are caught and the rapidity with which they decompose, vessels generally return with the catch to the processing plant at the end of the day. Accordingly, the fish are usually landed at the plant within 10 to 15 hours after being taken from the water. Vessels equipped with refrigerated holds may remain at sea for several days, particularly when catches are running light, and still deliver the fish in satisfactory condition.

Company-owned carrier vessels are operated by captains selected for the fishing season. The captain is paid a fixed price for quantities of fish delivered to the reduction plant. The price paid for the fish varies from year to year, but is fixed at the beginning of the season and apportioned among the crew members according to a standard wage scale. A certain percentage of this amount is withheld by the companies and paid to each crew member at the end of the fishing season. In some cases, vessels may be leased from independent companies or the vessel owners will contract to sell the catches to a reduction plant on a share basis. The value of the catch to the fishermen in 1961 was $25,200,000[11].

TABLE 11.1. LANDINGS OF MENHADEN, BY AREA, 1950–61

Year	Atlantic Coast, tons	Gulf Coast, tons	Total, tons	Value to the fishermen, thousands of dollars
1950	350,144	163,015	513,159	10,402
1951	384,550	178,982	563,532	12,983
1952	461,804	229,992	691,796	13,221
1953	629,516	218,522	848,038	18,578
1954	668,262	200,622	868,884	23,491
1955	693,396	240,496	933,892	25,037
1956	768,702	279,918	1,048,620	28,425
1957	663,798	181,266	845,064	22,211
1958	553,136	221,413	774,549	21,933
1959	725,448	375,918	1,101,366	26,213
1960	588,678	420,454	1,009,132	20,301
1961	643,856	510,144	1,154,000	25,200

Source: Data for 1950 to 1959 are from U.S. Dept. Interior, *Statistical Digest;* for 1960 from U.S. Dept. Interior, *Current Fishery Statistics*, No. 2801; for 1961 from *Current Fishery Statistics*, Nos. 2863 and 2900.

In the decade between 1952 and 1961, menhaden accounted for somewhere between 33 and 45 per cent of the total annual fish production in the United States. Landings have increased almost every year since 1935 and, beginning with 1946, exceeded those of any other domestic fishery. No other fishery in North America has enjoyed such a sustained record of production. True, there have been marked variations in catch in different parts of the range, but a seasonal decline in one locality usually was compensated by increased landings in another.

Prior to World War II, the fishery was conducted principally along the Atlantic Coast. Beginning in 1947, however, the fishery in the Gulf of Mexico expanded greatly, and landings there increased from less than 15,000 tons in 1940 to over 174,000 tons in 1950. In 1961 Gulf landings reached a record of over 500,000 tons.

Table 11.1 shows the landings of menhaden on the Atlantic and Gulf coasts between 1950 and 1961. The total catch increased annually from 1950 to 1956, during which time it nearly doubled. Following a decline in 1957 and 1958, the catch increased in 1959, decreased slightly in 1960, and reached an all-time record of 1,154,000 tons in 1961. Annual landings during this period averaged 861,868 tons.

Over 99 per cent of the menhaden catch is utilized in the manufacture of fish scrap or meal, oil, and condensed solubles. The remainder is sold for bait.

Processing

Menhaden are processed by the wet reduction method in which cooking, pressing, centrifuging of press liquor, and drying of the press cake are the principal operations[14]. Although the reduction procedure is essentially the same throughout the industry, the details of plant layout, type of equipment, number of processing units, and methods of handling the materials at different stages of processing vary from plant to plant. The processing capacity of most plants is based on the maximum anticipated quantities of fish in a given locality, rather than on average landings. Many of the companies maintain plants in different localities and thus are able to take advantage of seasonal increases in the availability and abundance of the fish. In recent years, processing operations have become highly mechanized and efficient through the use of continuous-feed equipment, conveyor and pump systems, and other labor-saving devices.

Unloading, Measuring, and Storage of the Catch. Most reduction plants have facilities for unloading two or more carrier vessels simultaneously. The unloading capacity varies between 150 and 200 tons of fish per hour. The fish are pumped from the carrier vessel by first partially flooding the hold with sea water. The fish and sea water are drawn through openings in the bottom of the hold by centrifugal or reciprocating pumps and conveyed through a series of pipes and connecting hoses to a dewatering screen. In some plants, the fish are discharged onto a short conveyor belt and automatically weighed as they pass over a mechanical integrator. From the weighing belt, the fish are dumped onto a second conveyor belt which carries them directly to the cookers, with the surplus diverted to a temporary storage bin called a "raw box." In most plants, the fish pass from the dewatering screen into a rotating hopper where they are measured volumetrically and then conveyed to the cookers or raw box. Each segment of the hopper holds 22,000 cubic inches, a unit measure of 1000 "standard fish." The actual number of fish per unit of measure, of course, varies with the size of the fish, but each measure of 22,000 cubic inches is estimated to weigh 667 pounds.

Regardless of the type of weighing equipment employed, this unit of measure is used throughout the industry to express the quantity of catch.

The size of the raw box varies according to the processing capacity of the plant and the number of vessels employed. Most raw boxes hold between 300 and 600 tons of fish, but some of the larger ones have a capacity of several thousand tons. They may be constructed of wood, concrete, or steel, but are of the same design. They are rectangular in shape, varying from 12 to 25 feet in depth and up to almost 200 feet in length, with a floor that slopes toward the middle. An enclosed drag or screw-type conveyor is located at the bottom and runs the full length of the box. Fish are fed into the conveyor through removable grates or wooden sections and carried to hoppers which feed the continuous cookers.

Cooking. The cooking process usually is begun simultaneously with the unloading of the carrier vessels. During cooking, the raw fish are exposed to jets of live steam for approximately five minutes. The extent of cooking is controlled by regulating the speed at which the fish are passed through the cooker as well as the amount of steam. The temperature of the fish during cooking averages about 180°F. Moderate control of the cooking process is essential, since it is desirable only to coagulate the protein and rupture the fat cells without overcooking. Most plants are equipped with more than one cooker, each having a capacity of from 15 to 35 tons of raw fish per hour. The cooking process usually is completed within 12 to 15 hours after the catch has been unloaded.

Pressing. The thoroughly cooked mass of fish and oil, along with the condensed steam used for cooking, is conveyed to hoppers which feed the continuous screw presses. During the passage through the presses, the water, oil, and soluble components, called press liquor, are squeezed out of the cooked material. The discharged press cake contains about 50 per cent water and some residual oil.

Separation of the Press Liquor. The press liquor is pumped to vibrating or rotary screens which remove much of the suspended solids. Finer solids may be removed by basket centrifuges. The oil and aqueous fraction from the screening process is fed into a battery of centrifuges for separation of the oil. In some plants, the oil is then passed through centrifuges, known as purifiers, where the residual water and solids are removed. The resulting "polished oil" is pumped into large capacity storage tanks to await shipment to market. A number of plants employ settling tanks for removal of residual water and solids prior to storage of the oil.

The liquid fraction removed during oil separation, called stickwater, is sent through evaporators which concentrate the material approximately ten times. The resulting syrup, known as condensed fish solubles, is pumped into storage tanks to await shipment. A recirculating system and agitator prevent the build-up of solids at the bottom of the tanks during storage. Prior to shipment, the pH of the solubles is adjusted to a level below 5.0 by the addition of acid.

Drying. The press cake discharged from the screw presses, along with the recovered suspended solids, is conveyed directly to a rotary dryer. In some cases, the solids discharged from the screening and centrifuging processes are recycled through a foots press before passing to the dryer. During passage through the dryer, the press cake and solids are reduced to scrap which has a moisture content of about 10 per cent. Both steam-tube and direct-heat dryers are used, but the latter are more common. From one to seven dryers may be employed, each having a capacity ranging between 3½ and 15 tons of scrap per hour.

In recent years, a number of plants have produced a "full" or "whole" meal by adding back the solubles to the press cake before drying. The rate at which the solubles are returned is variable but in some cases may be adjusted to meet customer specifications.

Storage of Scrap and Meal. As the scrap is discharged from the dryer, it is carried by overhead conveyors to a large storage shed and deposited in piles on the floor. The scrap partially cools as it falls to the floor from the overhead distributing conveyor; however, the piles subsequently must be turned and aerated to further cool the scrap. Most menhaden processors use an antioxidant to control the build-up of heat which normally occurs in the scrap piles. This is added at some stage after the scrap has left the dryer. If properly applied, antioxidants reduce some of the problems of handling the scrap during cooling and permit bulk storage of the dried material without the danger of fire, caking, or other undesirable changes. The antioxidant most commonly used is butylated hydroxy toluene, although others have been tested and found to be satisfactory[10].

The scrap is handled in a number of different ways, depending on storage and transportation facilities, customer specifications, climatic conditions, and other factors. Much of the scrap is conveyed directly from the scrap shed to a hammer mill where it is ground into meal. From the hammer mill, the meal is automatically weighed into burlap sacks which often are placed on pallets for storage. Recently, bulk storage of the scrap or meal in warehouses or silos has become common practice. Some companies place their scrap production in burlap sacks which are then stowed in a warehouse to await shipment.

Shipment of Products. Bulk scrap and meal usually are loaded into freight cars or trucks by conveyors or blowers, whereas sacked material is handled by fork-lift trucks. Companies which sack their scrap or meal production for storage may empty the sacks prior to shipment.

Crude oil and solubles are transported by railway tank car or tank truck, while the refined oil is transported by tank car, tank truck, or in drums. Crude oil destined for European markets usually is transported by barge to seaports for ocean shipment.

Yield of Menhaden Products. The yield of scrap per unit of raw material is fairly constant throughout the industry and averages approximately 1 ton for every 5 tons of raw fish. The composition of the scrap, however, varies in relation to the size and fat content of the fish, period of storage of the raw material, thoroughness of cooking, drying temperatures, and other processing factors. The processors attempt to reduce this variation by careful control of each stage of processing. The protein, moisture, and fat content of the scrap sometimes are considered in judging the quality of the finished product.

TABLE 11.2. PRODUCTION OF MENHADEN PRODUCTS, 1950–61

	Scrap and meal		Oil		Condensed solubles		Total
Year	Tons	Value, dollars	Gallons	Value, dollars	Tons	Value, dollars	Value, dollars
1950	103,365	12,864,751	10,209,958	5,866,554	(1)	(1)	18,731,305
1951	115,464	13,879,523	12,537,115	9,771,154	(1)	(1)	23,650,677
1952	144,025	17,847,361	12,888,646	5,785,395	(1)	(1)	23,632,756
1953	174,752	21,767,205	17,824,477	8,806,317	39,038	3,592,551	34,166,073
1954	183,091	23,783,364	18,641,433	9,755,320	56,274	5,564,717	39,103,401
1955	190,628	25,457,512	21,232,141	12,195,454	61,938	4,396,642	42,049,608
1956	210,582	27,439,634	22,428,082	14,092,275	72,852	5,339,834	46,871,743
1957	172,388	21,725,888	15,797,919	9,466,198	69,398	5,615,490	36,807,576
1958	158,074	20,698,929	17,064,818	9,434,108	72,471	6,252,986	36,386,023
1959	223,893	26,391,987	20,628,278	10,743,781	108,079	5,582,514	42,988,282
1960	218,423	19,201,716	24,453,736	11,582,027	65,850	2,299,209	33,082,952
1961	247,551	25,852,498	31,355,570	12,913,447	73,305	3,142,397	41,908,342

(1) Data unavailable.
Source: Data for 1950 to 1959 are from U.S. Dept. Interior, *Statistical Digest;* for 1960 and 1961 from U.S. Dept. Interior, *Current Fishery Statistics*, Nos. 2541 and 2863.

The yield of condensed solubles varies from plant to plant but averages approximately 1 ton for every 13 tons of raw material. Processors strive to maintain a minimum solids content of 50 per cent, but careful control of each processing step is essential to ensure a uniform product without loss of valuable proteins, minerals, and vitamins.

The oil yield of fish caught in different localities varies greatly both within and between years. Fish of medium size often contain more oil per unit of body weight than do larger fish, and small fish usually contain little oil. Furthermore, Gulf menhaden average more oil per unit of body weight than do Atlantic menhaden. The average annual yield of oil generally varies between 24 and 33 gallons per ton of fish, but in individual localities may range from almost nil to over 50 gallons per ton. The unique properties of menhaden oil, including the unusually long chain fatty acids and their high degree of polyunsaturation, perhaps render this product of greatest potential to the menhaden industry[4,14].

In 1961, there were produced 247,551 tons of menhaden scrap and meal, valued at $25,852,498; 31,355,570 gallons of oil, valued at $12,913,447; and 73,305 tons of solubles, valued at $3,142,397. These quantities represented 80 per cent of the domestic fish scrap and meal production, 91 per cent of the fish oil production, and 66 per cent of the condensed fish solubles production[1]. The yield and value of menhaden products for the period 1950–61 are given in Table 11.2.

Marketing of the Products

The greatest share of the meal, scrap, and solubles produced by the menhaden industry is sold on contract to animal feed manufacturers, either directly or through brokerage concerns. In some localities these products enter local markets. The bulk of menhaden oil production currently is exported. Sales of this product are handled through brokers, exporters, or company sales representatives.

Recent Changes in Marketing Practices. The recent increased world supply of fish meal and oil has brought about a number of changes in marketing practices within the menhaden industry. Prior to 1959, sales of menhaden meal and scrap were made on the basis of long-term commitments. With the recent shift from a seller's to a buyer's market, many customers have converted to short-term contracts and "spot" purchases. This has prompted the menhaden industry to establish a closer liaison with the feed mixers, users, and various trade associations. A number of companies also have added scientifically trained personnel to their staffs in an effort to improve the quality of present products and search for new products.

Since the production of menhaden meal and solubles is seasonal, the feed manufacturers previously carried large inventories of these products so as to be assured of adequate supplies. Fish meal buyers now frequently specify that shipments be scheduled through the year, thus requiring the producers to assume a large share of the cost and responsibility for inventories.

Distribution of the products also have become a problem to the producers. Since reduction plants are located on the seacoasts, much of the meal, scrap, and solubles production must be transported long distances to inland feed-mixing plants. Differential freight rates and increased shipping costs, often amounting to as much as 20 per cent or more of the delivery price, formerly were borne by the buyer. Under present market conditions, the producers must absorb a greater share of these costs to be competitive. A number of reduction plants are located at some distance from a railhead, consequently, the added costs of trucking and double handling have become an important economic factor in certain localities.

Market Prices for Menhaden Products. Menhaden meal and scrap generally are sold on a 60 per cent-minimum protein basis. Prior to 1959, prices of these products were relatively high and subject to only slight variations arising from moderate changes in supply and the influence of competitive feed ingredients. From 1952 to 1959, the average annual price for menhaden meal at New York City fluctuated between $132.52 and $144.18 per ton (F.O.B. East Coast). As a result of a record production and increased imports, the average annual price in 1960 dropped to an all-time low of $97.88 per ton. With stabilization of the market in 1961, monthly prices increased and during most of the year averaged about $115.00 per ton.

Menhaden solubles generally are sold on a 50 per cent solids content basis. The prices of solubles have fluctuated much more than the prices for meal. Between 1952 and 1959, the average annual price of menhaden solubles at New York City ranged from $75.00 per ton (F.O.B. East Coast) in 1955 to $107.50 per ton in 1953. Following the downward trend in the meal market in 1960, prices of solubles declined to a low of $39.34 per ton. Although prices increased and stabilized by mid-1961, they remained below $50.00 per ton during the remainder of the year.

For many years oil was considered the most important product of the menhaden industry. Prior to World War II, menhaden oil was used in the manufacture of a variety of industrial products. Technological advances eventually led to the exclusion of fish oils in many of these products, with the result that a depressed market condition for menhaden oil now exists. At present most of the crude oil production is exported to Europe, chiefly to West Germany, Sweden, and the Netherlands, where it is manufactured into margarine. The remainder is sold in the United States where, because of special properties, menhaden oil is still preferred for certain industrial uses.

As a result of the decline in the domestic demand for menhaden oil and the increased world supply of fish oil, prices recently have been more variable than those of meal and solubles. From 1952 to 1956, the average annual price of menhaden oil at New York City (F.O.B. Baltimore) increased steadily, reaching a maximum of 8.86 cents per pound (78 cents per gallon) in 1956. Since that time prices have declined and reached their lowest level in 1961. The average monthly price during the first six months of 1961 varied between 6.00 and 6.75 cents per pound (52 and 59 cents per gallon), but by the end of the year had declined to 4.62 cents per pound (40 cents per gallon), the lowest value in 10 years.

Future of the Industry. To ensure continued growth of the menhaden industry, U.S. Government and industry-sponsored laboratories are engaged in research designed to develop new and diversified uses for menhaden and menhaden products. In addition, the industry is engaged in a vigorous promotional program, aimed at expanding uses of the present products. Attention also is being given to biological studies on menhaden to provide a basis for maximum utilization of the resource without endangering the future supply. Although there appears to be no immediate or easily attainable solution to the complex economic problems currently facing the industry, the above measures will help substantially in broadening the market base for menhaden products and assist in the wise utilization of the menhaden resource.

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CHAPTER 12

The Shrimp Fishery

C. P. Idyll

Commercially Important Species

All the species of shrimp of commercial importance in the southern fishery belong to the tropical and temperate water family Penaeidae. In the South all sizes are called shrimp, while in some other areas the large varieties are called prawns, and the smaller shrimp, especially the northern species which belong to the family Pandalidae, are called shrimp.

Prior to about 1948 over 90 per cent of the shrimp produced in the United States were white shrimp, *Penaeus setiferus*. These are usually found in shallow water, and the fishery took place largely in bays and other inshore areas less than 15 fathoms in depth. Louisiana has always been the center of the white shrimp fishery; about half the catch of this species has come from there in recent years.

In the late 1940's large quantities of two other species, the brown shrimp, *P. aztecus*, and the pink shrimp, *P. duorarum*, began to be caught. It was discovered that these "grooved shrimp" could be caught in much larger quantities at night than in the daytime. This was followed by the opening of new grounds off Texas, Alabama, Florida, and Mexico and then to the development of markets for the new varieties, whose appearance was unfamiliar to the public. In 1959 brown shrimp were landed in larger quantities than other varieties, with the biggest production coming from Texas. White shrimp occupied second place and pinks third. Most of the latter species were landed in Florida, from the Tortugas grounds west of Key West and from the Campeche grounds off the Yucatan Peninsula of Mexico.

Minor quantities of sea bobs, *Xiphopeneus kroyeri*, are landed, nearly all from shallow waters in Louisiana. They are small in size and are usually dried or canned. Royal Red shrimp, *Hymenopenaeus robustus*, a deep water variety, entered the catch to a small degree in the 1950's. They occur in water 175 to 300 fathoms deep, and as a consequence they are costly to catch. It is possible that if demand becomes great enough and if fishing costs can be lowered, this variety may achieve significant commercial importance.

American boats fishing in Central America and South America catch a second species of white shrimp, *Penaeus schmitti*, and a third grooved shrimp, *P. brasiliensis*, in addition to pink shrimp.

The California, Oregon, and Washington fisheries produce mostly the ocean pink shrimp, *Pandalus jordani*, which accounts for about 3 to 5 per cent of the total U.S. landing. In Alaska three pandalids are landed in quantity: the pink shrimp, *Pandalus borealis;* the side-stripe, *Pandalopsis dispar;* and the coon-stripe shrimp, *Pandalus hypsinotus*.

The relative commercial importance of the different kinds of shrimp in 1958 and 1960 is shown in Table 12.1.

TABLE 12.1. CATCH BY SPECIES, 1958 AND 1960

	1958		1960	
Species	Quantity (heads off)	Proportion of Total	Quantity (heads off)	Proportion of Total
	1000 lbs	%	1000 lbs	%
Brown	56,960	45	71,510	48
White	32,943	26	27,278	19
Pink*	25,531	20	40,581	27
Other	11,802	9	9,114	6
Total	127,236	100	148,483	100

* *Penaeus duorarum.*

Location

The major shrimp fishery of the United States is located in eight southern states and extends from Beaufort, North Carolina to Brownsville, Texas. A smaller industry is based in the four Pacific Coast states, while minor quantities of shrimp are landed in Maine, Massachusetts, New York, and New Jersey, mostly for bait.

In the South, fishing is continuous from Bull Bay, South Carolina to the St. Johns River, Florida and in scattered areas north and south of there. These grounds, and those of Louisiana and Mississippi, are the oldest exploited in this country. Late in 1949 the Tortugas grounds west of Key West, Florida were opened up by north Florida fishermen.

Several years later the small Florida grounds off Sanibel and Tarpon Springs began to be exploited. There is a gap between Tarpon Springs and the next shrimping area, near Apalachicola. From Pensacola Bay the grounds are nearly continuous to the Mexican border. American vessels fish off the coast of Mexico below Brownsville, landing in that port and others nearby. Vessels also sail from Tampa, Ft. Myers, and other ports to the Campeche grounds off the Yucatan Peninsula of Mexico.

As the industry expanded rapidly under the stimulus of newly discovered fishing grounds and increased markets in the 1950's, some vessels found it increasingly difficult to catch profitable amounts of shrimp. One consequence was that boats began to go farther and farther afield. American fleets have fished in Honduras, Nicaragua, and other Central American countries, and in the early 1960's American boats are producing shrimp in British Guiana and shipping them back to the United States frozen. Catches by United States boats in domestic waters and in waters off foreign countries for 1960 are shown in Table 12.2.

TABLE 12.2. CATCH OF SHRIMP OFF UNITED STATES AND ON THE HIGH SEAS OFF FOREIGN COASTS BY UNITED STATES BOATS LANDING AT AMERICAN PORTS, 1960*

Area Fished	Catch (heads on)
	Pounds
Off Foreign Coasts	
Gulf of Mexico, Caribbean Sea, and Atlantic Ocean	
High Seas off Mexican Coast, west of 94° Longitude	6,127,093
High Seas off Obregon-Campeche	20,543,171
South of 21° north Latitude	499,911
Total	27,170,175
Pacific Ocean, off Canada	19,000
Total off Foreign Coasts	27,189,175
Off United States Coast	222,262,825
Grand Total	249,452,000

* Source: Fishery Statistics of the United States, 1960, and Shrimp Landings, 1960. Washington, U.S. Fish and Wildlife Service (1961).

Until the late 1940's most shrimp fishing took place within about 6 miles of shore; occasionally vessels went out about 10 miles, and in Louisiana fishing was done in some cases out to 50 miles. By 1950 the character of the fishery had changed, with the best catches of large shrimp being made in deep water (up to 25 fathoms or more) considerable distances offshore. Vessels from Key West and Ft. Myers go as much as 90 miles to the Tortugas grounds, and Tampa boats go about 600 miles to the Campeche grounds.

As with the southern shrimp fishery, that of the Pacific Coast was originally centered in the bays and inshore waters. Small shrimp have been caught for many years in San Francisco Bay, and small quantities have been produced from Puget Sound for a long period. In recent years the fishery has expanded considerably in all four of the Pacific states, under the impetus of increased markets and with the innovation of an efficient shrimp peeling machine which allows the small shrimp of this area to be handled without undue labor costs. The potential of this fishery appears to be very large, especially in Alaska, and there seems to be every expectation of great expansion if markets can be encouraged. At present the shrimp from this area are mostly sold canned or in the cooked frozen state rather than breaded or raw frozen as is the case with the larger southern species. Production of frozen, peeled meats preformed into shapes or logs for later fabrication into breaded shrimp, shrimp sticks, or other forms has recently begun and appears to be a promising outlet for the small Pacific shrimp.

Production

Beginning in 1952 shrimp has been the most valuable marine resource of the United States, replacing salmon and tuna, one or the other of

TABLE 12.3. QUALITY AND VALUE OF UNITED STATES SHRIMP CATCH FOR VARIOUS YEARS

Year	Quantity (heads on)	Catch Value
	Thousands Pounds	Thousands Dollars
1889	9,048*	108*
1902	16,178*	199*
1908	18,563	494*
1918	48,003*	1,098*
1930	108,550	3,119
1940	152,663	5,954
1950	191,474	43,452
1951	224,316	51,862
1952	227,221	55,103
1953	260,357	76,641
1954	268,334	60,831
1955	244,335	61,782
1956	224,173	70,894
1957	203,882	73,145
1958	213,842	72,940
1959	240,182	58,133
1960	249,452	66,932

Source: U.S. Bureau of Commercial Fisheries.
* Values for Gulf of Mexico only.

which had occupied this position for many years previously. In 1960 shrimp landings in the United States totalled 249,452,000 pounds, valued at $66,932,000. The record year of production was 1954 when 268,334,000 pounds were caught; the highest value was attained in 1953, when the catch was worth $76,641,000. Table 12.3 shows total United States production of shrimp for various years.

TABLE 12.4. UNITED STATES PRODUCTION OF SHRIMP BY STATE, AND TOTALS BY AREA IN 1960*

State	Production	
	Quantity (heads on)	Value
	Thousands Pounds	Thousands Dollars
South Atlantic States		
North Carolina	5,988	1,607
South Carolina	8,030	2,167
Georgia	10,403	2,575
Florida (east coast)	6,793	2,163
Total	31,214	8,512
Gulf States		
Florida (west coast)	44,464	12,155
Florida (east coast)	6,793	2,163
Alabama	7,169	2,090
Mississippi	11,031	2,899
Louisiana	61,758	15,881
Texas	81,303	24,606
Total	205,725	57,631
West Coast		
Alaska	7,436	297
Washington	1,805	162
Oregon	1,149	101
California	2,028	204
Total	12,418	764
Other	95	25

* Source: Commercial Fisheries Statistics, Nos. 2478, 2566, 2695, 2763, 2795, and 2801, Washington, U.S. Fish and Wildlife Service.

Texas leads other states in shrimp production, having taken over this position from Louisiana in 1954, principally as a result of the great increase in the production of brown shrimp. Table 12.4 shows the production of shrimp by state for 1960. Table 12.5 shows the quantity and value of shrimp produced in the United States in 1959, by method of processing.

The rapid expansion that has taken place in the shrimp industry is also indicated by the increase in the number of fishing craft engaged. Table 12.6 shows the number of boats and vessels in the shrimp fishery for various years.

Table 12.5. Quantity and Value of Shrimp Produced in the United States in 1959, by Method of Processing*

Items	Unit	Quantity	Value, Dollars
Fresh and Frozen			
Headless	Pounds	61,598,413	36,980,274
Raw, peeled (incl. deveined)	"	11,096,373	9,945,187
Cooked (incl. peeled and deveined)	"	1,890,703	2,815,626
Breaded, raw and cooked	"	69,764,216	45,313,584
Specialties (burgers, cocktail, creole, dinners, stuffed, with deviled crab, with lobster sauce, bait with heads on, and some dehydrated)	"	3,635,451	2,693,485
Canned			
Wet and dry pack	Standard cases	922,150	16,948,470
Specialties (dips, soups and stews)	"	3,710	50,947
Sun dried	Pounds	321,897	290,985
Cured			
Salted and pickled and smoked	"	11,805	24,270
Meal and bran	Tons	627	38,657

* Source: Manufactured Fishery Products, 1959, Annual Summary, Washington, U.S. Bureau of Commercial Fisheries.

Table 12.6. Number of United States Shrimp Vessels and Boats, 1950–1960*

Year	Number	Year	Number
Vessels†			
1950	2,674	1956	3,363
1951	2,909	1957	3,509
1952	3,013	1958	3,896
1953	3,011	1959	4,003
1954	3,267	1960	3,804
1955	3,288		
Boats‡			
1950	4,056	1956	3,818
1951	3,676	1957	3,316
1952	3,452	1958	3,427
1953	3,489	1959	3,655
1954	3,907	1960	3,903
1955	3,644		

* Source: U.S. Bureau of Commercial Fisheries.
† Vessels are craft having net capacity of 5 tons or over.
‡ Boats are craft having a net capacity of up to 5 tons.

There is a marked difference in the average production of shrimp by vessels operating in the southern shrimp fishery compared with that of vessels in the Alaskan fishery. Vessels in the latter fishery in 1959 averaged 250,000 pounds of shrimp, while vessels operating in the Campeche fishery considered 60,000 to 70,000 pounds a very good annual production. On the other hand, the average price per pound of Alaskan shrimp was only about 4 cents compared to about 26 cents (heads on) for southern shrimp in 1959.

The southern shrimp fishery operates the year around, but catches are normally highest from June to October. Vessels large enough to do so usually move from one ground to another, following seasonal changes in abundance.

In recent years the quantities of shrimp imported from foreign countries have increased markedly. From less than a million pounds in the early 1930's, imports rose to a record of 113.4 million pounds in 1960. The value of shrimp imports rose from $385,000 in 1940 to $56.4 million in 1960. Mexico has always supplied the greatest quantity of shrimp imported into the United States. Before 1950 Mexico was the only important supplier, accounting for over 99 per cent of the quantity imported. In 1960, 55 countries sent shrimp to the United States. Mexico's share in 1960 was 65 per cent; other important suppliers included Panama, El Salvador, Ecuador, British Guiana, and Colombia.

Fishing Methods

About 95 per cent of the shrimp caught in the southern fishery are caught by otter trawls. The relatively minor quantities from the Northwest are captured by beam trawls, but in recent years otter trawls have been used successfully. Cast nets and bag nets in the South and baited pots in the Northwest catch the remainder.

The common southern shrimp boat design is said to have been derived from Greek boats whose owners were engaged in the sponge fishery of the west coast of Florida. Such "Florida-type" vessels (Figure 12.1) are usually 50 to 70 feet in length, typically 67 feet. They are usually of wood, and are powered with 150 to 200-horsepower diesel engines. These vessels have a fuel capacity of 6000 gallons and an ice capacity of 45 tons. They are capable of fishing anywhere in the Gulf of Mexico or the Caribbean Sea. The cost of a 67-foot vessel in 1960 was estimated at $47,500.

A second, less common vessel employed in the southern shrimp fishery is the "Biloxi-type." This is used mostly in inshore fishing and ranges in size from about 30 to 45 feet. Unlike the "Florida-type" vessel, it has the wheel-house and engine room aft.

The trawl in common use by the whole fleet through most of the 1950's, and still used by the majority of the vessels fishing for white shrimp, is typically 80 to 100 feet across the mouth. These trawls are of two kinds, the flat trawl and the balloon trawl[2]. A principal difference between the two kinds is that the head rope of the balloon trawl rises higher in the water; in addition, it picks up less "trash," such as shells and sponges, than the flat trawl.

A major change in gear took place in the late 1950's when many vessels began to replace the single trawl net by a pair of smaller trawls.

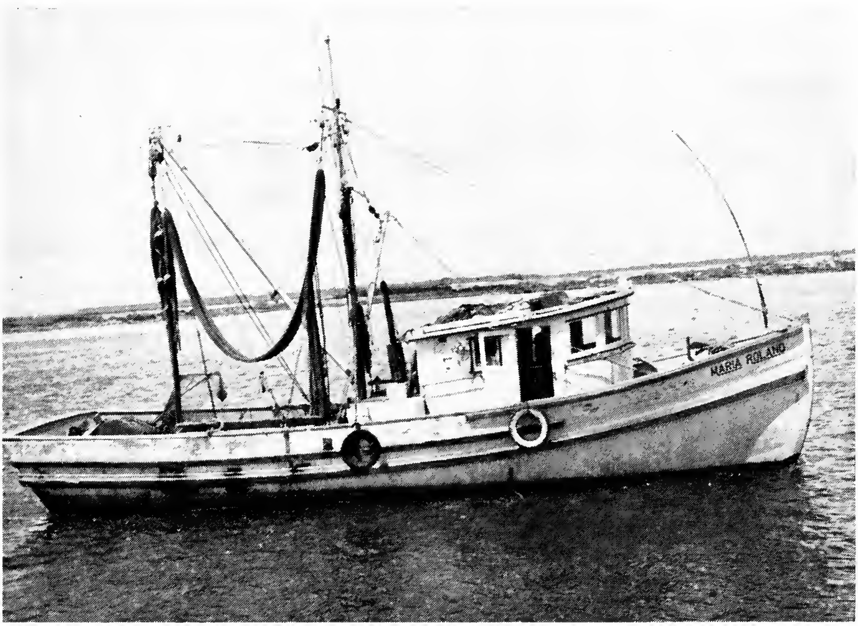

Figure 12.1. "Florida-type" shrimp vessel.

"Double-rig" trawls were used in the early 1960's by nearly all boats fishing for pink and brown shrimp. The two nets are each 40 to 45 feet across and are fished from long, stout outriggers, one on each side of the vessel. The port trawl is fished about 25 fathoms behind the starboard trawl to avoid fouling. Between them is fished the try-net. This is a miniature trawl, eight to ten feet across the mouth, which is employed to inform the fishermen it is worth while putting the big nets overboard. The general adoption of the two-trawl gear has been due to the easier handling of the smaller nets, smaller initial cost of gear, smaller losses in case of destruction or damage to the nets, increased safety, and of greatest consequence, increased production.

Usually two men handle a southern shrimp boat, although three may be employed, especially in offshore operations; in a few cases vessels have been handled by one man.

Fishing for white shrimp takes place mostly during the day while the best catches of pink and brown shrimp are made at night. In some areas, including North Carolina to northeast Florida and parts of the Gulf of Mexico, vessels return to port each day. In the Tortugas fishery, boats are usually on the fishing grounds for periods of four to seven days or longer; in the Campeche fishery the usual length of trip is 45 days. In the case of these long trips, vessels send their early catches to port with other boats, transferring loads about every seven days. In turn, a vessel will ordinarily carry part of the catches of several others when they complete their trip.

The length of time that the net is dragged varies considerably but is ordinarily about two to three hours. In addition to shrimp, the nets pick up considerable quantities of "trash," including fish, sponges, crabs, and other animals, plus stones, shells, and other material. The trash may constitute a major proportion of the catch, the amount varying with locality and season. Much of the material caught in this way would make meal which is useful in poultry feeds or could be used for animal feeds or to manufacture other useful products. So far no proven method has been devised for the economical collection and processing of this material, but autoenzymatic breakdown at a low pH may be useful[14].

Handling on the Vessels

When the trawl net has been dumped on the deck of the vessel, the shrimp are separated from the trash (Figure 12.2) and the latter is dumped overboard. In the southern shrimp fishery the shrimp are usually beheaded on the boat, but if the catch consists of large quantities of small shrimp or if the vessel expects to return to port without delay, this may not be done. The shrimp are put into metal baskets of about 85 pounds capacity and washed with a stream of sea water from a hose. They are then stored in the hold of the vessel in crushed ice.

Temperatures are high in the southern areas where most of the shrimp are caught, with water temperatures ranging up to about 85°F and air temperatures rising to the 90's. Temperatures on the metal decks of some vessels reach higher levels than this. As a consequence, shrimp are damaged if they are not quickly handled. Bacterial and autolytic spoilage, as well as a condition known as "black spot," may be well advanced before the shrimp reach shore unless care is exercised[16].

Black spot is a condition affecting the shell of shrimp and, in severe cases, also causing discoloration of the flesh. It usually appears as a black banding on the shell and produces an unsightly appearance which may cause customer resistance to the fresh or frozen product. Black spot is caused by an oxidation-reduction enzyme system and is thus aggravated by exposure of the shrimp to air[8]. It can be kept to a minimum by rapid handling of the shrimp. Some fishermen dip the shrimp in dilute solutions ($1\frac{1}{4}$ per cent or less) of sodium bisulphite before packing them in ice[3]. This serves to inhibit the formation of the black spot. This practice is not universally popular with buyers, however, since it removes

Figure 12.2. With catch nearly sorted from one drag, the worker is surrounded by carpet of shrimp. (*"Fish Boat," H. L. Peace Publications.*)

a danger signal which some of them use to warn of shrimp which have been mishandled and which may be partly spoiled. Black spot can be reduced by short drags, beheading on the boat, thorough washing, and rapid icing[11].

At the dock the shrimp are unloaded into wash tanks which serve to clean them and separate them from the crushed ice. If they were not beheaded on the boat, this operation is now performed. Sometimes the shrimp are graded for size at this point. The shrimp are packed with crushed ice, 100 pounds of tails to the box, or iced in bins in refrigerator trucks.

Size grades of shrimp are expressed as "count," meaning the average number of tails to the pound. Commercial size categories in common use are shown below:

Classification	*Number of shrimp per pound (heads off)*
Extra jumbo	Less than 15
Jumbo	15 to 20
Large	21 to 25
Large-medium	26 to 30
Medium	31 to 42
Small	43 to 65
Very small or bait	66 or more

The price received for shrimp varies with the size, the largest shrimp bringing the highest price.

Refrigerated Brine. In some fisheries, especially in the Northwest, refrigerated brine has been successfully used to replace ice as the cooling agent for fresh fish on board vessels[13]. Experiments in the southern shrimp industry suggested that this might be a promising technique[9,10]. Temperatures as low as possible above the freezing point of the brine and the shrimp are desirable, these being about 29 to 32°F. Off-odors of the shrimp held in this way can be combated by small concentrations of aureomycin (five parts per thousand). Some early commercial trials in the southern United States shrimp industry were discouraging and the system was abandoned. Refrigerated brine is used by shrimp boats in some other countries, including Panama and Colombia. In the Alaskan shrimp industry, trials have been made involving the use of refrigerated brine, but in the early 1960's this technique had not been perfected[4,5,6,15].

Freezing at Sea. It is possible to freeze shrimp at sea as shown by experiments by Dassow[7]. At present it appears not to be economically feasible to carry out this processing on the vessels, however, due to the extra costs associated with the freezing equipment and the skilled men needed for such an operation.

Processing

Shrimp are marketed in several forms—fresh, frozen, breaded, canned, cured, and as specialty products. In the past most shrimp were sold fresh, but this restricted the market to areas close to the port of landing. In recent years consumers have received shrimp mostly as frozen tails, shell on. An increasing proportion of shrimp are being sold as frozen breaded or as peeled and deveined shrimp. Canned shrimp now supply a decreasing proportion of the market, resulting from a nearly constant quantity being canned while increased supplies of shrimp have been sold in other forms. Miscellaneous items include dried, spiced, and smoked shrimp, shrimp soups, paste, shrimp in cocktail sauce, and others of minor importance. Meal is produced from the heads and other waste from shrimp processing, most of it coming from the dried shrimp and canning industries. The meal is used as a feed supplement for poultry and other animals.

Canning. Shrimp canning was first done in the United States in 1867 by the Dunbar family of Louisiana. In 1960 there were 45 shrimp canning plants in this country; this was a reduction of about one-third of the number in the early 1930's. Shrimp were canned in 1959 in eight states, the distribution of canneries being shown in Table 12.7.

TABLE 12.7. NUMBER OF SHRIMP CANNERIES, AND VOLUME AND VALUE OF THE PACK OF SHRIMP, BY STATES, 1959 AND 1960*

State	No. of Plants		Standard Cases†		Value, Dollars	
	1959	1960	1959	1960	1959	1960
Alabama	2	1				
Georgia	1	1	53,098	65,775	961,403	1,139,369
Texas	1	2				
Mississippi	9	12	193,836	232,844	3,873,529	4,781,318
Louisiana	19	18	506,072	573,354	9,385,954	10,071,609
Total	32	34	753,006	871,973	14,220,786	15,992,296
Washington	3	3	64,817	27,997	1,041,389	462,928
Oregon	2	2				
Alaska	9	6	104,327	51,249	1,686,295	777,369
Total	14	11	169,144	79,246	2,727,684	1,240,297
Grand total	46	45	922,150	951,219	16,948,470	17,232,593

* Source: U.S. Bureau of Commercial Fisheries.
† A standard case represents the various size cases converted to the equivalent of 48 cans to the case, each can containing 5 ounces.

In 1957 shrimp canning in the Pacific states increased sharply in volume, principally due to the encouragement provided by successful application of mechanical peeling machines. These machines had been developed in the Gulf of Mexico area, and their use on the small shrimp caught in Oregon, Washington, and Alaska waters reduced the cost of processing by eliminating hand labor in the heading and peeling process. In 1960, however, several of the plants on the Pacific Coast ceased operations and others curtailed their production as a consequence of weak market demand.

In 1959, 922,000 cases of shrimp were canned in the United States.

In 1960, a production of 951,000 cases was reported. The record shrimp pack was in 1937 when 1,435,000 cases were produced.

Canneries used about one-fifth of the total U.S. production of shrimp in 1959, employing especially the small sizes. Shrimp smaller than 60 to the pound (heads off) went principally to the canning market, while substantial quantities of 30–60 count shrimp were also canned. The small shrimp in Alaska and other Pacific Coast states were nearly all marketed peeled, either canned or cooked. Canneries in the southern states packed about equal quantities of brown and white shrimp and small quantities of pink shrimp and sea bobs.

Canning Process. Shrimp received at the cannery are first dumped into a washer and deicer, from which they are removed by a wire mesh belt. They pass on the belt in front of inspectors who remove broken, decomposed, and discolored shrimp, as well as extraneous matter. The shrimp are now weighed, and it is usually not until this point that the cannery assumes ownership of the shipment. This encourages better care of the shrimp by the boat operator.

Shrimp are usually delivered to canneries with the heads on. When market conditions demand it, canneries will occasionally buy fresh headless shrimp. In certain rarer instances, frozen headless shrimp may be purchased. The removal of the heads and shells or the shells alone is called picking. This operation was formerly done entirely by hand, but in the late 1940's machines were developed for this purpose. Now nearly all the shrimp canned in the United States is machine peeled. About 50 to 55 per cent of the weight of shrimp is lost when the head and shell are removed.

After picking, the shrimp are subjected to another inspection for quality. Some canners now grade the shrimp for size so that the largest individuals can be deveined. The "vein" is the intestine of the shrimp, which runs down the dorsal side near the surface. Commonly it is filled with food or sand, and its removal improves the quality of the canned product. Nearly all deveining is done by machines. The deveining is accomplished by splitting the muscle of the shrimp along the length of the intestine and removing the intestine by passing the shrimp through a rotating, indented cylinder partially immersed in water.

Blanching (or precooking) is the next process. Some canners regard this as one of the most critical operations, since improper blanching markedly affects yield and grading. Proper blanching is said to set the color, to curl the shrimp so that packing and grading can be accomplished, and to extract water and solubles.

The blanching solution is hot brine. The strength is ordinarily about 25° salinometer, and the length of blanching varies from about $1\frac{1}{4}$ to 3 minutes, depending on the size of the shrimp. The shrimp are carried or propelled through the boiling saline solution. If the blanch brine is not actively boiling when the shrimp are put into it and if the shrimp are not stirred, they may not curl properly. The uncurled shrimp may drop through the wrong holes in the grader.

Figure 12.3. Peeling and deveining shrimp. (*"Fish Boat," H. L. Peace Publications.*)

In some canneries shrimp are discharged from the blancher directly into a cold water vat. This stops the cooking process quickly and helps control yields. The shrimp pass from the cooling vat onto a drying belt where the excess moisture is removed. In other plants the shrimp are discharged directly from the blancher onto the drying belt. Following this, they are graded in shaker-type graders in which the shrimp fall through various sized holes in five size categories. Visual inspection follows, to correct errors made by the grader and to remove broken shrimp as well as extraneous matter.

Shrimp are placed in the cans by hand and are carefully weighed. The put-in weight varies with the size of the shrimp, the species, and the manner of blanching. The cost of the raw material requires careful supervision of the quantity packed in each can. Satisfactory automatic filling machines have not yet been developed in the shrimp canning industry. In 1959 about two-thirds of the United States shrimp pack was put in cans containing $4\frac{1}{2}$ ounces of shrimp, one-fourth in cans containing 5 ounces, and the remainder in cans containing $2\frac{1}{2}$, 3, and over 5 ounces.

The filled cans are carried by conveyor belt to the closing machine. En route, a hot solution (or less often hot water plus a salt tablet) is added to the can of shrimp. This produces "wet-pack" shrimp, the normal product. The saline solution varies in strength, this also having a marked effect on the quality of the finished product. Whether the solution is added as a concentrated brine which is then diluted with hot water, directly as brine of the final concentration, or as water and salt tablet, the final strength of the solution is approximately 25° salinometer.

The vacuum in canned shrimp is not ordinarily produced by an exhaust machine or in a steam box, but as a result of the heat of the saline solution. The closing machine ejects enough saline solution to produce the required head space and then seals the lids on the cans.

The filled cans are removed to the retorts in metal baskets. The processing is done at a temperature of 250°F under pressure. Processing time varies with the size of the can, being 12 minutes for the common sizes of 211×300 and 307×113. At the end of the processing time the steam valves are closed, the blow-out valves opened, and the retort is flooded with water. This stops the cooking process quickly since shrimp are easily ruined by overcooking which softens them and reduces the shelf life. The cans are cooled to approximately 100°F. This provides sufficient heat to dry the cans after draining and helps prevent rusting of the containers. The cans are placed in cases after being thoroughly drained and dried. In one plant on the Gulf, storage of the finished product is at reduced temperatures, refrigerated rooms at about 65°F being used.

The above process describes the preparation of "wet-pack" shrimp. "Dry-pack" shrimp, once an important item, are ordinarily no longer prepared in the American industry except by special order. The process differs from that described in that the shrimp are usually blanched for 8 to 10 minutes, the cans are lined with parchment paper, no liquid is added, and the shrimp are processed for 60 minutes at 250°F.

In the Pacific Northwest and Alaska the shrimp canning process differs from that described for the Gulf of Mexico and South Atlantic areas as a consequence of the different kind of shrimp involved and different canning concepts. The following information is reproduced through the courtesy of L. W. Strasburger of New Orleans: Some plants in Alaska and the Pacific Northwest "age" their shrimp by holding them in ice or refrigerated seawater for two to four days. This is said to aid in the peeling operation. Blanching times are from 45 seconds to 1½ minutes. Citric acid is added to the brine placed in the can. The brine is added cold. Vacuum closing machines are used in this industry, instead of depending on hot brine to produce a vacuum. Processing times vary from 18 to 24 minutes at 240°F.

In common with several other canned fishery products, canned shrimp sometimes contain crystals of water-insoluble magnesium ammonium phosphate hexahydrate, ordinarily called struvite. These crystals resemble glass fragments and they sometimes produce unfavorable consumer reaction, even though they are harmless. Magnesium is the limiting factor in the formation of struvite crystals, and one method of control is to leach the product in order to remove magnesium. A more successful method is to keep the crystal from forming by adding a sequestering agent. A method patented by the Blue Channel Corporation of Port Royal, South Carolina involves a mixture of aluminum sulfate and EDTA (Calcium disodium ethylene diamine tetraacetate), known as Strucol. This is added to the can of shrimp in the form of tablets or dissolved in the brine (Strasburger, personal communication).

Shrimp canners also encounter problems of discoloration of the inside of cans and of the shrimp meats resulting from the formation of iron sulfide. This seems to be associated with a high pH of the shrimp meat. White shrimp and most of the other common varieties have a normal pH of about 6.8; values of 7.2 and above allow increased discoloration[12]. Lowering the pH by the addition of citric acid or lemon juice reduces the discoloration but sometimes impairs the flavor and texture of the finished product. The discoloration is especially prevalent with sea bobs and is one reason that this species has not been more used for canning.

Freezing. *Frozen Shell-on Shrimp.* About 40 per cent of the shrimp produced in the United States is frozen raw with the shell on but the head removed. These shrimp are usually sold in five-pound packages. Commonly, bulk purchases of "fresh" shrimp at meat counters in retail stores are in reality frozen raw shrimp which have been thawed and placed on the counter as needed. Frozen shrimp in this form are sold to wholesalers, retailers, to the restaurant and hotel trade, and to processors of breaded shrimp.

Shrimp are received at the freezer plants in bulk or in boxes, in either case mixed with crushed ice. They are dumped into a wash vat where they are separated from the ice and rinsed. They are then removed from the wash vat by scoop or by conveyer belt. Usually they are graded for size at this point, mechanical graders separating them typically into four size categories. They may be inspected while on the conveyer belt en route to the grader, the inspector removing extraneous material and broken or spoiled shrimp that can be detected visually.

Graded shrimp are packed into waxed cardboard cartons, slightly more than five pounds of shrimp tails to the carton. The excess weight is to allow for adhering water and for shrinkage. The carton is weighed and the weight adjusted if necessary. The size grade is then stamped on the carton which is placed on a pallet or other device for transport to the freezer.

The usual method of freezing is by blast freezer or plate freezer. The temperature is usually maintained at 10 to −40°F, and unless the freezer is overloaded or some other abnormal circumstance prevails, the shrimp are frozen in about 15 hours.

After removal from the freezer, the top of the package is raised and about eight ounces of water are added to the package with a spray. The lid is then closed and the package inverted. In this way a nearly solid block of ice and shrimp is formed, protecting the shrimp from desiccation. Ten five-pound packages are packed in a master carton and placed in cold storage to await shipment.

Frozen Peeled and Deveined Shrimp. Frozen peeled and deveined shrimp were first produced in the United States in about 1947, but the quantity was so small for several years that the production was not listed as a separate item. The convenience of the item to the housewife created an increasing market so that its production has risen at a rapid rate (Table 12.5). In 1960 there were 45 plants producing raw or cooked frozen, peeled, and deveined shrimp. Many of these plants were those set up primarily to produce frozen breaded shrimp, with the peeled and deveined shrimp being a secondary item.

About half the raw peeled and deveined shrimp is packed in seven-ounce cartons and is sold to housewives. The remainder is packed in packages containing two pounds or more and is purchased by restaurants for shrimp cocktails or for breading.

The raw material for the peeled and deveined shrimp is mostly fresh, iced shrimp, delivered directly to processing plants on the water front. Some plants, either because of the geographical location or because of unavailability of fresh shrimp, use frozen headless shrimp, domestic or imported.

If fresh shrimp are used, they usually are delivered to the plant headed and iced in 100-pound boxes. They are washed, graded, and inspected in the same way as shrimp destined to be frozen in the shells, described above.

The peeling and deveining operation is done by machine. There are several kinds of these. The single-feed machine involves placing the

Figure 12.4. Checking weight of packaged raw shrimp prior to freezing. (*"Fish Boat," H. L. Peace Publications.*)

shrimp into the machine by hand one at a time. A knife splits the shrimp along the "vein" or intestine, strips off the shell, and washes out the vein with a jet of water. The peeled and deveined shrimp are delivered into a hopper or endless belt, and the shells and veins are discharged onto a waste belt. The bulk-feed type of machine is used in some plants It peels the shrimp first in one machine and then de-veins them in another by splitting the shrimp with a razor blade and removing the vein by catching it on indentations on a cylinder revolving in water.

The tails are now inspected again for fragments of shell or vein and for damage, and those that require additional cleaning are given to workers for this purpose. The cleaned shrimp are now placed in packages for freezing, or are put on metal sheets so that they do not touch each other, or are pinned to a moving line to be frozen individually. Freezing is usually done at about −10 to −20°F, and the operation takes about 25 minutes. The packaged shrimp are glazed by putting a small quantity of water in the frozen package or, in the case of the individually frozen shrimp, by dipping them in a vat of water. These shrimp are packaged, weighed, closed, and put in master cartons.

Breaded Shrimp. Frozen breaded shrimp were first produced in 1948. The Trade Winds Company of Georgia was the first firm to manufacture frozen breaded shrimp; in 1959, 48 plants in 13 states were engaged in this activity. Half of these plants, in Florida, Texas, and Georgia, accounted for 85 per cent of the breaded shrimp production in that year. While frozen breaded shrimp was the principal product of most plants manufacturing this item, other seafoods, including frozen shell-on shrimp, frozen peeled and deveined shrimp, and shrimp specialities, are also produced by the same plants. The quantities of frozen breaded shrimp in 1959 are shown in Table 12.5.

Breaders prefer to use fresh shrimp as their raw material since it is stated that yields are better than those from frozen shrimp. However, supplies of raw shrimp are often insufficient and large quantities of frozen shrimp are used by the breaders. In 1959, over a quarter of the shrimp used by breading firms was imported frozen shrimp.

When fresh shrimp are used, the first steps of washing, inspecting, and grading are the same as those for processing frozen shrimp, described earlier. Then, whether the raw material was fresh or frozen, the next step is peeling and deveining. This also is done as described above for the frozen peeled and deveined shrimp, except that many breaders use hand labor for this process or employ a machine which leaves the terminal segment of the shell (the "fantail") still attached.

The peeled and deveined shrimp are placed on a conveyer belt which takes them through a batter mixture. This usually consists of dried egg, non-fat dry milk solids, wheat and corn flours, salt, spices, and other ingredients; there is a wide variation among breaders as to the constituents used in the batter.

After having been dipped in the batter, or pulled through it, the shrimp are covered with breading material (Figure 12.5). This consists of a large variety of dry materials which adhere to the wet batter and produce a coating around the shrimp. Sometimes the breading is bread or crackers, toasted to the form of crumbs. In other cases, the breading is a mixture of toasted milled cereal and small quantities of milk and egg solids, soya and potato flours, and seasoning.

The shrimp may be put through the batter and breading mixtures more than once to increase the amount of breading. The proportion of breading varies considerably; ordinarily it ranges from about 40 to 48 per cent, but in some breaded shrimp it is as low as 20 per cent of the total weight or as high as 80 per cent. Breading costs much less than shrimp, and there is, therefore, a tendency to increase the amount of breading in order to reduce the cost of production of the finished product.

Figure 12.5. Breading of raw shrimp. The breading line is on the left, the packing lines on the right. (*"Fish Boat," H. L. Peace Publications.*)

After breading, the shrimp are conveyed to the packing table or the cooker. Cooked or raw breaded shrimp are packed by hand into waxed cardboard cartons. These are adjusted to exact net weight by altering the size of shrimp on the top layer. A wax paper label is ordinarily put on the carton. The cartons of shrimp are now frozen at temperatures around 0 to $-40°F$. The packages are packed in corrugated master cartons.

Drying and Dehydration. *Dried Shrimp.* Drying is a minor method of processing shrimp in the United States. Most of the drying plants are in Louisiana, near New Orleans, where about 25 small firms are engaged in this operation in 1961. Several concerns have dried shrimp in California in past years.

Shrimp used for drying are usually the small sizes. A large proportion of the sea bobs, *Xiphopeneus kroyeri*, which are caught are processed by this method.

The production of sun-dried shrimp in the United States in 1959 was 322,000 pounds, valued at $291,000.00. The quantities produced have shown a steady decline over many years; production in 1940 was nearly two million pounds and in the early 1950's about a million pounds. The

Figure 12.6. Packing of raw breaded shrimp (*"Fish Boat," H. L. Peace Publications.*)

decreasing importance of dried shrimp has probably been brought about by the introduction of mechanical peeling. The small sizes of shrimp previously used for drying, which could not economically be hand-peeled, can now be peeled mechanically. Canners, therefore, use shrimp formerly bought only by the driers.

Shrimp are delivered to the drying plants with the heads on. They are washed and boiled in brine for approximately 15 minutes, depending on the size and kind of shrimp. The cooked shrimp are dipped from the vats and transported by wheelbarrow to the drying platform. The platform is raised above the ground on posts to allow free circulation of the air beneath. The platform is built in undulations about three feet high, with about 30 feet between the crests. The shrimp are sun-dried, and at night, or when it rains, the shrimp are raked onto the crests of the undulations and covered with a tarpaulin to protect them from moisture. The shrimp are spread over the platform in layers about three inches thick and are turned every two or three hours. Drying usually requires about three or four days in the summer; in the winter five to ten days may be required.

The shells and heads are removed from the dried shrimp by rotating them in a wire mesh cylinder. The heads and shells drop through the meshes and the meats are retained in the tumbler.

The peeled shrimp meats are packed in 100-pound bags and sold to concerns which package them in smaller lots. The heads and hulls (shrimp meal or bran) are also placed in 100-pound sacks and sold to firms making poultry feed.

Freeze-Drying. At least one plant on the Gulf of Mexico was freeze-drying shrimp in 1961[1]. Two considerable advantages are claimed for shrimp processed in this way, these being much reduced weight and good keeping qualities. The weight is said to be reduced by as much as 80 per cent, seven pounds of green shrimp being reduced to 13¼ ounces, which fit into a No. ten can. Packed and sealed cans of freeze-dried shrimp require no refrigeration and are said to last indefinitely.

This product is made from frozen, graded shrimp which are first thawed, cleaned, peeled, deveined, and cooked. They are then frozen in a blast freezer and placed in high-vacuum drying cabinets. The amount of heat applied to the product in the vacuum cabinet is just less than the amount removed by the subliming moisture. Through this exact temperature control, the moisture removed from the shrimp is in the form of vapor and does not pass through the liquid phase. The moisture is collected in condensing traps and the shrimp remain frozen. When the shrimp are to be used they are soaked in water and regain approximately their original form.

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CHAPTER 13

The Oyster, Clam, Scallop, and Abalone Fisheries

LYNNE G. MCKEE

The Oyster Fishery

The oyster was one of the first sea foods utilized by man. This species, living in shallow waters between tidal levels and in protected bays and estuaries, was easily taken by primitive man who had not developed tools and weapons. Since the oyster is a sedentary organism, this food supply was available at all seasons of the year. Ample evidence, such as huge kitchen middens and shell mounds, indicate that the oyster was a staple food supply for primitive peoples in certain favorable areas for many hundreds of years. These vast beds of an easily available food enabled nomadic tribes to settle down and form permanent settlements.

The genus *Ostrea*, which embraces at least nine commercial species, is found on the shores of all continents with the exception of the Antarctic region. In the United States three species are of commercial importance. On the Atlantic Coast the vast beds of *O. virginica* found by the early colonists became the basis of the present great oyster industry. On the Northwest Coast a small species, *O. lurida*, was of commercial importance until about the turn of the century when over exploitation nearly brought about the extinction of the native oyster industry. Experimental plantings of the eastern oyster, *O. virginica*, on the West Coast did not prove successful, and the Japanese oyster, *Crassostrea gigas*, was then imported and trial plantings made on Willapa Bay and on Puget Sound. These experimental plantings showed such promise that the efforts were continued and *C. gigas*, now known as the Pacific oyster, is now the basis of the West Coast industry.

The oyster is a bivalve mollusc, that is having two shells as do the clams and scallops. The sexes may be separate or may alternate within the same individual depending upon the species. At first a free swimming organism, the young soon settle to the bottom where they attach to any hard object. This characteristic, and the fact that the oyster grows in shallow protected areas, has made it possible to raise oysters as a crop and has been an important factor in saving the industry from extinction.

Harvesting. Oysters may be harvested by three methods: (1) by gathering by hand when the tide is low, (2) by "tonging," and (3) by the use of power dredges when the beds are flooded. Hand gathering or "picking" was, of course, the means employed by primitive man and was used up to the inception of the industry. This method of harvesting had the disadvantage that it could only be used for brief daily intervals when the beds were exposed at low tide. With primitive peoples this was not important. As commercial use of the beds increased, however, more efficient means were needed, especially a means of harvesting when the beds were flooded. Thus "tonging" came into use. Oyster tongs are a device similar to two rakes hinged together near the lower ends and with the rake-like teeth facing each other. A man standing on the deck of a boat or bateau floating over the beds can, by lowering the tongs to the bottom and by opening and closing the handles, scoop up a quantity of oysters between the rake-like heads. Tonging, like hand picking, is slow and has largely given way to power dredging. The dredge may be a power-driven boat or a barge. The dredge tows a "drag," a metal frame having a toothed bar across the front. This toothed bar dislodges the oysters from the sand and mud and they roll back across the drag bar into a chain mesh bag that collects and holds the oysters until the drag is lifted and the contents dumped onto the deck of the dredge boat. Power dredging is the most economical method of harvesting oysters and now accounts for two-thirds of the oysters harvested.

Processing. Oysters are prepared for market in various ways. The larger plants employ large scale conveyor equipment to move the oysters through the plant[1]. Thus, travelling crane hoists may be employed to carry shell stock to bins over the shucking tables.

If the oysters are to be marketed as shell stock, that is unopened, only washing of the shells, packing in sacks or barrels, and chilling are required. Prior to shipment, the oysters may be kept in chlorinated water for a time to eliminate undesirable bacteria. Oysters are marketed in this manner if they are to be served in restaurants as "oysters on the half shell." By far the greater volume of shell stock has the meats removed at "shucking" houses at the point of origin. Meats, when removed from the shell, go to a device known as a "bubbler" or washer where the meats are churned about in fresh potable water by air blown in from the bottom of the tank. The violent agitation and the bursting of the air bubbles forces the oyster mantles apart and dislodges sand and silt that may be trapped within. Oyster meats take up water quite readily and increase materially in weight if kept long in the washer. This weight increase is known as "floating" the meats. To prevent undue absorption of water, the time the meats may be blown is usually limited by regulations.

After washing, the meats are flooded onto a table and graded for size. Grade size, or number of meats per gallon, varies in different areas but is indicated on the container along with the permit number of the opening house. In most states producers must have a permit and be subject to the state sanitary regulations of the area in which the oysters were grown and prepared for market. Oysters for market should be grown only in waters free from pollution. Oyster meats from the washer are graded into glass or metal containers. Glass containers are usually the pint and half pint sizes. Metal containers may vary from 201 × 400 retail size to the 603 × 700 can for institutional use. All containers are sealed at the point of origin of the fresh shucked meats to prevent floating or contamination by intermediate handlers. Containers of fresh shucked oyster meats are shipped in crushed ice to the sales outlet and must be kept chilled to at least 34°F. Maximum storage life of chilled meats is about 16 days. Meats in metal containers for long storage are sharp frozen and stored at −5°F.

A comparatively new oyster product is the fresh oyster meats, breaded and packed into five or ten pound cartons for institutional and restaurant use. For the retail trade the 10 to 14 ounce carton is used. These breaded meats are frozen and individual meats may be removed as desired and the package returned to the freezer.

Another frozen oyster product recently developed is oyster stew. Freshly opened oyster meats are sliced or diced and, with other ingredients such as salt, pepper, milk, and monosodium glutamate are packed into 201 × 400 containers and sharp frozen. Oysters have also found a place among the array of precooked foods available on the market. Oysters are breaded, deep fat-fried, cartoned, and frozen and need only reheating in the oven to be ready for the table. Canned whole oysters and oyster stew are also prepared from steam-opened oysters. Shell stock is first washed and then passed through a steam retort for about ten minutes at low pressure The shells gape open and the meats are easily removed. After washing, the meats are graded for size. If to be packed as whole oysters, the meats and oyster juice or brine are packed into the 201 × 400 can and sterilized in the retort. Meats diced, sliced, and packed with milk, butter, salt, and MSG produce a ready-made oyster stew, needing only reheating for table use. The 401 × 700 can is used for a product known as stew base. Stew base is sliced or diced oyster meats with oyster juice, salt, and MSG added. Restaurants and institutions need only add milk and butter to serve as oyster stew. For the retail trade oyster stew is marketed in the 201 × 400 size container. Oysters, smoked and packed with vegetable oil, are marketed in the $3\frac{3}{4}$ ounce glass jar or in the 301 × 106 metal container and also in the regular sardine rectangular can.

By-Products. Oyster shells are an important source of poultry lime supplement and, when ground to a flour, are a supplement to stock feed. In some areas where shells are plentiful, especially in the Gulf states, oyster shells have been an important road building material. Oyster growers return empty, clean shells to the beds in large quantities as a "cultch" to collect young oyster spat.

Composition. Oysters have considerable value from a dietary standpoint. They contain glycogen, are low in fat, and are high in minerals needed by the body.

Typical Analysis:

Protein	7 %	Glycogen, varies from 3% to 22%	
Carbohydrate	3.2%	Copper	7 ppm
Ash	2.1%	Iron	160 ppm
		Zinc	60 ppm

Importance of the Industry. In 1959 the United States oyster fishery produced 64,710,000 pounds having a value of $29,483,000[2]. Of this production, 60 per cent were taken on the Atlantic Coast, principally in Chesapeake Bay; 21 per cent in the Gulf of Mexico area; and 19 per cent on the Pacific Coast, principally in Washington.

The Clam Fishery

Like the oyster, the clam was an important source of food for the early-day colonists on the Atlantic Coast. Vast beds of various species were available at low tide for the taking, and the saying that "when the tide was out the table was set" had real meaning for those struggling to get a foothold in a new land. As the years passed, the clam, which at first was only an article of local trade, became of increasing importance, first as a bait for other species of sea foods and, as transportation improved, as an item of trade with areas removed from the sea coast. Today with high speed transportation and refrigeration, the clam and its products are available in all parts of the country. Clam bakes, in which clams with vegetables were baked in pits lined with hot stones, probably originated with the Indians. This manner of preparing the bivalve is still a popular attraction with tourists and picnic parties.

As is usual with a new and apparently unlimited resource, the clam industry suffered from overfishing and the beds began to decline in productivity. To save the industry from extinction, studies undertaken led to the establishment of clam farms. As the farms proved successful the numbers of farmed beds increased and in some areas the clam farms are an important source of supply.

Clams are found all along the Atlantic Coast from Maine to Mexico. Some species, such as *Mya arenaria,* are found in limited quantities as far north as the Arctic regions. The most intensive clam fisheries are concentrated in Maine, Massachusetts, and especially New Jersey, although the industry is of importance in all other Atlantic Coast states. North of New York the soft clam, *Mya arenaria,* is of particular importance. Farther south the hard clam, *Venus mercenaria,* is the basis of the industry. Other species such as the surf clam, *Spisula solidissima,* and the ocean or deep water quahog, *Arctica islandica,* are important commercially. The latter species is found in water up to 20 fathoms in depth and is taken only by dredges. The quahog now supplies a considerable portion of the minced meat used in canned clam chowders.

On the Pacific Coast, clams are found from Alaska to Mexico. The clam *Siliqua patula,* called "razor" clam because of the long shell, is in demand as a fresh and canned product. Since its habitat is on exposed sandy beaches having active surf action, the razor clam has become a great attraction for the summer tourists. Although regulations limit the number of clams each digger may take on a tide to save the species from overfishing, many millions of these clams are taken yearly. Other species of importance are the *Tivela stultorum,* the Pismo clam of California; the little neck clam, *Protothaca staminea;* and the butter clam, *Saxidomus nuttalli,* of the Oregon, Washington, and northern coast to Alaska. The eastern soft shell clam, *Mya arenaria,* has been introduced to the West Coast probably with eastern oyster seed shipments.

One peculiar clam of no commercial importance is the giant geoduck clam, *Panope generosa.* This species is found only in limited areas in Puget Sound. Although the clam is buried to a depth of two or three feet, the siphon is capable of reaching to the surface of the ground. Individuals have been found that weighed seven to eight pounds. The geoduck is highly regarded as a food clam but the take is rigidly restricted due to its limited numbers and areas in which it is found. The world's largest clam is found in the South Seas. *Tridacna gigas* may have a shell weighing 500 pounds and containing 20 pounds of meat.

The clam, like the oyster, is a bivalve mollusc. Unlike the oyster, the clam does not live out its life on the surface of the ground but spends its life buried in the sand and mud, usually a few inches beneath the surface. To feed, the clam extends to the surface a tubelike appendage, the siphon, which contains two passages, the in-current canal which conveys the food-ladened water to the organism below and the out-current canal which discharges the water strained of food and containing waste products. When the clam is disturbed, the siphon may be quickly withdrawn from the surface and into the shell for safety.

Harvesting. For large scale operations power-driven dredges similar to oyster dredges are used. In some cases the clams are pumped aboard the vessel with water as they are picked up by the dredge.

The aborigines and early settlers harvested clams by the primitive method of "treading," that is, by wading in the shallow water and feeling for the clams with their bare feet. Where the beds are exposed between tides, the clams may be located by the siphon holes in the sand and the clams dug with a shovel. This is the method used on the Pacific Coast where the long run-out tides may expose large areas of the clam beds.

On the East Coast, where the beds may not be exposed, other means are used to take the clams. Tongs similar to oyster tongs and having handles 14 to 16 feet long are used by operators on skiffs or bateaus. Also a "basket rake," similar to the tongs but having teeth about 10 inches long, is employed. Back of the rake head is a bag formed of wire mesh which will catch and hold the clams as it is dragged along the bottom. Both tongs and rake are operated from a barge or anchored skiff. The basket rake has a handle sometimes 25 feet long with a "T" head. A man standing on a skiff drops the basket rake overboard and by means of the "T" handle drags the rake towards the skiff and hoists it aboard, dumping the clams which are retained in the basket.

Processing. For market the clams must be washed free of adhering sand and silt and be graded for size. If market conditions are not favorable, the clams may be rebedded in shallow water until conditions improve. Sink floats or live boxes may also be used for a short-time storage. Live boxes may be constructed by using two parallel logs with a slat container resting between them. The water flowing back and forth between the slats serves to cleanse the clams of sand and to wash silt out of the siphons. In some cases shell stock may be given a short-time storage in water treated with chlorine to free the clams from harmful bacteria.

Clam meats may be canned as whole meats or as minced clams with juice. The clam juice has a pleasing flavor and is quite nutritious. Any excess of that needed for canning is bottled and sold as "clam nectar." Clam chowder is another popular canned product. The ingredients vary with the section of the country where it is prepared, but it usually contains bacon, potatoes, onions, tomatoes, parsley, thyme, marjoram, salt, pepper, and, if properly made, plenty of clams. All or a portion of these ingredients may be used, depending upon the preference of the trade. Cans used for the steam-canned product range from the No. one tall salmon can to the No. one picnic or eastern oyster can. For minced clam products, the one-half pound flat can is popular. Small amounts of clams are pickled, salted, smoked, or dried.

On the Pacific Coast the razor clam is in demand as a fresh market item and as a canned, minced product. The bulk of the canned pack is now produced in Alaska where the beds have been subject to less intensive fishing than those farther south. The clams are washed free of sand and passed through a steam box having a reciprocating mesh-covered screen. The reciprocating motion of the screen keeps the clams moving forward and the meats are steamed loose from the shells. As the clams are discharged at the end of the steam box, a blast of air at right angles to the direction of travel of the conveyor blows the shells aside into the waste conveyor. Razor clam shells are much lighter in proportion to the total weight than other species and may be easily diverted by the air blast. The meats pass on to other workers who clip off the dark ends of the siphon tips and slit the siphons to wash out the sand and silt and separate the visceral parts. Meats go through a grinder and are filled mechanically into the cans. A small portion of the pack is put up as whole clams.

The composition of clam meats for the eastern species is:

Protein	9 %	Carbohydrate	5.2%
Fat	1 %	Minerals	2 %
Moisture	8.8%	Shell waste (quahog)	67.5%

Importance of the Industry. In 1959 the United States clam fishery produced 44,995,000 pounds, having a value of $11,594,000. Nearly 80 per cent of this quantity was produced in the Middle Atlantic and Chesapeake Bay areas, 16 per cent in New England, and 3 per cent on the Pacific Coast.

The Scallop Fishery

Primitive peoples have long appreciated the scallop, not only for its excellent food value but also for the beauty of the shell. Scallop shells have served a utilitarian purpose as money, as a trade item with tribes far from the coast, and as a source of material for many beautiful ornaments. The early colonists to the New England shores were apparently unfamiliar with this bivalve and used it only as a fertilizer. When its food value became known, the scallop industry developed to the point where the bivalve in some areas was in danger of extinction.

Scallops are found all the way along the Atlantic Coast from Maine to the Gulf of Mexico. The industry, however, is centered in the area from Maine to New York. The greatest scallop beds known are the Georges Banks which lie directly east of Massachusetts. Several species of scallops are present on the Pacific Coast, but the industry has not developed to any great importance.

The scallop is a bivalve mollusc, as are the oyster and the clam. Unlike the oyster and the clam, the scallop has the ability to move about quite freely or to remain attached in one place. Scallops belong to the family Pectenidae, which includes about 40 species. Only two or three species are of commercial importance on the Atlantic Coast—the shallow water scallop, *Pecten gibbus* or *P. irradians*, and the giant deep water scallop, *Placopecten megellanicus*. The latter species is found in waters up to 150 fathoms in depth.

Harvesting. To protect the industry from overfishing, a closed season has been established in some areas through the spawning season, usually from about April to October. Bay or shallow water scallops were formerly taken largely by a device known as a "pusher." This is simply a long handle fitted on the end with an 18 × 36 inch frame having a web bag attached. The operator wades in the shallow water pushing the device ahead of him. As the scallops rise from the bottom they are caught in the bag. Most hand methods have now been replaced by dredges towed by power boats. A single power boat may handle several dredges which are dragged on the bottom and lifted alternately. The contents are dumped onto the culling or sorting board where the marketable scallops are separated from the trash.

Processing. Scallops are shucked on board the vessel and the large adductor muscle, commonly known as the "eye," is removed. This is the only portion of the scallop marketed for food in this country. The remaining portions are generally discarded. About 15 bushels of sea scallops will produce ten gallons of adductor muscles or meats. The meats are packed in muslin bags holding about 3½ gallons each, and the bags are packed in containers with crushed ice. Bay scallops are smaller than sea scallops, and the smaller meats are sometimes plumped in water, which increases the volume about 40 per cent. The plumped meats will not stand prolonged shipment and sales outlets are limited to nearby market areas. Scallops for inland markets are frozen commonly in the five and ten pound cartons and the 603 × 812 metal can. For retail trade the family size 12 and 14 ounce cartons are common in the chilled display cases. Frozen scallops are also marketed in the breaded form, both as the raw and precooked product.

By-Products. Only about ten per cent of the whole scallop is used for food. The remainder may be salted or frozen for use as fish bait, or used as fertilizer, but is more commouly discarded at sea. The lower shell is used for ornamental purposes and in the manufacture of souvenirs.

Composition. The chemical composition of scallops averages about as follows:

Water	80.3%	Carbohydrate	3.4%
Protein	14.8%	Ash	1.4%
Fat	0.1%		

The above analysis is on the basis of the whole meat in the scallop, whereas only the adductor muscle is eaten.

Importance of the Industry. The United States scallop industry for 1959 produced 25,800,000 pounds having a value of $12,960,000. About 80 per cent of this production was in the New England states.

The Abalone Fishery

The name "abalone" is a Spanish word of unknown origin. The organism is a marine snail having only one shell and a large flexible foot which can attach firmly to a hard, smooth surface. The abalone is confined to the Pacific Coast where it is found from Mexico to Alaska. The Alaskan species is much smaller and the shell darker than the southern variety. The early aboriginal inhabitants of the California coast used the abalones as a staple article of food. The Chinese who came to this coast in the gold rush days recognized the food value of the abalones and engaged in drying and smoking them for export to Hawaii and China.

The abalone is a univalve, or one-shelled organism, belonging to the genus *Haliotis*. Six species are found on the Pacific Coast, only three of which are of commercial importance—*H. splendens*, *H. ruffescens*, and *H. cracherodii*. The habitat of the abalone extends from shallow water to a depth of several fathoms.

Harvesting. Abalones can best be harvested by divers. While some harvesting can be carried on in shallow water by wading, the bulk of the commercial take is by divers working from boats. Divers, using regular diving gear, free the abalones from the rocks by quickly slipping a chisel-like tool beneath the foot of the abalone and suddenly prying it loose. If alerted to danger, the suction foot will adhere so firmly to the rock that it is difficult to dislodge the organism. Abalones, as collected, are placed in a basket suspended from the boat above, which follows the line of bubbles as the diver moves about. To protect the abalones during the spawning season, fishing is prohibited from January 15 to March 15 in California which is the principal producing area.

Processing. As a fresh product, the abalone is considered a rare delicacy. The large central muscle, which is also the foot of the organism, is cut from the visceral mass and then cut into slices which may be used as steaks or minced for chowder. When used as steaks, the slices are pounded to produce a more tender texture. The juice is retained for use in soups and bouillon. For the oriental trade the muscle as well as other parts of the flesh are used as a dried product. The meats are first brined, precooked, and dried in the sun four or five days. They are then regathered and given a final cook, smoked, and again dried for about six weeks. This process reduces the original weight by about 90 per cent. The resulting hard, brown product may be sliced and crumbled for use in soups and other dishes. Abalones for drying and canning purposes are imported from Mexico as California law restricts locally-caught abalones to the fresh market. The steam-canned product may be either minced or diced.

By-Products. The beautiful shells have a considerable commercial value. Large numbers are sold as souvenirs. The mother-of-pearl lining of the shell is used for buttons, ornamental handles, and for inlay purposes. Pearls have been found in abalones.

Importance of the Industry. In 1959 the fishery had a production of 912,000 pounds and a value of $497,000 in the United States.

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CHAPTER 14

The Crab and Lobster Fisheries

JOHN A. DASSOW

The commercial species of crabs and lobsters belong to the Decapoda (ten-footed Crustacea) order which includes the most highly organized crustaceans from both the biological and the gastronomical viewpoint. Much experience and study has been devoted to the special problems of harvesting, holding, and shipping the highly perishable crab and lobster. In the Atlantic blue crab fishery, the market for fresh crabs and crab meat is of greatest significance. King crab processors in Alaska, on the other hand, have had to apply modern techniques of freezing or canning in order to provide the consumer, three to four thousand miles from the fishing areas, with a product of high quality. The American lobster industry still depends largely on shipment of the live lobsters to meet market demand.

The relative importance and value of both the catch and manufactured products for the species of crabs and lobsters are shown in Table 14.1. In some species, e.g. lobsters, the import volume (Table 14.1, column 4) constitutes an important fraction of the total domestic supply.

General Characteristics

The crab and lobster fisheries share a number of species characteristics that provide a simplicity of processing operations for the fresh products. In processing frozen and canned products, however, technological problems not found in other major fisheries are encountered.

Biological Factors. Common factors in the biology of the decapod crustaceans should be considered before we look at the particular industry characteristics.

TABLE 14.1. SUPPLY OF CRABS AND LOBSTERS IN 1960, AND MANUFACTURED PRODUCTS[16]

	Catch	Value	Import	Manufactured Products			
				Fresh & Frozen	Frozen Specialties	Canned, Standard Cases[e]	Total Value Mfd Products
	1,000 lb	$1,000	1,000 lb	1,000 lb	1,000 lb		$1,000
Crab							
Blue	149,646	7,810		15,356	7,422	62,137[c]	22,940
Blue, soft and peeler	5,051	1,366					
Dungeness	36,157	5,333		4,877	18[a]	56,672	6,358
King	28,570	2,286		1,593	586[a]	100,105	4,846
Misc (rock, stone)	2,149	259			20[b]		14
Total for all species	221,681	17,068	5,607[f]	21,826	8,046	218,914	34,158
Lobster, northern	31,168	14,251	23,809[f]	975	177	7,516[d]	3,271
Lobster, spiny	3,210	1,344	32,879[f]		1,075		609

[a] Frozen sections in shell.
[b] Stone crab, frozen claws. Rock crab products are included under blue crab.
[c] Includes 7,895 cases of canned specialties.
[d] Includes canned meat and specialties.
[e] "Standard cases" represent the various size cases converted to the equivalent of 48 cans to the case, each can containing 6½ ounces.
[f] Imports include 4,507,000 pounds canned crab, 2,406,000 pounds canned lobster, 533,000 pounds canned spiny lobster. Balance represents fresh or frozen import quantity.

Exoskeleton. This is a flexible substance composed of the carbohydrate chitin which is reinforced and hardened with calcium salts after each growth molt. The molt cycle produces physiological characteristics of special significance. For example, immediately following the molt, the crab is in a soft shell stage and quite helpless—also in the case of blue crab quite edible. Before the shell hardens it must be enlarged to allow for new growth; therefore, the tissues of the body become engorged with water and expand up to 15 to 20 per cent by volume. Crab taken at this time for commercial purposes tend to be watery, poor in texture, and low in per cent yield of meat per pound of live crabs. Since the molting cycle relates to the mating process, conservation regulations usually set commercial seasons in relation to the cycle.

Distribution. Crabs maintain a close relation to the coast line and bays with relatively smooth shallow bottoms and tend to move laterally from shallow to deeper water and back during the seasonal cycle. Movement along the coast is not significant in most fishery areas. Lobsters have a similar distribution except that rocky bottoms are preferred for the greater abundance of the food supply and the natural protection provided from predators. This distribution encourages the development of a local inshore fishery with a wide variety of gear to suit individual conditions.

Appendages. The degree of segmentation and the development of the appendages for walking, swimming, or grasping show a considerable variation in crabs and lobsters. These natural anatomical divisions control the amount, yield, and edible characteristics of the individual meat sections.

Respiration and Circulation. In crabs and lobsters, as in most Crustacea, the oxygen-carrying pigment in the blood is a copper hemocyanin rather than an iron hemocyanin. The blood is relatively colorless but leads to objectionable discoloration in processing because of the facility with which the copper compound forms light blue to blue-black complexes. A related feature in the circulation of crabs and lobsters is the absence (or vagueness) of blood vessels in the peripheral areas. The blood circulates in sinuses of poorly defined structure. Part of the problem in holding crabs in good condition before processing lies in the general perfusion of the tissues with the blood and the difficulty of bleeding the animal before death. Some of these problems and possible solutions in processing Dungeness crab (*Cancer magister*) have been discussed by Farber[9] and Elliot and Harvey[7].

Live-holding Requirements. In earlier years of the Pacific crab fishery, the fishermen and processors often held the crabs out of water. Processors recognized that when the crabs died before butchering, adverse quality changes took place. Even if the crabs were still (but barely) alive when butchered, discoloration, chalky texture, and poor keeping quality of the meat were frequently a result. Recognition of the need for maintaining the crabs in a vigorous healthy condition until butchering has brought general acceptance of live wells for holding the crabs in circulating sea water on the vessel and ashore prior to processing.

Holding pounds have been used in the lobster fishery of Maine for more than 60 years[6] and provide facilities for long holding or conditioning periods in order that lobsters can be marketed to the best advantage. Blue crabs ready to molt are commonly held in floats in order that the soft-shell crab can be harvested after the molt.

Preliminary Process Requirements. In contrast to shrimps, crabs and lobsters must be given a water or steam precook to firm the meat and to allow ease of removal from the shell. If raw crabs or lobsters are frozen, the meat is most difficult to remove from the shell after being thawed and cooked. Indeed, the meat appears to be glued to the shell. In some instances a minimum precook or blanch has been tried; however, a complete cook is almost invariably used for marketing the crab in the shell or for subsequent meat processing. Although the obvious changes in crab meat during cooking suggest that the meat shrinks in weight, loses water, and increases in total solids content, recent studies on composition of raw and Dungeness crab indicate no marked change in composition resulting from cooking.

Food Value of Crabs and Lobsters. Cooked or canned crab and lobster meat are moderately high in protein, 18 to 20 per cent, and total minerals, 1.7 to 2.7 per cent ash, and quite low in oil content. A food energy value around 90 calories per 100 gm (about 3.5 ounce) suggests that crab and lobster meat can provide variety in a low calorie diet. Little carbohydrate, less than one per cent, appears in analysis by difference. The variable and rather high values for sodium, 350 to over 1000 mg per 100 gm, reflect the variation in the uptake of salt during brine treatment of the meat in the plant. Data indicate that crab and lobster meat are a reasonably good source for minerals and trace elements. Seagran[18] showed that in raw king crab meat over 24 per cent of the total nitrogen fraction proved to be non-protein nitrogen, thus indicating a possible source of error in calculating protein values.

The Crab Fisheries

Three species of crabs dominate the fisheries. The Atlantic coast blue crab (*Callinectes sapidus*) contributes the largest share. The Dungeness crab (*Cancer magister*) and the king crab (*Paralithodes camschatica*) of the Pacific coast and Alaska have each provided approximately 15 to 20 per cent of the total catch during the last few years; however, the Alaska king crab catch has shown increasing strength. In 1961 the king crab catch exceeded the Dungeness crab for the first time. Minor species of crab include the rock crab (*Cancer irroratus*) of New England, another rock crab (*Cancer species*) of California, and the stone crab (*Menippe mercenaria*) of the Florida coast.

The major portion of the crab catch is harvested by means of pots, although a substantial part of the blue crab catch depends on trot lines with baits, dredges, and otter trawls. Otter trawls are used also for a small part of the king crab production.

Blue Crab. The blue crab (*Callinectes sapidus*) is a small but very important market crab from 2½ to 7 inches in width across the carapace. It is easily distinguished by its blue and green colors and the spikes on each end of the shell. The range of the blue crab is along the Atlantic coast from New Jersey to the northern part of South America. It prefers the shallow salt water with low salinity in bays, sounds, and river channels; however, the female seeks the deeper water offshore during the winter season. The blue crab spawns in the summer and reaches full growth and maturity during the second summer when 12 to 14 months old[21]. During this period the growing crab molts frequently, about 15 times before maturity. Large numbers of the young crabs are sought in the spring and summer to provide the peeler crabs which in turn are held for the emergence of the soft-shell crab. The diet of the blue crab includes both fresh and decaying fish or meat; hence it readily takes bait in many forms.

Historically it appears that the blue crab fishery was first established about 1878 in Norfolk, Virginia, where the fishery is still of major importance. The production and marketing of the fresh, chilled meat was developed in the early years and continues to be a primary factor in the industry to the present date. Attempts to increase the storage life of the fresh meat without changing its desirable characteristics were not successful until the development of the low temperature pasteurization technique[1] in 1941, which was later patented[2]. In 1960 the blue crab production accounted for about 70 per cent of the total crab catch of 221 million pounds and over 50 per cent of the total catch value of 17 million dollars.

Fishery Methods. Methods and gear for harvesting the blue crab are of considerable diversity, as might be expected from the complex life history and wide range of the species. Various types of gear include dip nets, push nets, scrapes, fykes, haul seines, pots, dredges, and trotlines[22]. In 1960[16] 60 per cent of the catch was produced by pots, 20 per cent by trotlines with bait, 7 per cent by dredges, and about 7 per cent by otter trawls. Scrapes and trotlines were important for soft and peeler crab production, producing about half of the five million pound catch. In 1959 an industry survey report[20] showed a total of 158 blue crab plants in nine eastern and Gulf states. Maryland and Virginia showed the greatest crab output because of the Chesapeake Bay production, which has accounted for approximately two-thirds of the United States blue crab production during the past ten years.

Soft-shell Crab. The peeler crabs are retained in wood floats until one to two hours after the crabs shed. The crabs must be carefully watched to ensure that they are removed from the water after the shell has hardened sufficiently to provide a firm skin for shipment, yet be of proper softness for consumption. The hardening process is suspended when the crabs are removed from the water. At that point they can be shipped to market alive by packing carefully in shallow trays with parchment and crushed ice. The whole or cleaned soft-shell crabs can be frozen successfully by wrapping individually, placing in cartons, and quick freezing.

Fresh and Frozen Blue Crab. Almost all blue crab meat is marketed as fresh chilled or pasteurized chilled meat. The crabs are delivered alive to the plant and are cooked whole by steaming in a large pressure cooker at five to fifteen pounds of steam pressure. The cooking consolidates the meat so that picking is facilitated, reduces the bacterial contamination, and produces the typical crab flavor. Ulmer, *et al.*[20], concluded, after studies of the cooking methods, that pressure cooking the crabs at 250°F (15 psi) for eight to ten minutes produced higher yield than crabs cooked for shorter or longer periods; however, boiling in water for ten to fifteen minutes resulted in a superior yield and flavor compared to that obtained by steaming. The study further showed that refrigeration of the crabs and good sanitation in the post-cook handling were of greatest importance in the improvement of the product. The pasteurization process, by which the internal temperature of the meat was raised to 170°F for one

Figure 14.1. Picking the meat from blue crab in an East coast plant. (*U.S. Fish and Wildlife Service.*)

minute, extended the limited storage life of the fresh meat to six months at 33 to 38°F[12].

In picking the meat (Figure 14.1), the crabs are allowed to cool and the worker removes the back shell, legs, claws and viscera. The meat is picked from the shell with a small, sharp knife and graded according to size and style. The usual styles are: (1) backfin lump, the highest quality consisting of the unbroken muscle lump; (2) special body meat topped with broken lump; (3) regular, small body meat; (4) claw meat, the lowest priced. The meat is usually packed in one pound cans and iced for shipment. Pickers can produce up to five or six pounds of meat per hour.

Current developments and the economic need for increasing production efficiency of the plants favor the introduction of mechanization to a significant extent for handling, picking, and packing the meat.

Frozen blue crab meat is not considered satisfactory from the standpoint of quality and storage life; therefore, the production is minor. The meat tends to become spongy and fibrous in texture very shortly after storing of the frozen product, and the delicate flavor of the fresh product

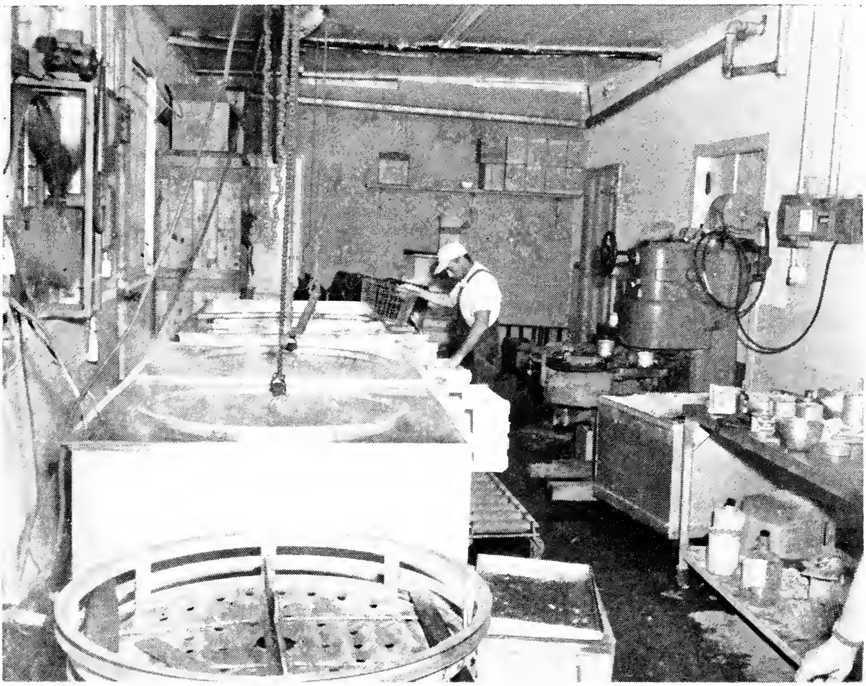

Figure 14.2. Pasteurization of blue crab meat in an East coast plant. Open tanks can be used since the cans of crab meat are pasteurized at a temperature well below the boiling point of water. The tanks in the background are used to cool the cans. (*U.S. Fish and Wildlife Service.*)

is soon lost. Because of these changes, frozen blue crab meat can only be successfully stored for a few weeks, generally not over one month, at 0°F in commercial practice.

Canned Blue Crab. A relatively small proportion of the blue crab catch is canned, owing to the high costs of picking such small crab and canning in competition with much larger species such as Dungeness crab. In addition, there is a ready and closer market for the fresh and pasteurized chilled meat. An objectionable bluish discoloration of the meat in the can frequently develops from the interaction of the copper pigments (hemocyanin) in the crab blood with the ammonia and sulfur compounds formed from the breakdown of part of the protein during heat processing. A patented process[10] minimizes the discoloration, improves the product quality, and forms the basis for the canning of blue crabs in the Chesapeake area. Citric acid is used to adjust the pH of the meat on the acid side to minimize the discoloration reaction. Either aluminum or zinc sulfate (not over 0.04 per cent) is added for further protection against formation of colored complex salts.

The inspected meat is dipped in one per cent brine with the above additives, drained, and filled into C-enamel (seafood formula) cans. The cans are vacuum sealed by use of an exhaust box or vacuum closing machine and in common practice are retorted 30 minutes at 250°F for a 6½ ounce can. As in the case of processing other crabs, it is essential in handling blue crab meat that all catalytic metals such as iron and copper be eliminated from the production line, preferably by substitution of stainless steel or other noncorrosive materials.

Dungeness Crab. The Dungeness crab (*Cancer magister*) is distributed from the coastal waters of northern California northward along the Pacific coast to the central coast of Alaska. Generally, the season in Washington, Oregon, and California is early winter to late spring. In Alaska the different timing of the molting cycle provides a season from late spring to fall.

Fishery Methods. The Dungeness crab is much larger than the blue crab, usually weighing from two to three pounds, and it has a carapace width of from eight to nine inches. It is caught almost entirely in circular-type metal pots designed for stability in use on the open ocean bottom. Some rectangular pots are used, also ring nets in some locations where there is little current action. No other type of gear is legalized by the Pacific Coast states.

The circular pot is about 42 inches in diameter and 14 inches deep and has two entrance tunnels. A metal or plastic container is hung inside the pot with bait of clams or fish heads. After the fisherman hauls up each pot, he empties it, sorts the crab rapidly, and rebaits the pot ready for use. Legal males in good condition are placed in the live well in circulating sea water. Boats fishing close to the plant may simply store the crabs in boxes on deck.

At the dock, either the crabs can be held for a few days in the vessel's well or they are transferred to live floats off the dock or to live tanks on the dock. In some areas the pollution of harbor water makes it unwise to leave live crabs in dock floats or tanks, and it is necessary to use a storage float in unpolluted water some distance from the plant.

Fresh and Frozen Dungeness Crab. The restaurants are a major factor in the demand for fresh crabs, although many retail food stores in the coastal areas market them when available. During periods of shortage, or in the off-season, the demand for "fresh" crab may be met by marketing the thawed product. In one study[3], the keeping quality of commercial Dungeness crab meat from different plants varied from two to eighteen

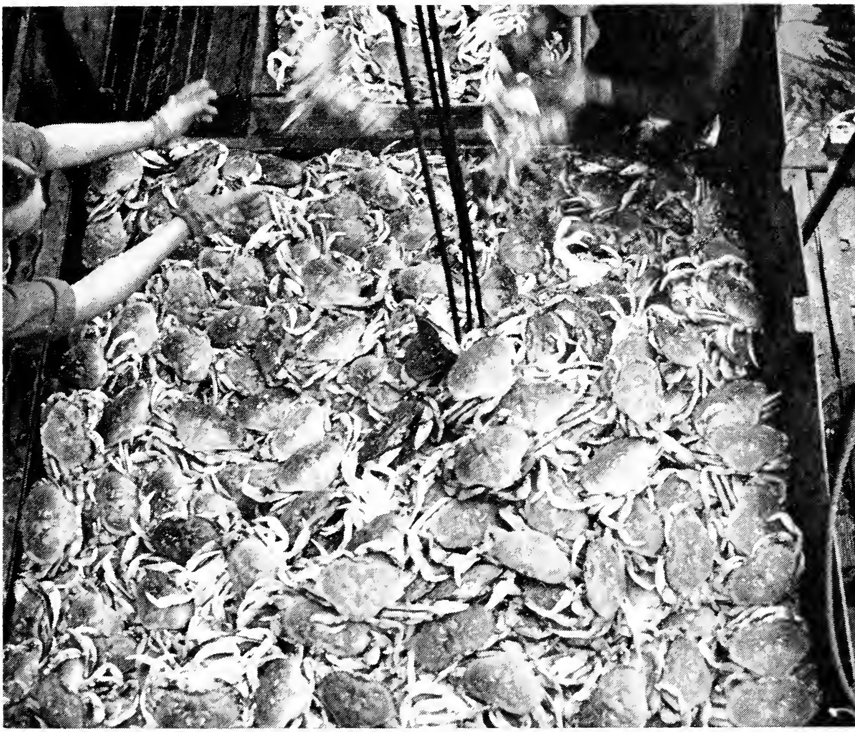

Figure 14.3. Unloading live Dungeness crab from the live well of the fishing vessel. The bottom of the well is lifted in order to raise the crabs to the top of the tank for unloading by hand. (*U.S. Fish and Wildlife Service.*)

days at 40°F, although seven days appeared to be the average period for most lots.

The methods for preliminary preparation of the crab and recovery of the meat are similar for fresh, frozen, and canned products[11]. The live crabs are butchered by removing the carapace with the use of a fixed blade, breaking the crab in half with five legs on each side, and removing the gills and visceral parts. The crab halves or sections are cooked most commonly in boiling fresh water for ten to twelve minutes, then cooled briefly in cold water before transfer to the shaking table. The body and leg meats are removed by breaking away parts of the shell and shaking the meat with a vigorous motion into aluminum or stainless steel baskets. The body meats, and sometimes the leg meats, are dumped into a tank of strong sodium chloride brine (90 to 100° salinometer) in which the shell fragments sink to the bottom. The meat is then conveyed through a fresh water spray which removes excess salt and debris, inspected, placed in aluminum or stainless steel baskets, and is then ready for packaging or canning. Some processors provide an additional step of dipping the meat into dilute solutions of citric acid (0.5 to 1.0 per cent) and/or sodium benzoate (regulation allows no more than 0.1 per cent in the meat) for preservation. Fresh meat is usually packed into No. ten C-enamel cans holding five pounds of meat, sealed, and stored at 32 to 40°F.

Whole and eviscerated crabs are cooked, washed, inspected for uniformity, and packed in crushed ice for shipment to the fresh market. In recent years small lots of crabs in the shell have been frozen by immersing in refrigerated brine at 0 to 5°F for 20 minutes, packaged or ice glazed, and stored at 0°F. The product should not be held for more than a few months under ordinary cold storage conditions because the meat tends to lose its tender texture and delicate flavor. Use of improved packaging to reduce moisture loss and lower storage temperatures (−10 to −20°F) will extend the keeping quality.

The greatest volume of crab meat is frozen and stored in hermetically sealed cans. Dungeness crab meat that has been carefully prepared and packed in the one or five pound cans can be stored for six months at 0°F with no marked quality change. For periods longer than six months the use of vacuum packaging to remove oxygen, the addition of a dilute salt solution (not over two per cent by weight), and storage at −10°F is recommended.

Canned Dungeness Crab. The inspected meat is removed to a separate packing area for canning where the meat is packed into half pound C-enamel cans holding 6.5 ounces of meat. Leg meat is the most desirable and is packed at the ends or, in some cases, on the top only. Body meat or leg meat portions are packed in the middle. About $\frac{2}{3}$ ounce of dilute salt solution and citric acid is added to provide about 1.5 per cent salt for flavor and a pH in the final product of 6.6 to 6.8 to minimize iron sulfide discoloration. The cans are vacuum sealed, heat-processed at 240°F for 60 minutes (the processing conditions vary but this is the recommended time and temperature), cooled immediately after retorting to just above room temperature with fresh water, and allowed to dry before casing or labeling.

In order to produce a uniform, high quality of canned Dungeness crab, it is essential that great care be used in washing and handling the meat to remove blood, bits of viscera, shell, and debris. At the same time, speed in process steps is essential so that the meat is exposed to air, warm temperatures, and contamination for a minimum period of time. In recent years the production of canned Dungeness crab meat has declined because of the increasing demand for the fresh and frozen products, and the competition from imported canned crab meat.

King Crab. The king crab (*Paralithodes camschatica*) is a giant among the edible crab species, weighing as much as 24 pounds and spanning up to 5 feet from tip to tip of outstretched legs. It lives on the bottom in the cold waters of central and western Alaska, extending from the end of its range off southeastern Alaska to Prince William Sound, Kodiak Island, and out along the Aleutians and into the Bering Sea. Before 1940, American operations for king crab were on a minor scale and Americans were most familiar with the Japanese canned king crab meat.

Following World War II, American fishermen and industry investigated the king crab potential on a commercial scale[8]. In little more than a decade, vessel and shore operations in Alaska for the production of the frozen and canned king crab have expanded to produce a 1961 catch of 43 million pounds and 151,000 cases of the canned product[17].

Fishery Methods. King crab are harvested almost entirely with large pots because of the conservation regulations in Alaska that prohibit the use of otter trawls in certain state waters. Pots are limited to a total of 30 per fishing vessel, but the large size of the king crab pots and their adaptability to the variety of fishing conditions have resulted in a high level of productivity.

Conservation regulations forbid the taking of females and any male less than 6½ inches carapace width. Mutilated and dead crabs are discarded. The crabs are held in the live well in circulating sea water aboard the boat, but occasionally inshore boats will bring in the crabs as a deck load. Fishery seasons and areas are determined in part by conservation regulations and partly by the quality and yield of the crabs.

Canned King Crab. Process requirements include the use of only prime, healthy crabs for butchering, prompt cooking, thorough washing and chilling of the meat before packing in the cans, and addition of salt for flavor and citric acid solution for control of pH in the canned product[5]. In recent years, various methods for precook and meat recovery have been developed. Some processors use a single batch cook of 20 to 22 minutes in water at 212°F prior to squeezing or blowing the meat from the shell. Others favor the use of a two-cook process in which the butchered crab sections are given a low temperature cook at 160 to 165°F for ten minutes in fresh water.

Sections, while still warm, are then put through rubber rollers, similar to a wringer, which provide a squeezing action that breaks the shell just enough to force out the meat, leaving only the shell to proceed through the rollers. The meat is washed, inspected, and passed into a second cooker of the continuous type. The meats pass through a boiling, dilute brine for about four minutes, depending on the skrinkage desired for proper fill in the cans. The meats are then spray-washed, inspected, and passed to the packing table.

Figure 14.4. A tank with live king crab awaiting processing at an Alaskan plant. Note the crab pots at the left background. (*U.S. Fish and Wildlife Service.*)

Some packers have found that an ultraviolet light is valuable to detect shell fragments by the resulting flourescence. Packers cut the large leg sections to fit the can and fill most packs with one layer of leg meat, followed by smaller leg sections and shoulder meat. Parchment paper ends are commonly inserted to minimize possible tin-plate discoloration.

Use of small retorts for frequent process-cooks is desirable and used by most packers. The retort time and temperature most commonly accepted by the industry is 55 minutes at 240°F, followed by water cooling until the cans are slightly above room temperature. A final meat pH of 6.6 to 6.8 is desirable. Canned king crab meat, in common with other canned crab and lobster meat, should be stored at a relatively cool storage temperature to minimize color and flavor changes. Packs are marketed preferably within one or two years for best quality.

Frozen King Crab. King crab meat is much more suitable for freezing and storage than other species of crab, and experimental and commercial packs have been stored for one year at 0°F with good acceptability. Important factors in attaining good keeping quality of the frozen meat are: high quality of the initial meat, careful packaging to avoid air spaces within the package, use of a good moisture vapor-proof packaging material, and storage at a uniform temperature of 0°F or lower[5]. Experimental samples stored at −20°F, in comparison with samples at 0°F, demonstrated improved flavor retention, whereas samples stored for a few months at 10°F showed development of straw-like off-flavors and loss of the normal delicate flavor.

Preparation of the meat for freezing is similar to canning. Following the cook, the meat is preferably chilled before squeezing or blowing the meat from the shell. The prompt chilling of the meat is important in minimizing breakage of the meats. King crab meat is usually frozen as a large block. One common size block incorporates 250 ounces of crab meat and 24 ounces of fresh water to fill the voids. The blocks are inspected and packaged in a suitable film and waxboard carton. After freezing, the block is glazed and shipped for later sawing into consumer-size blocks. Restaurant and institutional needs are easily met by the subdivision of the large blocks into 1 or 2½ pound units. The development of this flexible and efficient frozen block of king crab meat has been a key factor in the expansion of the frozen king crab industry.

To provide frozen king crab in the shell, the cooked, butchered sections are chilled, thoroughly washed and scrubbed, trimmed, and segregated into uniform ten-pound lots. After freezing and glazing, the large cartons are ready for shipment to restaurants or may be used for retail sale in random weight subdivisions. Graded leg sections are further trimmed and split in half longitudinally to provide consumer and institutional packs of split frozen king crab legs ready for broiling.

The Lobster Fisheries

The lobster fisheries include the true or northern lobster (*Homarus americanus*) of the New England Coast and the spiny or rock lobster *Panulirus argus* of the South Atlantic and Gulf Coast and *P. interruptus* of the Pacific Coast). Several characteristics of the lobster fisheries are: use of pots (traps) for harvesting, high value of the catch per pound, primary market form as fresh or frozen in the shell, and importance of imports for supplying the domestic market. In 1960 the 31 million pound catch of northern lobsters was valued at over 14 million dollars and was approximately ten times the volume and value of the spiny lobster. Import volume of northern lobsters was approximately two-thirds of the catch and was principally from Canada; import volume of spiny lobsters was more than ten times the catch, consisting mostly of frozen tails from Australia, South Africa, New Zealand, and countries of the Caribbean. Spiny lobsters are readily distinguished from the true lobster by the absence of the large, crushing claws and by a flexible rather than stiff tail fan.

Northern Lobster. Although the northern lobsters are found occasionally as far south as North Carolina and are taken in substantial volume in New Jersey and Massachusetts, the primary production is centered in Maine, where 24 million pounds was landed in 1960. For this reason it is frequently referred to as the Maine lobster. Spasmodic efforts have been made to introduce the true lobster to the Pacific Northwest Coast but to date these transplants have not been successful. Market lobsters average nine to ten inches in total length but may be much larger. Offshore lobsters caught incidental to ground-fish trawling off Cape Cod are commonly five to six pounds each.

Lobster pots, sometimes called traps, are the principal method of catching and consist essentially of an oblong box made of ordinary wood laths. The spacing of the laths is set to permit under-sized lobsters to escape. The ends of the pot have cotton netting arranged in a funnel shape to permit the lobster to enter the pot containing the fish bait hung in the middle. The pots are weighted and lowered to the bottom with a line secured to a bouy painted a distinctive color for identification. There were over 700,000 pots fished in Maine during 1960[16].

Holding Pounds. Since most of the northern lobster catch is sold alive, the industry developed holding pounds as early as 1875 for storage of the lobsters from the time of catch until marketing. Tidal pounds holding up to several hundred thousand pounds of live lobsters are common in Maine[6] in order to allow conditioning of the catch of new-shell lobsters during the summer and to market the lobsters to meet the seasonal demand despite marked fluctuations in abundance. In addition, crates or floats are anchored in live cars near docks and circulating sea water tanks are used for temporary storage. Artificial sea water may be used if it is free of chlorine and of metals such as copper and zinc to which the lobster is sensitive.

Shipping Lobsters Alive. Lobsters may be held and shipped alive if they are kept cool (about 40 to 50°F) and moist. Barrels are commonly used for truck or rail shipment and are packed with layers of lobsters and seaweed with crushed ice around the side and top[14]. It is important that the ice and water do not come in direct contact with the lobsters; otherwise, they may die. The claws are immobilized with plugs or wire ties. In recent years a number of suitable and lighter containers for express and air shipment have been developed, including corrugated boxes with plastic liners, waterproof-cellophane, and aluminum containers.

Freezing Lobsters. A small amount of cooked, whole lobsters and lobster meat is frozen for later marketing. Tests[11] in which large deep-sea lobsters were cooked in boiling sea water for 30 minutes, air-cooled, and frozen by immersion or blast freezer indicate that they could be stored satisfactorily at 0°F for not more than four weeks. Flavor changes rendered the cooked meat quite unacceptable after four weeks. Other tests[15] indicate that storage of the cooked meat in hermetically sealed cans at −20°F resulted in a better quality of the meat after 18 weeks than meat similarly packaged and stored at 0°F. Raw lobsters are not recommended for freezing because the meat sticks so tightly to the shell. Frozen lobster specialties and recipes have been introduced recently with some success; however, low storage temperatures and a quick turnover are essential for quality.

Canned Lobster Meat. Little lobster is canned because the canned lobster meat is much inferior to the fresh cooked meat in flavor and texture. Usually only quite small lobsters are used for canning. The cooked, picked meat is washed free of blood and bits of viscera, drained, and dipped into an organic acid, either citric or acetic, to prevent sulfide blackening. The meat is packed into C-enamel cans with the claw meat on top and heat processed like canned crab. The product does not store well and should be marketed within a year for best results.

Spiny or Rock Lobster. The spiny lobster (*Panulirus argus*) is caught mainly by the wooden lath trap and improvised traps on the Florida west coast[4]. There is a smaller production of *P. argus* on the Florida east coast and of *P. interruptus* in Southern California. These lobsters are taken mainly in waters less than 50 feet deep, although they sometimes occur in deeper water. A specialized dip net, called a bully net, is used for spiny lobster fishing from a small skiff. Since there are no claws, the spiny lobster tail is the main edible portion. The tail is simply removed, cleaned and washed, and frozen either raw or cooked for shipment. The tails are graded into five sizes from six ounce and under to sixteen ounce and over. Packaged frozen tails, either raw or cooked, may be stored successfully for six months at 0°F or preferably at lower temperatures. Some frozen meat is packed in small four to six ounce cans with transparent plastic tops. The frozen meat of the spiny lobster tends to get tough, stringy, and strong-flavored if stored too long or at too high a temperature. Storage for more than a few months should be at −10 or −20°F to minimize these adverse changes.

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CHAPTER 15

Marine Mammals

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Fur Seals

Distribution. Seven species of fur seals belonging to the genera *Callorhinus* or *Arctocephalus* are currently recognized. Members of the genus *Arctocephalus* are more abundant in the southern hemisphere, where they support industries in South Africa, Southwest Africa, and Uruguay. The northern fur seal, the only species in the genus *Callorhinus,* breeds on the Pribilof Islands, the Commander Islands, and Robben Island (USSR), and in small numbers in the northern Kurile Islands. Fur seals are taken for commercial use on the Pribilof, Commander, and Robben Islands.

More than 80 per cent of the northern fur seals resort to the Pribilof Islands in the Bering Sea each summer to reproduce. The Pribilof fur seals are known to winter 10 to 100 miles or more offshore from the Bering Sea to lower California and off the coast of northern Japan where they intermingle with seals from Asian islands.

Sealing Operations. Because fur seals are polygamous and because equal numbers of males and females are born, most of the males can be utilized without detrimental effect on the herd. Until recent years, the only females taken were killed inadvertently because of the difficulty in identifying the sexes. However, the need for taking females as a vital part of maintaining a productive herd is now recognized. Table 15.1 shows the kill, by sex, on the Pribilof Islands since 1911.

During the summer months, the young males congregate on areas, known as hauling grounds, adjacent to the rookeries. From late June to mid-August of each year, the seals are driven daily from the hauling grounds to suitable killing fields. During the peak of seal arrival, up to 5000 males may be taken in one day from drives containing as many as 10,000 animals. "Pods" of 15 to 25 seals are detached from the main group and continuously moved up to a six-man clubbing team. The clubbers quickly fell the male seals judged to be 41 to 47 inches in length.

Table 15.1. History of Seal Killing on the Pribilof Islands, 1911–1962

Year	Male	Female	Year	Male	Female
	Number	Number		Number	Number
1911	13,343	—	1937	55,010	170
1912	3,191	—	1938	58,165	199
1913	2,406	—	1939	60,312	161
1914	2,735	—	1940	64,940	323
1915	3,947	—	1941	92,802	2,211
1916	6,468	—	1942	150	—
1917	8,170	—	1943	116,407	757
1918	34,890	—	1944	47,533	119
1919	27,764	57	1945	76,391	573
1920	26,568	80	1946	64,028	495
1921	23,605	76	1947	61,153	294
1922	31,063	93	1948	69,893	249
1923	15,716	204	1949	70,553	337
1924	17,053	166	1950	59,815	279
1925	19,750	110	1951	60,503	186
1926	22,035	96	1952	63,670	252
1927	24,912	30	1953	65,824	845
1928	31,039	60	1954	63,224	658
1929	40,023	45	1955	64,727	726
1930	42,449	51	1956	96,066	27,599
1931	49,462	62	1957	46,248	47,413
1932	49,232	104	1958	47,872	31,101
1933	54,471	79	1959	30,195	28,064
1934	53,408	60	1960	36,320	4,315
1935	57,061	235	1961	82,196	43,849
1936	52,227	219	1962	53,680	43,760

About 95 per cent of the male seals within these size limits are three or four years old—ages when the fur is of the best commercial quality. Animals that are too small or too large are allowed to return to the hauling grounds. Size criteria for selecting females to be taken are not yet definitely established. The seals are dragged into rows of ten, bled by a knife thrust in the heart, measured, and stripped of their skins by use of specially designed tongs.

The skins are taken by truck from the killing fields, then washed and

Figure 15.1. Fur seal harem on St. Paul Island, Alaska.

soaked in sea water in wooden or concrete tanks for 24 hours. Blubber is removed with a beaming knife after the soaking period, and the skins are then cured in a saturated brine solution and piled to drain for several days.

Fur Company Operation

Processing Sealskins. Skins are rubbed with a mixture of salt and boric acid, tightly rolled, and packed still damp in barrels for shipment to the Fouke Fur Company of St. Louis, Missouri and Greenville, South Carolina.

The Fouke Fur Company currently (1962) has a contract for processing and selling all United States Government sealskins. They also process skins for the governments of Canada, Japan, South Africa, and Uruguay. Upon arrival at the fur company, the barreled skins are put in cold storage in above-freezing temperatures. Each skin is inspected and graded, washed and laced in a hoop in preparation for removal of the guard hair. The skins are first placed in a heated room where temperature and humidity are closely controlled. The loosened guard hairs are pulled free by passing a dull knife over the fur. The knife is essentially the same as that used for removing blubber. Unhairing is one of the most important steps in the entire process; extreme care must be taken to prevent damage. After being unhaired, the skins are tanned with "uncracked" oil obtained by cold extraction from salted blubber which is shipped from the Pribilof Islands specifically for the tanning process. The seal oil, rich in unsaturated fatty acids, is applied on the leather side of the skins and then kneaded into the skins in a mill. The mechanical action provides an effective, uniform, and rapid oil tannage. During the tanning process, the fur becomes very greasy and must be cleaned, before being dyed, by tumbling with hardwood sawdust. Each skin receives a sawdust treatment approximately 30 times during processing. Following the initial sawdust cleaning, skins are started through the dye process which involves methods and treatments developed by, and belonging to, the Fouke Fur Company. Each Alaskan sealskin is finished in one of four colors: a dark brown, marketed as SAFARI; a lighter neutral brown, known as MATARA; a dark gray with bluish highlights, called KITOVI; or BLACK. The final steps are "machining" and "finishing." It is impossible to remove all the stiff guard hairs from the skins during the unhairing process, especially those which are buried in the underfur. To eliminate these stiff hairs and to give the fur a smooth appearance unbroken by ripples, the skins are machine clipped. The soft fur fibers are blown down and held by an air blast, leaving residual guard hair fibers upright. Sharp cutters, operating like scissors, trim the hair at skin level, leaving an unbroken and smooth pile. Excess leather is removed or "buffed" on an abrasive drum to reduce the skin to a thickness suitable for furriers' use. Today's fur seal skin is much lighter than any skin processed before. Making the pelt supple and setting the fur so that all fibers are parallel are the final steps of processing before the skins are sold at auction. More than 125 processing operations result in the finished fur sealskin.

The processing of skins from female seals is in an experimental stage. The unhairing of female skins is more difficult than for male skins. By close shearing, a processed pelt, called lakoda, is produced. It was first sold without dyeing. Future lots will probably be dyed.

By-Products. A reduction plant on St. Paul Island produces blubber oil, carcass oil, and seal meal. Blubber oil is a more valuable product than carcass oil. Seal meal is primarily used as a protein supplement in poultry feeds. It is sold by protein units. A recent analysis of fur seal meal follows:

	Per cent
Protein (N × 6.25)	65.0
Moisture (loss at 105°C.)	5.2
Fat (petroleum ether extract)	16.7
Fiber	trace
Ash	12.6

The reduction of seal carcasses is not profitable at current world prices. An alternate possibility, now being tested, is the use of the ground, frozen carcasses for feeding pen-raised fur animals.

Whaling

Whaling is carried on in the United States from three shore stations on the Pacific Coast—two on San Francisco Bay at Richmond, California and one at the mouth of the Columbia River at Warrenton, Oregon. Six catcher boats are used. The annual catch has averaged about 300 whales during recent years.

Species Taken. The following six species of whales are presently utilized commercially in the United States:

Baleen Whales. Blue whale (*Balaenoptera musculus*) is the largest species, reaching a length of 25 meters (82 feet) in our waters. It occurs off the California coast in small numbers during late September and October. It feeds on "krill" (euphausiids).

The fin whale (*Balaenoptera physalus*), length to 23 meters (75 feet) in our waters, is common off the California coast from April to October. It feeds chiefly on krill and is the most important species economically.

Sei whale (*Balaenoptera borealis*), length to 15 meters (50 feet), is abundant off the California coast from July to October. It feeds on anchovies, sauries, krill, and copepods.

Humpback whale (*Megaptera novaeangliae*), length to 15 meters (50 feet), is common off the California coast from March to November. It feeds chiefly on anchovies and is important economically, but over-utilization usually results in severe local depletion of stocks near shore stations.

Toothed Whales. Sperm whale (*Physeter macrocephalus*) has a length for males up to 16.5 meters (54 feet) and for females up to 11.5 meters (38 feet). Males are fairly common off California all year; females rarely are encountered from April to September. It feeds on squids, skates, sharks, and bottom fishes.

Giant bottlenose whale (*Berardius bairdi*), length to 11 meters (37 feet), frequently occurs off the California coast from June to October. It is rarely taken because of its relatively small size.

Hunting. The five catcher boats used by the two California whaling stations are diesel-powered, 31 to 41 meters long, with a maximum speed of 18 to 22 km per hour. They carry a crew of four to six men—captain, gunner, engineer, cook, and deckhands.

Mounted on a platform above the bow is a harpoon gun with a bore diameter of 90 mm, which fires a harpoon 1.85 meters long, weighing about 75 kg. The head of the harpoon consists of an explosive grenade. This is triggered by a time fuse which is activated when the harpoon head penetrates the body of the whale. The harpoon is attached to about 100 meters of polypropylene or nylon line, the "foregoer," which is coiled in front of the gun. This is followed by about 1000 meters of steel cable which runs through a block-and-tackle shock absorber to a winch.

When a whale is killed it is inflated with air so that it will float. It is secured to the gunwales by a heavy chain which is passed around its tail immediately anterior to the flukes and is towed back to the station. As the heavy blubber layer prevents loss of body heat, a whale must be processed within about 20 hours after death to avoid spoilage of the meat.

Processing. At the whaling station, a whale is hauled up a slipway onto the flensing deck by a heavy winch.

The flensers, with the aid of long-handled, curve-bladed flensing knives and a pair of smaller winches, remove in two strips the blubber from the belly and from the side which is uppermost, in the same manner that a banana is peeled. Next they strip the loin (epaxial muscles) from that side and finally remove the lower jaw and one baleen row. The carcass is then rolled over, and the blubber (in one strip), loin, and baleen are removed from the other side. Next the head is removed, the rib cage and abdominal wall is stripped from the upper side, and the viscera are pulled out. Finally the inner loins (hypaxial muscles) on either side are removed, and the other side of the rib cage is severed from the backbone.

The meat, as soon as it is removed from the carcass, is trimmed of connective tissue, tendons, and excess fat and is cut into 5 to 10 kg chunks. These are placed in large tanks of chilled salt water for cooling. After several hours, the tanks are drained and the meat is removed. The meat is then ground and packed in bags of 23.7 kg (50 pound) capacity. Each bag is laid in a wire tray on a rack, which is then placed in the freezer.

The bones, after removal of usable meat, are sawed into manageable pieces. The blubber and viscera are cut up with the aid of flensing knives and long-handled hooks. One of the California companies has designed and installed a rotary crusher for chopping up bones, blubber, and viscera; it can accommodate an entire skull or vertebral column. The blubber, bones, and viscera are then hauled to a commercial rendering plant for extraction of oil and preparation of meal.

Products. *Meat.* Whale meat is the most important product of the United States whaling industry. The meat of baleen whales is preferred. Sperm whale meat, because of its oiliness and dark color, is not much in demand. Most of the whale meat is sold to fur farms for use as mink food. Much of it is also used as an ingredient in canned pet food. Smaller amounts are occasionally used for miscellaneous purposes—food for zoo animals, a culture medium for the larvae of screw-worm flies, etc.

Whale Oil. In the trade the name "whale oil" is applied only to the glyceridic oil of the baleen whales and not to the oil of sperm whales. It is used primarily in the production of soaps, glycerine, and margarine.

Sperm Oil. Sperm whales and bottlenose whales yield a waxy oil. Sperm oil has many uses—principally in cosmetics and as a lubricant.

Meal. The cooked blubber, bones, and viscera are processed into meal for stock and poultry feed and for fertilizer.

Whaling Regulation. The International Convention for the Regulation of Whaling limits shore stations to a six-month season each year (eight months for sperm whales). The following minimum size limits on each species are applicable to whales taken by shore stations, provided the fresh meat is utilized in the country of origin:

Blue	19.8 m (65 ft)
Fin	15.2 m (50 ft)
Sei	10.7 m (35 ft)
Humpback	10.7 m (35 ft)
Sperm	10.7 m (35 ft)

The capture of certain species (gray whale, right whale, and bowhead whale) is prohibited, and it is forbidden to take females which are accompanied by a calf.

Other Marine Mammals

Steller sea lions have been harvested experimentally in Alaska. The ground meat is readily salable to mink raisers. Its protein content is about 20 per cent, and fat ranges from 3 to 6 per cent[4]. The skins are not in demand by tanners because of the numerous scars[1]. It has not been established that sea lions can be profitably harvested. A refrigerator vessel is required to conduct the harvest in isolated Alaskan waters and considerable hand labor is needed to butcher and bone the carcasses. Experimental killing has been concentrated on large males which are more efficient to handle than smaller animals. The price of meat in 1959 was ten cents a pound.

Hair seals are taken off Greenland, Newfoundland, Laborador, the Gulf of St. Lawrence, Jan Mayen, and Novaya Zemlya, and in the White Sea, Caspian Sea, Okhotsk Sea, and Lake Baikal. The harp seal (*Pagophilus groenlandicus*) is the most important species taken in the North Atlantic. Over 200,000 harp seals were taken in 1954 off Newfoundland and 60,000 in the Gulf of St. Lawrence in 1953[2].

A small industry based on the oil of the southern elephant seal, *Mirounga leonina*, is located on South Georgia Island in the Falkland Island Dependencies[3].

Walrus may not be taken commercially, although Eskimos sell ivory carvings and a small number of bull skins for the manufacture of buffing wheels.

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PART III

Fishery Industrial Products

CHAPTER 16

Processing Fish Meal and Oil

CHARLES F. LEE

Sources of Raw Material

In the United States, fish meal and oil and condensed solubles are generally all products of the same operation, using as source of raw material either whole raw fish or waste from fish canneries or other food fish operations. By far the most important American source of fish for meal, oil, and solubles is the menhaden (see Chapter 11), one of the few species that is used entirely for industrial products. Alaska herring now also goes entirely for meal and oil but represents a minor resource. Otherwise, meal and oil in the United States are produced from wastes from food fish industries. Some of these sources will be discussed briefly (see also ref. 9).

Tuna. Tuna has become the nation's most important food fish and almost 100 per cent of the catch is canned. Thus the supply of cannery waste is so large that tuna meal accounts for about 8 per cent of the annual production, second only to menhaden. Tuna meal is primarily a West Coast product with the largest landings and canneries being located at Terminal Island and San Diego, California.

Herring. The sea herring is the main resource on which the meal and oil industries of Iceland, England, and all the northern European countries are dependent. In the United States, Alaska and Maine both produce herring meal. Alaska's is a whole herring meal while in Maine the catch is used primarily for canned sardines, with only excess fish, unsuitable fish, or cannery wastes going to the meal plants.

Pilchard, Anchovy, Pacific Mackerel, and Jack Mackerel. These four species are grouped together because they are all caught in the same general area—Central and Southern California—often by the same boats, canned in the same canneries, and the cannery wastes go to the same drying plants. Thus the meals made from these species rarely have a separate identity and are, in fact, not infrequently mixed with tuna meal. All are now minor sources of raw material, compared to tuna, although prior to 1945 the California pilchard was a major source of fish meal, annual production averaging 85,000 tons. This dropped to less than 200 tons in 1953 and has never approached its former status since that time.

Ground Fish. Otter trawlers and draggers working the "Banks" off New England land a number of species usually categorized as "ground fish." Included in this grouping are haddock, cod, the flat fishes or flounders, ocean perch, whiting, pollock, cusk, and hake. Most of this catch is dressed or filleted, and a portion of the waste from these operations goes to the meal plants. These are species with a comparatively low oil content, in contrast to the others afore-mentioned, so that only meal, often called "white fish" meal, is produced from this source. In recent years, there has been considerable competition for this raw material with most of it now going into canned pet food or being ground and frozen for fur animal feeding.

Industrial Fish. This name is now given to the material formerly more descriptively but inelegantly known as "trash" fish. It is properly considered with ground fish because these are bottom fish species caught with similar gear-drags and trawl nets. The species are mostly low in oil and, as with ground fish waste, much of the present production now goes for canned pet foods and fur animal feeding.

The name "trash" fish was derived from the fact that these were species unwanted for food when caught in the same trawls with the cod and haddock and, therefore, destined to be washed back overboard. In southern waters huge quantities of trash fish were brought up with the shrimp trawls. Now no longer unwanted, a considerable fleet of small draggers or trawlers fish especially for these non-food fish species. In the Gulf of Mexico small croakers, spot, butter fish, and half a dozen other species make up about 98 per cent of the catch. Although used as food fish in Atlantic waters, in the Gulf these species rarely grow to more than five inches long and a few ounces in weight and thus are grouped as industrial (i.e., trash) species[11].

In New England waters skates and rays, sea robins, sculpins, and other non-food species make up most of the industrial fish catch. As indicated, only a small part of this catch now goes to the dryers, although some has been digested to make "homogenized condensed" fish or "liquid fish" for mixture with some vegetable base meal.

Miscellaneous Sources. Salmon cannery waste has at times been utilized for meal and oil, though hardly economically feasible under present conditions. River herring, the "alewife" of Chesapeake Bay, is a source of meal and oil as whole fish or more commonly as the waste from canned "herring" roe or salted and pickled products.

The blue crab industry of the central and south Atlantic and Gulf states produces large amounts of waste—over 80 per cent of the live weight—and a portion of this, perhaps ⅓ to ½, is dried to yield a low-protein meal. Shrimp waste from the canneries on the Gulf of Mexico Coast also yields a small amount of meal, limited by the fact that most of the catch have heads removed at sea. Whale and seal carcasses have been rendered and dried for oil and meal. Both are more properly classed as meat products, and neither is available in quantities large enough to support a reduction plant under present conditions.

General Processes

Several basically different processes have been evolved for the manufacture of meal and oil from whole fish or waste products from food fish processing. The wet process is by far the most widely used, being continuous and capable of handling large quantities of oily fish. The solvent extraction processes also can be used with oily fish but have several disadvantages which have made them little used in the past for production of fish meals. They represent, however, the basic procedures for the production of the edible fish protein products formerly termed fish flour and now known as fish protein concentrate. Dry reduction processes have been used for non-oily raw material, and various digestion processes employing both chemicals and enzymes have been used to a limited extent on similar material.

Wet Process. This process is used almost exclusively for processing oily fish, including menhaden, herring, pilchard, and tuna cannery waste. In the wet process the raw material is first cooked with steam in a continuous cooker, then pressed in a screw-type continuous press. The press cake is dried in some type of rotary dryer, while the press liquors are centrifuged to separate the oil from the stickwater, so-called because it contains "gluey," water-soluble nitrogenous matter. Stickwater also has some residual oil, suspended fine solids, and dissolved minerals and vitamins.

Not many years ago this was discarded but now most of it is concentrated to 50 per cent solids, and this concentrate is marketed as "condensed fish solubles." The oil fraction may undergo various refining steps depending upon the end use for which it is intended.

The wet process, because of its importance, will be described in considerably greater detail in a subsequent section.

Dry Process. The wet process can only be operated efficiently when there is a fairly large and/or steady supply of raw material available, with a sufficient oil content to justify recovery costs. When only relatively small quantities of fish must be handled, or for species such as ground fish, shark, or others with a low-oil content (less than 3 per cent), the dry process is more practical.

The dry process is usually a batch rather than a continuous process. The fish is placed in a steam-jacketed vessel that serves both as cooker and dryer. A typical installation consists of a cylinder about 5 feet in diameter and 20 feet long that holds about 4 tons of fish. The vessel is fitted with a paddle-type stirrer that is rotated slowly but continuously during the rendering operation, which may take 6 hours. The dried scrap may contain more oil than is desirable. If so, excess oil is removed in a hydraulic press, also a batch operation, before the scrap is ground and sacked.

Solvent Processes. Solvent extraction has been used in the past when oil was the product primarily desired, such as in the preparation of vitamin oils from fish livers. It has also been tried in the past on batch-dried salmon meal and on a small scale with other raw material, but solvent and equipment costs have not made these operations economical. However, there is at the present time a great deal of interest in solvent processes for preparing so-called "fish flours," more accurately termed concentrated fish protein or fish-protein concentrates, for human consumption[6,8].

The various modifications in this process will, therefore, be reviewed briefly. The major differences are related to the starting material, which may be either raw fish, cooked and pressed fish, or dried scrap or meal.

Raw fish can be handled in two ways: by an azeotropic process using solvents that are non-miscible with water or by direct extraction, in which case the solvent must remove both water and fat. If press cake is used the same processes are applicable, but the operation is somewhat simplified by the prior removal in pressing of much of the water and oil as well as some possibly objectionable nitrogenous constituents. If dry scrap or meal is used, most of the fat can be removed by any of the hydrocarbon-type solvents or chlorinated solvents, but complete removal of lipids is difficult and involves multiple extraction using one of the alcohols as well as the afore-mentioned type of solvent.

Azeotropic extraction is dependent on the fact that when both water and solvent are present in a mixture the vapors distilling from the mixture contain both substances in proportions dependent upon their partial pressures. Dichloroethane or hexane are suitable solvents, the former being used in the Vio-Bin process[5,14].

As the vapors are condensed, the condensate separates into two layers and the solvent layer can be immediately pumped back into the process vessel to carry off more water. The mixed boiling point is lower than that of either constituent but approaches the boiling point of the solvent as the water content approaches zero, indicating completion of the cook in a batch process. The azeotropic principle has also been adopted to a continuous process[5].

After the water is removed, the fat phase remains in the vessel, dissolved in the residual solvent which then is filtered off. The residue is washed once or twice with clean solvent, then heated in a steam-jacketed vessel under vacuum to remove as much of the residual solvent as possible. As a final step, the vessel is sparged with dry steam to remove the last of the solvent from the fish protein, which is then ground and bagged.

In this, as in any solvent extraction process, economical operation depends on maximum recovery of the relatively expensive solvent, which requires that the entire system be vapor-tight and that solvent residue in both meal and oil be reduced to a minimum. Solvent is distilled from the solvent-oil mixture, and the oil is then further refined. This is usually needed because solvent extraction processes remove almost all the constituents responsible for color and odor of the raw material and these stay in the oil.

Isopropanol has been used for direct extraction of raw fish. The process is basically simple, the coarsely ground fish being mixed with the hot solvent, the solvent phase then being removed by filtration and/or by centrifugation. The residue is then treated with successive batches of fresh solvent until water and oil are reduced to the desired point. As in the azeotropic process, the solvent is costly and a high degree of recovery is necessary for the operation to be economically feasible. Recovery is somewhat more difficult because the water content of the solvent requires the use of fractionation techniques.

Digestion Processes. In the past, whole fish or wastes have been digested with acids, alkalies, enzymes, or various combinations of these reagents. In this process, proteins are broken down into the more soluble polypeptides or amino acids and the resulting liquid has been concentrated in evaporators yielding a product called homogenized condensed fish. More recently, digested fish has been mixed with soy bean meal or other vegetable carriers. This mixture can be readily dried to yield a product with a balanced protein which is also enriched with vitamins and unknown growth factors. Enzymes are preferable for digestion processes as strong acid or alkali treatment results in destruction of some of the amino acids. The enzymes may be added or whole fish may be chopped and digestion obtained with the autolytic enzymes present in the digestive tract. In this process the mixture is heated to a point that will retard bacterial decomposition but still permit enzyme activity.

Recent interest in a digestion process is derived from the possibility that the liquid, filtered and perhaps centrifuged to remove undigested solids and oil, might be spray-dried to yield a concentrated fish protein for human use.

Processing Fish by the Wet Process

World-wide, probably at least 95 per cent of fish meal and oil is manufactured by a wet process. The various steps involved in this process will be considered separately, including treatment of oil and stickwater. In Figure 16.1, a flow chart shows the alternative methods of handling encountered in present-day plants.

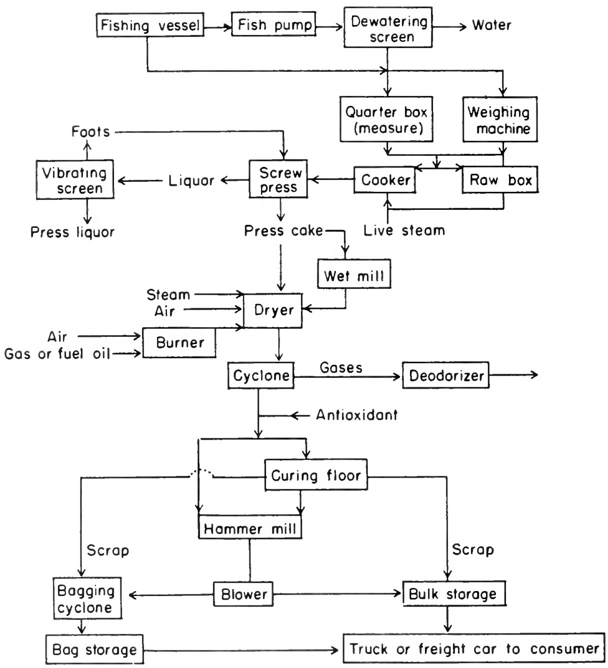

Figure 16.1. Flow diagram of production of fish meal, fish scrap, and press liquor by the wet-rendering process. (*U.S. Fish and Wildlife Service.*)

Cooking. Most of the fish used are small, less than 10 inches (25 cm) in length, and can be cooked without preliminary chopping. Cooking is necessary to denature the flesh protein and break cell walls so that oil and water can be removed by pressure. Direct steam is usually employed for heating the mass of fish and, in its most common form, the cooker is simply a horizontal cylinder from 15 to as much as 40 feet long and from 15 to 30 inches in diameter with a conveyor screw to move the fish through. Steam is introduced through a series of pipes leading from one or, more often, two manifolds that run the length of the cooker. Cooking is at essentially atmospheric pressure since only the mass of fish in the screw and in the feed hopper retains the steam, which may blow back if the feed-in is stopped for a short time for any reason.

Ideally this type of plant is designed so that the presses can handle most of the fish from the cookers and the dryers can take care of all the press cake coming from the presses. When equipment is matched in this way, there is neither an accumulation of cooked fish nor press cake when all the equipment is operating at its normal capacity. Irregular input or underloading results in inefficient pressing and overheating in the dryer as well as blowback in the cookers. It is for this reason that all the large

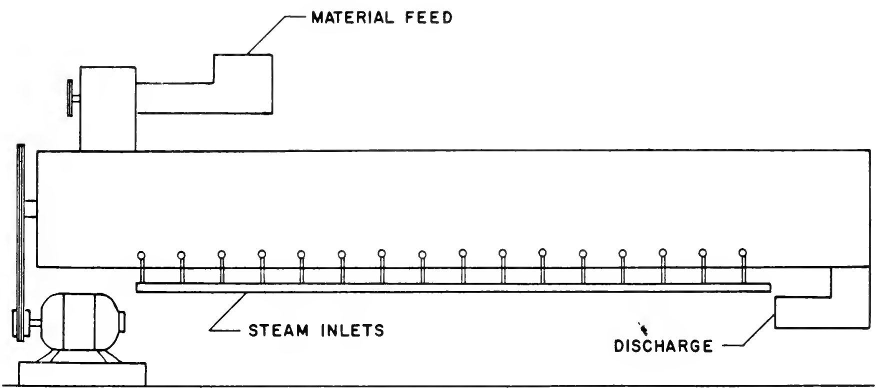

Figure 16.2. Diagram of fish meal direct steam cooker.

plants have a "raw box" or equivalent storage capacity for raw fish. This permits the accumulation of enough material to carry the process line through the intervals between arrival of the fish boats and the time needed to shift vessels and hook up the discharge pumps. Normally the plant, once started, runs continuously until the last of the fish are cleaned up.

A relatively recent modification, in limited use by the industry, is the indirect cooker in which the steam is retained in the jacket of the vessel and usually also in the special hollow conveyor screw. The indirect cooker has the advantage of reducing the amount of press liquors that need to be centrifuged and later evaporated. It also reduces the loss of solids and increases the yield of scrap and meal. Cost of this type of cooker is higher, and some operators believe that the excess water from condensed cooking steam is necessary to "wash out" the oil during pressing.

Pressing. The cookers are usually placed high enough so that the hot, cooked fish feeds directly into the presses by gravity. The presses, being of very heavy construction, usually are on the ground level on a heavy concrete base. The simple, straight screw press is still in almost universal use. Renneburg and Enterprise presses have almost a monopoly of the field. Both are effective and often are found side by side in the same plant.

The pressing operation has the objective of reducing the oil content from as high as 20 per cent in the raw fish to, ideally, about 3 per cent in the press cake. This would yield a meal with 6 per cent fat, but, in fact, meals from oily fish rarely contain less than 8 per cent, average about 10 per cent, and may run as high as 12 to 17 per cent fat. This indicates, and most plant operators readily agree, that pressing is a step that is difficult to control and normally is less than ideally efficient.

Condition of the fish is the main trouble spot, but as this varies from hour to hour, from boat to boat, and with the time the fish has been held in the raw box, efficient pressing requires almost constant supervision of both cookers and presses. Without indicators or automatic controls, this is entirely dependent on the skill and experience of the pressman. Temperature indicators on the fish from the cookers and power-input meters for the motors driving the presses help to make this more science than art, but this equipment is not yet in general use.

Drying. It is said with some accuracy that dryers never wear out, and this has delayed major reform in this step of the process. In many installations the same long cylindrical dryer used in 1910 can still be found. Yet progress has been made! The change from coal to fuel oil, and in many Gulf Coast installations to natural gas, has permitted much greater control over dryer temperatures. Improved fire box design, baffling, and other techniques have taken the flame out of the dryer and merit for many installations the designation of "hot-air" rather than flame dryers, as they have been known. Powerful turbine blowers greatly increase the air flow and drying rate. They also pull the rapidly drying fine particles through to be trapped in the "cyclone" before they can be overheated or charred as they often were in old installations that relied entirely on natural draft.

Recently progress has been made through altering the design of the drying cylinder itself—an example being the Renneburg "Dehydromat." Here change in rate of air flow and a temperature drop is attained through step increases in the tube diameter. Somewhat the same effect is obtained in the triple-pass dryers, short and squat compared to the straight tube installations, in which the air travels first down the center tube and then expands into concentric outer jackets.

Rotary steam dryers, at one time advocated as the sure answer to getting a meal of high nutritive quality[2], are not widely used by the fish meal industry. Heating is indirect, through high pressure steam in several banks of tubes running the length of the dryer. In this type of dryer it is impossible to burn the scrap since the scrap temperature cannot be raised above that of the steam (335°F for 100 psi steam). However, it is now known that longer exposure to temperature in the 250 to 300°F range can do as much damage to protein quality as shorter exposure to higher temperatures.

It is now generally conceded that properly controlled hot air dryers can produce fish meal of equal or even better quality than the steam dryer, as even steam dryers can be mishandled. Increasing use of temperature recorders in the exhaust gases and use of automatic controls on the burners to prevent the intermittent overheating that commonly results

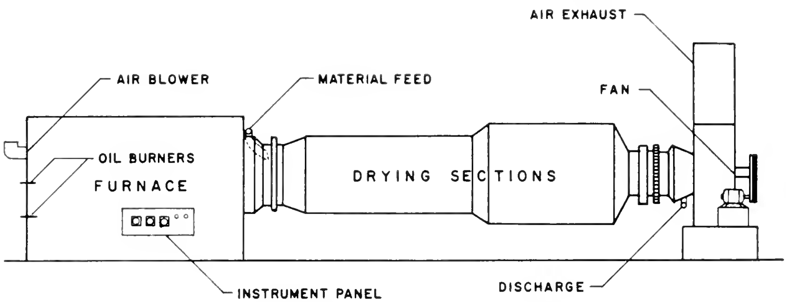

Figure 16.3. Diagram of fish meal hot air dryer.

with a variable feed rate of the press cake, are being more widely used to obtain more uniform meal quality and more even moisture content of the scrap.

Curing. Herring, white fish, and some other fish meals apparently can be bagged as soon as the scrap can be dried and ground. However the menhaden industry, which now accounts for more than 80 per cent of the fish meal produced in the United States, finds it necessary to "cure" the scrap, that is, to convert it to a stable state. When the scrap comes directly from the dryers it heats rather than cools in the storage piles. The exact mechanism involved in this heating is not thoroughly understood, but polymerization and/or oxidation of the oils is certainly involved. Meals that are relatively high in oil, above 10 per cent, and have a moisture content above 8 or 10 per cent seem more prone to excessive heating.

Antioxidants, mainly butylated hydroxytoluene (BHT), have been widely used to prevent overheating and the protein quality loss that often results from overheating. BHT apparently reduces the tendency to *rapid* heating but does not prevent oxidation of the oil in scrap. It merely delays its onset and probably stretches out the time necessary for essentially complete oxidation.

Recent evidence indicates that among the many factors involved in excessive heating of the scrap, a high initial temperature of the scrap in the first pile as it comes from the dryer may have the most detrimental influence. The critical temperature seems to be about 140 to 135°F; above this point pile temperatures build up, below it the temperature of the pile holds and gradually falls[7].

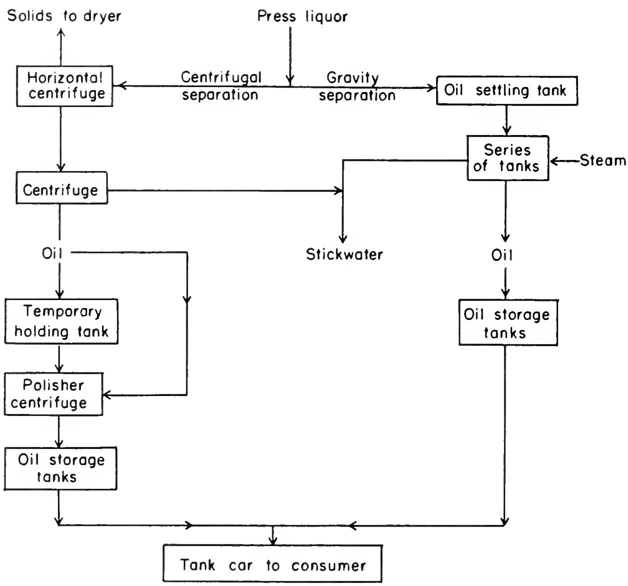

Figure 16.4. Flow diagram of production of fish oil from press liquor. (*U.S. Fish and Wildlife Service.*)

Several ways have been found in practice at various plants to reduce initial pile temperatures. Among the best are:

1. Using high ceiling conveyors to give the scrap a maximum drop and air exposure while it is hottest
2. Piling initially in 5 or 6 piles rather than building just one, then another, pile up to conveyor height—this gives more meal a long fall and the more slowly forming piles trap less heat
3. Making the first drop into a moving floor conveyor that then carries the scrap to an elevator and a second drop in another floor area
4. Using large blowers to give high air flow through the dryer and to move the hot scrap to the curing shed.

All these methods work by getting enough oxygen to the hot, reactive scrap to bring the oil it contains through its more reactive state, then carry away moisture and heat before these two enemies of meal quality are trapped in a rapidly building scrap pile.

It is still necessary to "turn" the scrap during storage, that is, push it to a floor conveyor, lift and drop it in another area, several times before curing is complete enough that the menhaden scrap can be ground and bagged. The number of turnings and the intervals between turnings vary with initial temperature, oil content, oil type, moisture content, and other factors so that it is impractical to set up a curing schedule that will work under all conditions.

Oil Separation. The hot press liquors are normally run from presses to shaker screens to remove coarse solids, then to some type of centrifugal separator to remove the fine solids. (DeLaval Super de-Cantors and Bird centrifuges are both widely used.) Solids go back to the presses or may be run directly to the dryers, and the liquid, reheated if necessary in a holding tank, is run to the oil centrifuges. The oil phase is usually quite clean and may be pumped to storage and shipped without further treatment. However, many plants use a second centrifuge, of slightly different design, to "polish" the oil, that is, remove residual stickwater and solids. This is accomplished by running the hot oil through the centrifuge with about 10 per cent of its volume of clear, very hot water which washes out the undesirable impurities.

Oil Refining

Menhaden oil, which makes up about 80 to 85 per cent of fish oil produced in the United States, varies widely in degree of unsaturation. Iodine values range from 135 to 190, with south Atlantic and Gulf of Mexico oils usually in the lower range[10].

Crude fish oil also has undesirable substances present in varying amounts. These are removed by refining or processing to increase its usefulness as a starting material for the manufacture of industrial products. These undesirable substances may be classed as follows: (a) suspended matter, mucilaginous, colloidal, and resinous or polymeric; (b) free fatty acids present or produced from the natural oil prior to or during the processing of fish; (c) natural occurring oil-soluble coloring matter; (d) volatile odoriferous and flavor compounds dissolved in the oil; and (e) saturated glycerides.

One of the oldest processes of refining oils is known as "winterization." Here, the oil is chilled until the higher melting and less soluble saturated glycerides precipitate. After filtration to remove the precipitated solids, an oil is produced that has much improved drying properties.

A process useful for the removal of coarse, suspended matter from fish oil involves simply the gravity settling of such matter. Maintaining the oil in a fully liquid state for several days in tanks is often sufficient. A clear oil may be drawn off the top of the tanks leaving the settled impurities on the bottom.

In many instances, colloidal and small suspended matter require more extensive treatment of the oil. This may involve blowing the oil with wet steam at 100°C for some time and then allowing the oil to settle. Salt may be added at a 1 to 2 per cent level to assist the handling of possible troublesome emulsions. Following the settling, the lower layers of condensed water and oil-water emulsion are piped off through centrifuges to separate the oil from the water. Such centrifugal separation leads to lower oil losses and a clearer, cleaner oil product.

Alkali-refining is the process known to be effective for the removal of free fatty acids. Alkaline treatment of the oil is also effective in removing various color-producing materials. In such a process, a solution of caustic soda is gradually mixed with warm fish oil and then heated to about 100°C. A slight excess of alkali above that necessary to neutralize all of the free fatty acids is used. The amount of excess depends on the color of the original raw oil. Concentrated solutions of soda ash (sodium carbonate) may be used in place of caustic soda. The oil, after alkaline treatment, is separated from fatty-acid soaps by centrifugal separators. Washing and a second centrifugation improves the yield and quality of the finished oil.

It is also possible to remove free fatty acids by the process of molecular distillation[12]. Owing to the high molecular weight of the glycerides, ordinary distillation methods of separation and refinement are not practical. Molecular distillation under high vacuum makes it possible to remove vitamins, steroids, and hydrocarbons (e.g., squalene), as well as fatty acids, from the raw oils leaving glycerides as a residue. This method has been used extensively for the recovery of vitamin A from fish liver oils on an industrial scale.

The natural coloring compounds found in fish oils vary from species to species. Some of the red oils are known to contain carotinoid pigments, while the greenish oils are believed to contain chlorophylls. To decolorize fish oils, adsorptive bleaching techniques are most common. Chemical methods of bleaching have been less successful with fish oils than with other natural fats and oils, probably due to the greater degree of unsaturation common to commercial fish oils. In common adsorptive bleaching methods fish oil is mixed with a clay-type adsorbent, such as fuller's earth or a chemically activated fuller's earth. Other adsorbents used include activated charcoals and diatomaceous earths. The amounts of adsorbent used vary from 3 to 5 per cent and more for fish oils. The process is carried out at about 120 to 140°C for ½ to 1 hour, followed by filtration. The inferior grade of oil retained by the filter cake can be recovered by solvent extraction[13].

Deodorization of fish oils may be effectively accomplished by steam distillation under reduced pressure. It is important in storage of the deodorized oils to exclude air because of the great tendency for such refined fish oils to revert or become rancid. This process finds its usefulness in improving the flavor of hydrogenated fish oils for use in shortenings and margarines. Such products are more common in Europe than in North America.

Fish Solubles

From the centrifuges the stickwater is usually run to large, temporary holding tanks. Sometimes the hot liquor will be held for 18 to 24 hours, possibly with the addition of enzymes, or until enzyme action and the

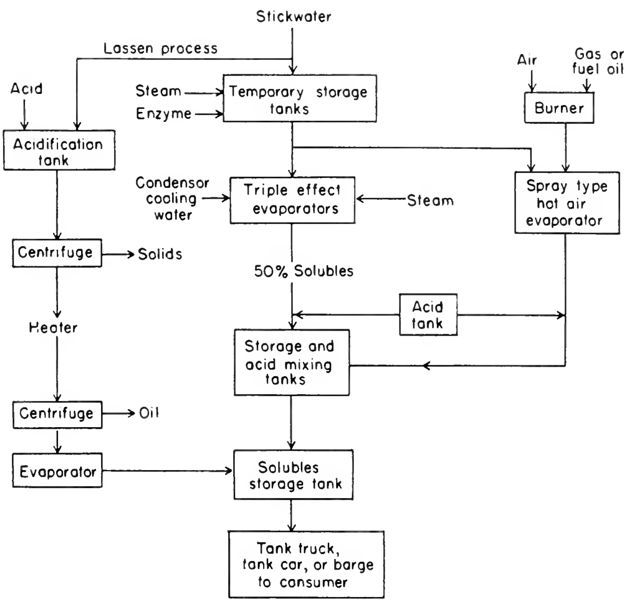

Figure 16.5. Flow diagram of production of condensed fish solubles from press liquor. (*U.S. Fish and Wildlife Service.*)

normal flora of heat-tolerant bacteria cause a partial breakdown of the protein and a consequent reduction in the viscosity of the finished condensed solubles.

As handled in menhaden plants, stickwater is evaporated to the desired concentration before sulphuric acid is added to pH 4 to 4.5, serving solely as a preservative. In the Lassen process[3], acid is added to the raw stickwater and serves also as a protein coagulant, precipitating some of the solids that are in part responsible for high viscosity and also freeing oil held in suspension.

Several types of evaporators are used for fish stickwater. Large installations in the United States have used continuous vertical, triple-effect vacuum evaporators almost universally. Steam jet ejectors are used to obtain the desired vacuum, and usually a horizontal preheater is used. These installations have high capacity and are practically automatic, once control valves are set for a given lot of stickwater, so that the plant operation can be handled by one experienced evaporator man. Initial cost is fairly high and shutdowns are not infrequent, with scale in the tubes or corrosion of the tubes both common sources of trouble.

Another type of evaporator that has been used with some success is the Vincent hot air evaporator. This works on the same principle as a spray dryer, the stickwater being fed into a turbine rotor in the center of the top of the conical chamber with the hot gas from the burner being introduced tangentially. Part of the water flashes off (solids content of feed is usually from 5 to 8 per cent), and the thickened material is thrown to the side walls from which it runs down to a sump. It is not usually practical to take the stickwater down to 50 per cent solids in one step, so that the sump contents are pumped to an identical or somewhat smaller second stage evaporator or to temporary storage for a later second run through the same unit.

The main objection to this type of installation is the fact that the solubles pick up undesirable contaminants from the heating gases. This may be only fine carbon from incomplete combustion of the fuel oil, which gives the product an abnormal greenish or gray color. However, high sulfur fuel oils are occasionally found and may result in high sulfur dioxide in the solubles, which occasionally will have a quite acrid or sharp odor, and other unidentified impurities may be acquired in this same manner.

Stickwater from small reduction operations connected with canneries may be batch-evaporated in steam-jacketed kettles in locations where this material cannot be discarded because of pollution restrictions. The capacity of this type of equipment is very low compared to the three-stage vacuum evaporators.

Full Meals. Solubles may be returned to the scrap in proportions approximating the original relative content of dry solids in the press cake and press liquors, forming a product known as full meal or whole meal. Since neither the chemical composition nor nutritive value of the mixture is sufficiently different for the whole meal to be readily distinguished from the straight meal, except by determination of the soluble protein, these products may not be separately identified as marketed. Consequently, neither the amount produced in the United States nor the typical proportion of added solids from stickwater in whole meals are figures that can be readily obtained. It can be stated that both are closely correlated to the demand and market price of 50 per cent condensed solubles. When the solubles price is less than half the price for meal, the larger amount will go into meal and vice versa.

The stickwater solids may be added back as raw stick, but rarely are. They are added as partly concentrated—30 to 35 per cent solids—solubles or as finished solubles. Any of these may be added to the press cake, to the dry scrap, or at some intermediate state, i.e., when the scrap has about 20 to 25 per cent moisture. The choice of procedure is usually dictated by the available capacity of the dryers and evaporators and the amounts of solubles solids that are being added.

Vitamin Oils

The production of oils having high potency of vitamins A and D from fish livers was a very important and lucrative specialized branch of the fish reduction industry for a number of years, roughly from 1930 to 1945. Then processes for producing the synthetic pure vitamins were developed to the point where the natural sources were unable to compete price-wise, and this industry almost disappeared from the United States.

However, production of vitamin oils is still important in other parts of the world. In some areas fish livers are still steamed aboard the trawlers, obtaining a crude separation very shortly after the fish are caught. This prevents spoilage of the livers, which results in undesirable flavors in the oil. The crude product is further refined in shore plants to remove small amounts of water and nitrogenous material from the liver tissue.

Shore plants, in addition to steam cooking, use an alkali digestion process which makes the tissues completely soluble to permit centrifugal separation of the oil[1].

Some livers have a relatively low oil content, but the oil has a very high vitamin potency (sablefish, tuna, halibut, swordfish, some shark). This type of liver is often treated with a low vitamin A oil (cod for example) which acts as a wash oil to increase the recovery of the high potency oil.

There has been a recent revival of interest in natural vitamin sources and improvements in processing which may lead to some degree of recovery of vitamin oil processing in the United States.

Problems in Meal and Oil Processing

The fish reduction business is not a quick and easy way to get rich. Pitfalls and problems are many. A few of these will be discussed briefly, to alert, if not to warn, the potential investor of some of the hazards that may be encountered.

Supply. Perhaps the greatest problem, rather surprisingly, is to get a supply of raw material that is both adequate and stable. Too often a plant is started to utilize a resource—say of trash fish from the shrimp boats—that seems tremendously large and inexhaustible. Too late it is found that this raw material cannot be brought to a central plant at a price that makes it possible to produce meal at the going market price and still make enough profit to survive.

In our example, the shrimp fisherman does not want to use ice and hold space for trash fish unless it makes money for him, but these fish are low in oil—no profit there. This means that if meal is worth \$110 a ton and we use the usual conversion ratio of five raw fish to one meal, then if our meal plant operator has to pay \$20 a ton (only a cent a pound) for raw fish, he has only \$10 per ton for all other costs: labor, fuel, bags, maintenance, etc.

To operate he has to figure out some way of getting fish for about \$15 a ton and this is, unfortunately, next to impossible. However, even if he gets raw fish at a profitable price, he still may fail because he does not have a stable supply of fish available from month to month and year to year in quantities large enough to justify the overhead of labor and other basic costs for minimum operations.

It is so common that it may be considered typical for fish to come in very heavy supply then drop off to a low level. "Fisherman's luck" is all too accurately descriptive of the uncertainty of the catch. Thus plants must be built large enough to capitalize on the gluts during the period of heavy landings and yet designed so that they can operate with fair efficiency at perhaps $1/10$ of the maximum capacity.

Quality. Fish meal quality will be discussed in detail in another chapter, but the problem of producing fish meal of reasonably uniform quality from raw material that is rarely uniform either in composition, freshness, or even species of fish is a very real problem. This situation has become increasingly serious as greater knowledge of nutritional requirements and scientific formulation of broiler diets put a premium on the uniformity in quality of each ingredient of the broiler-feed mixture.

Plant Location. Other problems are derived from the nature of the fish meal industry. Plants built years ago find resort areas building on nearby water fronts and urban expansion pushing residential sections even closer on the land sides. No longer can these plants afford to neglect the problems of odor and water pollution that were unnoticed in earlier conditions of semi-isolation. New plants must be initially designed with consideration of problems of water pollution and odor prevention.

The dryer is the source of most objectionable odors as the volatile odoriferous substances are freed by heat and carried away in the large volumes of air moving through the dryers. Wash towers and waste gas incinerators, or both in combination, have been widely used to largely eliminate odor of this origin. Other odor sources are the raw fish, which spoil rapidly in vessel hold or raw box, and liquids dripping from the raw box, from raw fish conveyors, and from the quarter box and dewatering screen where the raw fish are measured. Control of these odors is mainly a matter of "housekeeping," that is, good cleaning after every run of fish. Water pollution results if the pump water that is added to the hold to flow the fish into the suction pipe is discarded as it is separated in the dewatering screen. In many areas regulations against water pollution prevent discarding this in waters adjacent to the plant, and the pump water is recirculated. Under these circumstances, these pump liquors build up a fairly high solids and oil content, and plants have made a virtue of necessity by recovering this material in the oil centrifuges and solubles evaporators.

The solubles-evaporator plant is usually not a source of odors, since the jet ejector acts as a wash tower in condensing the evaporated, odor-carrying vapors. However, an exception should be noted—the hot-air solubles evaporators discharge large volumes of odoriferous gases into the air and this type of evaporator is not likely to be tolerated unless located a considerable distance from built-up areas.

Problems associated with fish reduction as a business venture are explored in somewhat greater detail in the U.S. Fish Reduction Industry[9].

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CHAPTER 17

Processing Animal Feed

RICHARD NELSON

Fish and marine products contribute substantially to animal feeding in North America. Fur-bearing animals, farm animals, zoo animals and birds, pets, and even hatchery fish are fed fish in their diets in varying amounts from a very small proportion to nearly 100 per cent. In 1960 over 421 million pounds of fishery products were canned in the United States for use as animal food, and in addition, 67 million pounds of fishery products were frozen for use either as animal food or bait[1].

Animal foods from fishery products are usually derived from the waste of an operation where fish is being prepared for human consumption. Fish fillet waste, steak trimmings, and cannery offal are typical examples. Whole fish is also taken for the specific purpose of preparing animal feed. The use of whole fish will undoubtedly rise as the need for animal feed increases.

The methods used to process fishery products into animal feeds are essentially the same as the methods used in processing fish for human consumption. Heat sterilization and freezing are the two most important methods used. This chapter will discuss the various aspects of fish processing which are peculiar to the animal food processing industry and which would not be discussed in other chapters. Fish meal and oil, for example, are extremely important in feed formulation, but these products have already been discussed.

Raw Material Sources

Of foremost importance in the development of any segment of the animal food industry utilizing fishery products is the availability of raw material. As most of the animal feed derived from fish is taken from species of fish or parts that are considered scrap, the type of product processed in a given locality depends upon the type of food fish being processed.

Some fisheries have by-products that are particularly desirable for certain types of animal feed. For example, the Southern California area where a high volume of tuna is canned produces large quantities of pet food from the red meat trimmed from tuna loins being prepared for canning for human consumption. In the northern areas along the Pacific Coast from Northern California to Alaska, a sizable mink feed industry has been established utilizing the scrap products from the fillet plants. The availability of this material as mink feed has been important in locating many mink ranches in this area.

A considerable quantity of whole fish from the Gulf of Mexico is used to prepare pet food. The species used, mainly croakers, are small and until recent years were regarded as valueless.

Processing Methods

In processing any product, the producer must consider the cost per unit of each step in his operation and base the selling price of the product accordingly. In processing fishery products into animal feeds, since the selling price is usually quite low, the cost of processing must be considered very carefully in order to be competitive with other types of feeds. Thus it is necessary that any method used in preparing animal feeds be relatively inexpensive and yield high production volumes.

Canning Methods for Pet Food. By far the most important canned fish product produced for animal feed is canned pet food. Over 360 million pounds of such canned products were packed in 1958 for use as animal feed.

The methods used in processing canned pet foods are essentially the same as those used in canning any fish product except for two factors—raw material source and product formulation.

Where the fish is harvested especially for pet food production, the entire fish is used. If the by-product of a food fish is used, the parts processed are usually the head, skin, viscera, and, in the case of tuna, the red flesh. Processing usually begins with a grinding operation in which all of the fish components are ground together to make a single homogeneous mass. This is then used to add to a formula including such products as red meat, cereals, yeast, and vitamin and mineral supplements. Most pet food processors consider their particular formulation and mixing procedures to be a proprietory secret.

Catfoods often contain 100 per cent fish while dogfoods usually contain a much smaller percentage of fish.

The potential of fishery products for use as pet food is very high.

Jones[2] stated that the largest potential source as raw material for feeding the nation's 25,000,000 dogs and 29,000,000 cats is undoubtedly fish. As this utilization of fish increases, no doubt improved processing methods and more diversified pet food products will be needed.

Handling Methods for Preparing Frozen Mink Feed. The most important frozen fish utilization in animal feeding is in the mink-raising industry. In recent years considerable expansion of fur farming in areas adjacent to fishing ports has taken place. Many of the mink ranchers have formed cooperatives for the special purpose of obtaining and processing feeds. Fish is their main source of material. Mink feed includes whole fish, fillet waste, cannery offal, and whale meat.

Raw Material. In most instances, the fish material utilized as mink feed is obtained from fish processing plants. The buyer usually hauls bulk loads by truck to his processing plant or ranch. In some areas, especially in the Great Lakes region, whole fish such as sheepshead are purposely taken for use as mink feed. On the Pacific Coast whole sole and turbot are utilized in preparing mink feed. In some cases mink ranchers even own and operate fishing vessels.

Grinding. The first step in processing the fish into mink feed is grinding, which is usually accomplished by using a medium size (10 to 25 hp) grinder of the plate and screw type. Grinding plates of approximately $^3/_4$ inch openings are preferred.

Packaging. The next step after grinding may be either freezing or packaging, depending upon the particular plant procedure. If the material is packaged prior to freezing, one of two types of package are commonly used. A multi-wall paper bag is most popular. The bags may be filled from an automatic hopper and stitched by machine. An alternate package is the fiber carton which is sometimes lined with waxed paper. The multi-wall bags are usually filled to 50 pounds net contents while the cartons may contain lesser amounts.

Freezing. If the ground product is frozen prior to packaging it is usually placed in metal trays. In any case, the bags, cartons, or trays of material to be frozen are placed in a freezer at temperatures between −40 and 0°F. The colder temperature is preferred. Blast, plate, or coil freezers are commonly used. After the freezing cycle is completed the bags are moved directly to a cold storage warehouse. The boxed material is often ice glazed on the top surface to prevent dehydration. The feed frozen in trays is removed from the trays and ice glazed. These frozen blocks are then packaged in cartons and are placed directly in the cold storage warehouse.

Storage. Frozen mink feed may be stored in any of several warehouses. The cooperative may have its own cold storage or it may rent space. Some individual farmers have cold storage facilities to accommodate fairly large volumes on their own ranch. Storage temperatures of 0°F or lower are preferable.

Special Handling. Mink are very delicate animals and are particular about their diet. Mink ranchers insist on having a very high quality feed. This means a feed must be fresh as well as nutritious. It has been found that mink must have a diet that is not excessively high in oil content or the mink may develop what is known as "yellow fat disease." An oil content of approximately five to eight per cent is preferred.

Certain feeds cause "cotton-fur" which is undesirable as it produces a low quality pelt. Feeds prepared entirely from certain species of fish produce Chastek paralysis (caused by thiamine destruction from the presence of the enzyme thiaminase in the fish) so thiamine must be added if these species are fed in high quantity.

Bacterial spoilage must be avoided in any mink feed. Mink ranchers are particularly cognizant of botulism as severe losses of mink have resulted from using contaminated feeds.

Frozen Whale Meat. A considerable quantity of whale meat is frozen for use as mink feed. Approximately 150 whales are taken each year off the Pacific Coast. These whales are processed in two plants located in California.

The whale is towed to the processing plant where it is cut up to remove the various sections. Meat from the loins, shoulders, ribs, and vertebrae are combined to produce a ground mink feed. The meat is cooled, ground, and bagged. It is then frozen in a conventional manner.

Frozen Zoo Animal Feed. Most zoos feed fish to certain species of animals and birds. Usually, because of the expense, the species of fish available at the lowest price is fed. Thus in many areas herring forms a major fish portion of the zoo diet. The normal processing method for preparing fish for use by zoo animals is freezing in small blocks.

Frozen Fish Scrap for Fish Hatchery Feed. The practice of using certain portions of fish waste to process hatchery fish food has not become as important as it might have had not the pellets of dry hatchery feeds been developed. However, there is some use of fish waste, especially salmon cannery offal, in preparing frozen hatchery diets. The material utilized is viscera and eggs. The scrap from the iron chink is conveyed in water to a draining table where excess water is allowed to drain away. The viscera is then bagged and moved to the cold storage for freezing.

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CHAPTER 18

Processing Marine Plant Products

F. Bruce Sanford

Through the ages seaweeds have held a peculiar attraction for man, challenging him to find valuable uses for them. As a result, he has employed them in many ways, depending upon the sophistication of his knowledge.

In this chapter three topics concerning seaweeds are discussed: what seaweeds are, what problems are encountered in their use, and what they are used for.

Seaweeds

Classification and Habits of Growth. Marine plants may be divided into two groups: grasses and algae. In this chapter, we consider only the algae, for they constitute the group with the greater commercial potential. Algae, in turn, may be further divided into two subgroups: those that are free to move from place to place according to the flow of ocean currents and those that grow in a fixed location. Again we will be selective and will focus our attention on those that remain fixed, since they are the algae of commercial importance. These fixed algae may be subclassified still further according to color into green, brown, red, or blue green varieties.

Algae, depending upon the particular variety, have certain characteristics that tend to limit their utilization. Those individuals contemplating commercial use of algae should, therefore, give this aspect study. The limiting factors are too numerous for comprehensive discussion here so only a few of the more important ones will be mentioned, such as their requirements as to light intensity and temperature, their size of growth, and their length of life.

Light. Possibly owing to color and consequent varying ability to absorb light, green, brown, and red algae, when they grow in the same areas, tend to grow in zones. The green are found in the shallowest water, the red in the deepest, and the brown in the intermediate depths.

The requirements of algae for light limits the maximum depth at which they may be found to about 100 fathoms—even at low latitudes and in the clearest water. Under less favorable conditions of latitude and water clarity, the maximum depth may be limited to 15 fathoms or even less. Because the depth increases rapidly along many sea coasts, the area in which algae are found is restricted.

Temperature. Different varieties of algae flourish best at different temperatures. Although red algae, for example, grow in cold water, they are most abundant in tropical waters. In contrast, brown algae are found primarily in colder water. The beds deteriorate and the plants die when surface temperatures reach 75°F.

Size. The green and especially the blue-green varieties tend to be so small as to be difficult to harvest. Thus it is the brown varieties and the red ones that are of commercial importance. Brown algae may grow to exceptional size, some specimens attaining a length of 165 feet or more.

The term "seaweed" is applied to marine algae exclusive of the minute forms, and the term "kelp" is applied to the larger of these seaweeds.

Life. Some seaweeds are annuals, some are biennials, and some are perennials. This factor of length of life is important as it determines the number of times a given species of seaweed can be harvested in a year and how well it will withstand continued intensive harvesting.

Constituents. As might be expected, the principal constituent of seaweeds is the carbohydrate called cellulose. Among other carbohydrate constituents are manitol, laminarin, alginic acid, and fucoidin. Manitol is an alcohol containing six OH groups. One use for it is in the manufacture of an explosive which is produced by nitration of the OH groups and which thus is similar to nitroglycerine. Laminarin is a reserve carbohydrate that is analogous to starch in land plants. Its potential uses are as a blood anticoagulant and as a substitute for plasma. Alginic acid is a compound of major commercial importance which will be considered later. Fucoidin is a polysaccharide sulfate ester, which so far has not found wide use commercially.

In addition to carbohydrates, seaweeds contain proteins, fats, minerals, and vitamins. Although they are low in fats, some varieties contain a fair amount of protein, and they are all rich in minerals. Seaweeds are also good sources of vitamins, among which are included beta-carotene (pro vitamin A); various B vitamins—such as thiamin, riboflavin, niacin, pantothenic acid, and vitamin B_{12}; vitamin C; and vitamin D.

Problems in Utilizing Seaweeds

Supply. To the casual observer, nature seems to be of unlimited bounty. Viewing a large bed of seaweed, he gains the impression that the supply is endless. He quickly learns otherwise, however, when he attempts commercial exploitation. As we have seen, a number of factors, such as the requirement for light, limit the growing area for seaweed in most localities to a relatively narrow strip of coast line. Other factors, such as the size of the seaweed, its content of the desired constituents, or its possible tendency to grow intermingled with less desirable species, impose further limitations. A fundamental problem in the seaweed industry thus is to obtain a continuing source of supply sufficiently close to the processing plant to keep the cost of transportation within economic limits.

Harvesting. Not only are seaweeds usually found along a narrow strip of coast line, but even in this limited area, they often grow in places where they are difficult or even dangerous to harvest. With the notable exception of the giant kelp, which will be discussed later, their habits of growth often do not permit them to be harvested easily.

Hand harvesting is the rule for most species. For this reason, the development of a mechanical harvester by the Scottish workers is of particular interest. They have invented a motor-driven steel-mesh belt with short hooks attached. This device can be operated from a vessel as it moves over a bed of seaweed. The German workers have developed an angle scythe for cutting reeds in pond fish culture. This device may lead also to better methods of seaweed harvesting.

Uses of Seaweeds

Seaweeds are sources of food, fertilizer, and chemicals, with chemicals being predominant in importance.

Food. *Human Food.* Although seaweeds are used extensively for human food in the Orient, particularly in Japan, these products are not very popular in Western countries. On a dry-weight basis, seaweeds generally consist almost two thirds of carbohydrates, such as cellulose, which Western people do not find digestible. In the United States, the main varieties of seaweed used for food, principally as relishes and as thickeners in soup, are Irish moss, dulse, and purple laver.

Owing to possible use in space travel, algae for feeding humans are of increasing interest. Powell and co-workers[2] found that using a mixture of

Chlorella and *Scenedesmus* strains, which when dried contained 59 per cent protein; 19 per cent fat; 13 per cent carbohydrate; 3 per cent moisture; and 6 per cent ash, 100 grams could be fed to a man per day. Larger quantities, however, tended to produce gastrointestinal disturbances.

Animal Food. Meal made from seaweed can be used as an animal food, but the salt content is high. Some manufacturers dissolve out part of the salt, and some also caramelize the sugars to remove the characteristic odor of the meal, which is not appealing to cattle. Up to 10 per cent of seaweed meal can be included in the diet of poultry and up to 20 per cent in the diet of sheep, pigs, and horses. At or below these levels, the meal apparently does not affect the odor of the meat. Seaweed meal has also been used in the diet of mink and is said to result in pelts of higher value.

In the United States, most of the seaweed meal has been produced in California. A product has been manufactured in which the seaweed is combined with fish meal and fish solubles. Seaweed meal also is available imported from such countries as Norway.

Fertilizer. Although seaweeds are relatively low in nitrogen and phosphorous, they are high in potassium and the trace elements. (Kelp from Puget Sound, for example, contains about 31 per cent potassium chloride on the dry basis.) With suitable supplementation, they make good fertilizer. Macpherson and Young[1] found in the seaweed of the Maritime Provinces a nitrogen content of 2.4 per cent and a phosphorous content one-tenth that high on the dry basis. The moisture content was 83 per cent. In contrast to many fertilizers, seaweeds are free of weed seeds and spores of crop diseases.

Chemicals. An astonishing variety of chemicals can be produced from seaweed—and in quantity. It has been estimated, for example, that the United States alone could produce 6 million tons of potassium chloride and 19 thousand tons of iodine a year from seaweed if necessary. These materials now are obtained more cheaply from other sources, but during World War I, our requirements for them were met by the production from seaweed in California. Also produced at that time were a number of organic solvents, including acetone, ethyl acetate, ethyl propionate, and ethyl butyrate.

In attempting to produce chemicals from our seaweed resources, pioneer investors lost large sums of money. Eventually, however, they were able to establish a stable industry in the production of phycocolloids.

Phycocolloids from Seaweeds. The term "phyco" is a Greek word meaning seaweed, so phycocolloids are simply seaweed colloids. Colloids are materials, such as gelatin, pectin, and starch, that have the property of forming gels. Although there are a number of phycocolloids that can be produced from seaweeds, only three—agar, algin, and carrageenin—are of commercial importance in the United States. Algin is produced from brown seaweeds and agar and carrageenin from red varieties. The phycocolloids are used as thickeners, humectants, coagulants, bulking agents, flucculation agents, and antibiotic carriers.

These seaweed products have been able to pay the cost of harvesting and processing because, being colloidal in nature, a small quantity produces a large effect, and they can be priced accordingly. Agar is valued in the neighborhood of $3.75 a pound; algin and carrageenin are each valued at about $1.25. Despite the higher price of agar, only one American company has been able to survive foreign competition. There are several companies producing algin or carrageenin. Altogether their output is valued in excess of 10 million dollars a year.

Agar: That the United States would be able profitably to manufacture agar is an apparent paradox in that the Japanese can produce the product more cheaply than we can. Fortunately, our product is of higher quality, which is what keeps us in business. Financially, agar yields less income to the United States than either algin or carrageenin. Nevertheless, it is a product of great value to our nation. During World War II, it became of considerable strategic importance, owing to its use as a solid culture medium in bacteriology. The following unique combination of five properties make it particularly valuable for this purpose:

(1) Melted agar remains liquid at low temperatures of 32 to 39°C
(2) This fluid has low viscosity
(3) After being cooled below 32 to 39°C, the fluid changes to a gel that remains semisolid at temperatures of 85 to 100°C
(4) Agar is nearly transparent and is nearly neutral in reaction
(5) Few common bacteria digest agar

In addition to this very important use in bacteriology, agar also is used for medicinal, dental, and industrial purposes.

During World War II, some agar-producing seaweeds were harvested on the coasts of North Carolina and Florida, but these areas have not been able to meet competition in the post-war period. The principal species of seaweed now yielding agar is *Gelidium cartilagineum*, which is found along the coasts of Southern and Baja California. It grows on rocks in fast-moving water and is harvested by divers.

The harvested seaweed is washed in fresh water, dried in the sun to a content of less than 20 per cent moisture (a higher content may result in spoilage), pressed into bales of 200 pounds, bound with wire, and shipped to the processor. Payment is made on the basis of agar content and gel strength of the extracted agar.

The process of manufacture is based on the fact that agar is considerably more soluble in hot water than in cold. Four grades are produced: bacteriological, medicinal, dental, and industrial.

Algin: In this country algin is the phycocolloid manufactured in largest quantity, accounting for more than half of the financial income from the phycocolloids produced here.

A significant factor is the ease of harvesting the seaweed from which the algin is made, most algin being obtained from the giant kelp (*Macrocystis pyrifera*) obtained off the coasts of Central, Southern, and Baja California. The beds of kelp are of large size, some being as much as two square miles in area. The kelp grows in water from 30 to 90 feet deep. The harvesting can be done mechanically. A large mowing machine, the cutting bar of which is set about four feet below the surface of the water, is operated from the front end of a motor-driven barge. As the kelp is cut, it is brought aboard the barge by means of a conveyor. As much as 300 tons a day can be harvested in this manner.

The giant kelp is a perennial. It lives 5 to 10 years and it can be harvested three or four times a year. The annual production from California is about 100 thousand tons. During World War II, four times this quantity was taken so the beds are of a size that will permit expansion of the industry. Kelp contains salts, laminarin, and manitol, which must be separated from the algin. This separation is made on the basis that alginic acid and the alginate salts of polyvalent metals are insoluble.

The viscosity and gel properties of algin solutions depends on the temperature, the acidity, and the addition of certain metalic salts. Algin solutions can form films that are clear, tough, and flexible and that have good adherent properties. These films are resistant to greases, oils, waxes, and organic solvents but are compatible with the common hygroscopic plasticizers, such as glycerine.

These various properties of algin have made them useful in foods, pharmaceuticals, and industrial applications.

Carrageenin: Carrageenin contributes substantially to the income from phycocolloids manufactured in the United States. It is produced from Irish moss (*Chrondrus crispus*), which is obtained from Massachusetts northward into Canada. Irish moss grows just above the low-water level down to a depth of about 20 feet and is relatively easy to harvest. Usually, it is picked by hand or raked. An experienced man using a rake having handles from 15 to 20 feet long can obtain as much as a half a ton on a tide. The plants are gathered in bags and are sent to a central collecting point for drying and baling.

An important use of carrageenin is in the suspension of cocoa fibers in the production of chocolate milk. Another important use is in the stabilizing of ice cream, in which it stops wheying off, controls ice-crystal formation, and gives improved melt-down characteristics. It also finds numerous uses in other foods, in pharmaceuticals, as well as in cold-water paints.

Considerable information on seaweeds is contained in the monograph of Scagel[3].

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CHAPTER 19

Miscellaneous Industrial Products

Maurice E. Stansby

Several industrial products are prepared from fish which have not been discussed in other chapters. These include those prepared from shell, scales, skin, and bones. While these products are individually of relatively minor importance, in the aggregate their value is considerable.

Products from Scale and Shell

A number of uses are made of the scales and shells of fish. The shell is used to prepare ornamental items and buttons. The scales can be used for preparing a meal for poultry feeding or as a source of pearl essence.

Pearl Essence. Pearl essence is a solution of guanine crystals which is used as a spray or dip for numerous items to give them an irridescent sheen reminiscent of pearls. Such diverse articles as beads, shoes, pencils, fishing rods, artificial flowers, ash trays, vanity cases, book covers, and finishes for textiles employ pearl essence treatment. The largest use is for the preparation of artificial pearl beads.

Pearl essence is usually composited as an eleven per cent suspension in a solvent or lacquer of guanine crystals obtained from fish (usually herring) scales.

Pearl essence preparation from fish scales has been an art since the fifteenth century[6], and the chemical basis for the effect has been known since the late nineteenth century[2]. In the United States herring from the New England sardine fishery furnish the scales for operation of several pearl essence plants in Maine. The herring are transported from the traps to the cannery in boats provided with special false bottoms which furnish a means for collecting the scales that are removed by the fish as they thrash about in the vessel. The guanine material is sometimes separated from the scales in an agitator with water which is then centrifuged from the guanine crystals[7]. In other cases the scales, which may remain on the fish until after they reach the processing plant, are separated from wash water within the cannery[3]. The crude guanine is generally next treated in acid solution with pepsin for about 48 hours. This digests much of the proteinaceous impurities. The guanine crystals may be suspended in water containing a little ammonia. More frequently they are dispersed in a nitrocellulose ethyl acetate lacquer.

Many efforts have been made, without complete success, to develop a synthetic guanine pearl essence product. Earlier this failure was ascribed to difficulty in getting the proper crystal size for the guanine to reflect the light in the most advantageous way. According to Decker[3], the particularly effective sheen from pearl essence made from fish scales is due to the retention of an envelope of hydrolyzed protein around the guanine crystals. Therefore, the optical effect of irridescence is a combined property of the hydrolyzed protein envelope and the guanine crystals. The pepsin digestion and other processing steps, if carried too far, will remove some of this proteinaceous envelope and thus reduce the desired irridescent properties of the pearl essence. It is, therefore, important to obtain the fish scales in a condition as free from impurities as possible, so as to reduce to a minimum the handling and processing steps. While presence of blood, dirt, and other foreign impurities reduces the quality of the end product, excessive processing to remove them may result in loss in quality of the pearl essence.

Clam and Oyster Shell for Poultry Feed. Oyster shells are commonly dried and ground for use in poultry feed. The shell is first dried, usually in an indirect flame dryer, and then passed through a grinder which may be of the hammer mill type. From the grinder, the material passes through a series of vibrating screens and may be sacked according to different mesh sizes or reground to a finer size before sacking. In some locations, e.g., Southern California, huge deposits of dead clam shells are located in tide flat areas. These are "mined" by being dredged up with large steam shovels at low tide when they are exposed and dried and ground similarly to the preparation of the product from the oyster industry. Thousands of tons of such clam shells have been removed from these beds and the supply in some areas seems to be almost inexhaustible.

Pearl Button Industry. Marine and fresh water shells are used to manufacture buttons and other items such as belt buckles. In general, in the

United States the marine shells used for buttons are imported, principally from Australia and oriental areas. Fresh water mussel shells for manufacture of buttons are taken from the Mississippi River and tributary streams. Since the latter industry is an exclusively domestic one, the description here will be largely concerned with the fresh water mussel shell operation, which resembles in many respects that of the marine shells.

U.S. Mussel Shell Industry. Prior to 1890, most buttons used in the United States were machine-made pearl buttons imported from Austria or Germany, which had a monopoly on automatic methods for button production. In 1890 a former German button maker discovered that mussels, abundant in the Mississippi River, had shells suitable for making pearl buttons. Within a few years a booming button industry was established at Muscatine, Iowa, which became the leading button manufacturing center in the country. Although today many types of synthetic button materials have drastically reduced the production of buttons from mussel shell, there are still eight button manufacturing concerns at Mascatine which use, at least for a part of their raw material, mussel shells from the Mississippi and tributary rivers. Since 1957 when changes in tariff regulations gave plastic buttons a favored position, there has been a considerable decline in the use of mussel shells, and factories in the Mississippi Valley area employ both plastic and mussel shell. A considerable quantity of mussel shell is now exported to Japan.

Mussels are obtained by dragging a crowfoot bar from a small, flat-bottomed boat. The crowfoot bar consists of a 14 foot ½ inch pipe from which trout lines containing hooks are suspended. The hooks are dragged along the bottom of the river and as they scrape past a mussel, it opens its shell and fastens upon the hook. A mussel shell boat employs two of the crowfoot bars. As one is being dragged, the other is aboard the boat where the mussels are removed. Upon reaching shore, the mussels are cooked to remove meats from the shell. The meats are generally employed as fish bait in river fisheries for catfish, buffalo fish, and other species. While originally all mussels were obtained from the Mississippi, they now come principally from tributaries such as the Tennessee River.

The first step in manufacture of the buttons is sawing of round "blanks" from the shell. This may be done at the site where the mussel shell is obtained, which may be a hundred miles or more from the factory; in other cases, the shells are shipped to the factory where all operations take place. The cutting of the blanks is carried out with a tubular saw which is of the same size as the blanks to be cut, and the blanks are then sorted by an automatic machine which separates them according to thickness.

The blanks are soaked for about a week in water; this makes them less brittle and not so likely to shatter during subsequent operations. A grinding machine having a revolving emery wheel removes the rough "bark" from the blank. Rough edges are next smoothed by tumbling the blanks in a churn of water, after which a dryer removes water. The button is then prepared from the blank by an automatic machine. This machine rounds the edges of the blank by means of a sharp steel lathe tool which also turns a depression in the middle of the blank. Then sharp steel drills cut two or four holes. From the finishing machine the buttons go to the polishing room where they are placed for about 1½ hours in revolving barrels containing sulfuric acid, very weak at first but gradually increased somewhat in strength. This process hardens the buttons and prepares them for taking on a high gloss. The acid is removed by steam or water, and the buttons are then given a vigorous shaking in boxes containing sawdust from which they emerge with a beautiful luster. The buttons may be dyed to any shade.

Products from Skin, Bones, and Sounds

Leather. The principal deterrent to the use of fish skins as a raw material for leather manufacture is the small size of most fish, which renders the obtaining of large enough skins very difficult. The chief sources of leather from fish, therefore, have been from such large species as sharks. The preparation of furs from seals has already been discussed in the chapter on marine mammals and will not be considered here.

Because sharks are large enough to obtain a reasonably large "hide" and since the skin is suitably tough to make a good leather, sharks have been a principal source for leather from fish. Since the disappearance of the natural vitamin A industry from fish livers in the United States, caused by the development of the synthetic vitamin A process, sharks are no longer fished for this purpose in this country, and hence there is no longer a supply of shark skins available as a by-product for leather manufacture. Since, however, there are extensive shark fisheries elsewhere, a very brief description of general processing methods is included here.

Suitability of shark skins for leather depends upon the size of the skin and the absence of defects such as scars, butcher cuts, wrinkles, or excessively variable thickness. The skins are carefully removed from the shark either at sea aboard the fishing vessel or as soon as the vessel lands its catch. They are then coated with salt, cured in piles, and shipped in bundles to the tannery.

The skins are freshened by soaking in water and then treated with slaked lime, after which flesh and other adhering materials are removed by machine. After the usual bating operation to remove lime, the skins are tanned either by the vegetable or chrome tanning process (see Ref. 7 for further details).

Food fish skins are seldom used as a source of leather because of their small size and fragile characteristics. At one time a process was developed for preparation of a leather from salmon skins[1], but this product is not produced at present.

Glue and Isinglass. The formerly large domestic salt cod industry was the basis for a substantial by-products industry for the manufacture of fish glue and isinglass. With the disappearance of the salt cod industry on the Pacific Coast and the greatly reduced operations on the Atlantic Coast, the magnitude of this industry has greatly declined in the United States.

Glue is manufactured from bottom fish skins, and sometimes heads and bones in the New England area, in a manner quite similar to that employed in the preparation of other animal gelatin glues. Where the raw material comes from the salt cod industry, a considerable preliminary freshening of the skins is required to remove salt. This may be accomplished by a thorough agitation of the skins in large tanks of water for a period of about 12 hours or longer. This may be followed by maceration with 0.2 per cent caustic alkali or saturated lime followed by an extended treatment with 0.2 per cent hydrochloric acid for removal of alkali and a final washing in running water[5].

The processing to make glue from fish skins consists essentially of a cooking of the freshened skins with dilute acid in steam-jacketed cookers in two stages for five to ten hours each, with glue being withdrawn after each stage. The approximately five per cent glue stock then goes to the evaporators (usually vacuum triple-effect type) where the moisture content is reduced until the desired viscosity is reached. Preservatives are added generally before cooking to minimize bacterial decomposition. Essential oils are added to provide a pleasing odor.

Fish skin glue, when made from the best skins and under the most careful conditions, can be used as photoengraving glue. Glues of less desirable characteristics are prepared from bones and other waste from the fish industry or from fish heads.

The word "isinglass" comes from the German word *hausenblase* meaning sturgeon's bladder, which was the original raw material from which the product was made. It is the purest form of fish gelatin which can be prepared, and it is used as a clarifying (filtering) aid primarily in wine manufacture. One ounce of isinglass will clarify 200 to 300 gallons of wine[4]. The sounds or air bladders from bottom fish are used in the United States for isinglass manufacture, those from hake being considered the most choice. The sounds are first washed thoroughly and then air-dried. They are then moistened with water and drawn into a ribbon which is rolled on spools. A fairly complete description of manufacturing methods for both fish glue and isinglass is given by Tressler and Lemon[7].

Liquid Fish Fertilizer

Before the value of fish meal for poultry feed was fully appreciated, most fish meal was used as a fertilizer. Today the value of fish meal for feed is so much greater than for fertilizer that it is all used as a feed. In recent years, however, a small quantity of fish solubles or "liquid fish" has been diverted to use as a fertilizer where for some special reason an organic-type fertilizer in liquid form is desired. This usage has, for example, appealed to the home gardener as providing an easily used material which can readily be sprayed or poured on flowers or other home plants. These liquid fish fertilizers are considerably more expensive than comparable liquid chemical fertilizers which are made from inorganic sources of nitrogen, phosphorous, potassium, and trace metals. The only advantage to the liquid fish fertilizers lies in the slower absorption by the plants and slower leaching by rain or other water of the organic material than is the case with the inorganic liquid fertilizers.

For preparation of liquid fertilizers, ordinary fish solubles, possibly centrifuged to remove some of the loosely suspended particles which otherwise settle in time to the bottom of the container, are treated with some odor-masking agent such as oil of citronella and bottled. Such a liquid fish fertilizer has a poor balance of components for most garden use because the ratio of nitrogen to other important elements (phosphorous and potassium) is much too high. Such liquid fish fertilizer may be fortified by addition of inorganic phosphorous and potassium. In other cases a liquid fish is prepared by digestion of the solid fish material with potassium hydroxide, neutralizing the excess alkali with phosphoric acid. Such a process results in boosting the deficient phosphorous and potassium to a more satisfactory level.

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CHAPTER 20

Fish Meal Quality

NEVA L. KARRICK

Fish meal was used for feeding purposes in Europe before 1900, and its use as a feed increased during World War I. At that time it was used in the United States primarily for fertilizer. However, methods of manufacture improved, a better product became available, and by the 1930's fish meal was an important ingredient in poultry feeds. It was recognized as a valuable animal protein supplement and as a source of vitamins, minerals, and unknown growth factors. Fish meals are still fed for the same reasons, though much more has been learned through the years about the components and why they are valuable as animal feeds. Basically, fish meals are added to the diet as high quality supplements to obtain efficient diets, particularly for poultry. Today, nearly all of the fish meal produced in the United States is used in formulation of feeds for poultry.

Fish meal is a general term for a number of different products that vary in type of raw material and method of production. This results in differences in quality and in composition. Many of the research investigations on fish meals have been attempts to determine amount of and reasons for variation. Attempts to assess quality and nutritional value are important parts of this research.

Specifications

Feed manufacturers, who use fish meals in their formulations, state that the most important need is a standard product. The Nutrition Council of the American Feed Manufacturers' Association made the following recommendations for recognized standards for fish meals:

(1) Uniform grind, color, and protein content per lot or shipment. Noticeable differences between producer's lots in respect to granulation and color are undesirable but not so troublesome as differences between bags within the same lot or shipment. The protein content of individual bags within a lot or shipment should not vary over a range greater than 5 pounds of protein per 100 pounds of meal. These differences cause many marked deviations in appearance and protein content of mixed feed. In addition, shipments should be uniform in color and grind.

(2) Maximum particle size.
  (a) All should pass #7 Tyler standard screen or U.S. #7 standard screen. Ninety-eight per cent should pass #9 Tyler standard screen or U.S. #10 standard screen.
  (b) The industry should be encouraged to establish particle size of their product and report a standard screen size basis (Tyler or U.S. standards) and by further study determine the minimum acceptable particle size.

(3) Moisture.
Moisture should be 10 per cent or under in meal at completion of drying. Meals of 12 per cent moisture are at the margin of the danger zone for spontaneous heating and mold growth. An average moisture content of 8 per cent with permitted deviations of 2 per cent is satisfactory.

(4) Oil or fat content.
  (a) Maximum oil content should normally be 10 per cent. The minimum should be 5 per cent. A high oil content increases the hazard during storage. A low oil content is undesirable because of dustiness.
  (b) Oil content varies with species of fish. Oil content should be controlled at a level which will permit safe shipping and storage without danger of overheating and spoilage.

(5) Sand.
If sand content is more than 1 per cent, the maximum percentage present should be stated.

(6) Salt.
The amount of salt present should conform to the specifications of the Association of American Feed Control Officials.

(7) Quality Maintenance.
  (a) Overheating and scorching during drying should be avoided.

Overheating quickly and seriously impairs protein nutritive quality and reduces the feeding value of the meal. Drying to less than 6 per cent moisture content is a hazard to protein quality.

(b) Meal should be well cured and cooled prior to sacking or shipment. Spontaneous heating during shipment is undesirable and may cause lumping and loss of quality. Sweating may cause moisture condensation, wetting, and mold formation.

TABLE 20.1. PROXIMATE COMPOSITION* AND VOLUME OF PRODUCTION OF PRINCIPAL U.S. FISH MEALS

Species	Biological Name	Raw material	Number of Samples	Amount Represented	Moisture Av.	Moisture Range
						%
Menhaden	*Brevoortia tyrannus*	whole fish	116	Random	8.3	4.7–13.2
Tuna	Mixed species	scrap	22	100-lb	6.7	3.2–14.4
			14	carload		
Mackerel	*Scomber japonicus*	scrap	4	100-lb	7.0	5.6–7.8
			8	600-lb		
Herring (Alaska)	*Clupea pallasi*	whole fish	29	carload	7.8	6.7–8.6
Herring (Maine)	*Clupea harengus*	whole fish	2	100-lb	7.2	***
Sardine (Calif.)	*Sardinops caerula*	whole fish	24	carload	8.2	3.9–13.3

Species	Protein Av.	Protein Range	Oil Av.	Oil Range	Ash Av.	Ash Range	1961 Production Tons
		%		%		%	
Menhaden	60.3	50.1–66.5	9.9	6.5–16.2	20.5	14.7–27.0	248,000
Tuna	61.3	52.5–67.2	10.6	7.1–14.3	19.8	17.4–22.2	
							21,000
Mackerel	58.6	54.1–61.4	10.7	8.7–12.4	21.0	18.9–23.7	
Herring (Alaska)	70.1	60.9–74.2	12.0	9.6–20.2	10.3	9.2–11.6	7,000
Herring (Maine)	60.9	***	13.5	***	17.3	***	1,000
Sardine (Calif.)	60.0	53.6–69.4	7.9	7.0–10.8	20.3	12.8–23.8	3,000
Miscellaneous							34,000
Total							314,000

* All results on "as fed" basis.
Vitamin content of fishery by-products, *Com. Fisheries Rev.*, **19**, No. 5a, 14 (1957).
Ibid., p. 11.
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Composition

The composition of fish meals varies. Processing and storage have an effect, but a number of other factors are important. These include whether the raw material was whole fish or fillet waste, whether it was fresh or decomposed, and whether solubles were added back to the meal to produce a "whole" meal. Composition of the principal commercial fish meals in the United States is given in Tables 20.1 through 20.3.

TABLE 20.2. VITAMIN B COMPLEX, CALCIUM, AND PHOSPHORUS IN PRINCIPLE U.S. FISH MEALS*

Species	Thiamine	Riboflavin	Pantothenic acid	Niacin	Choline	Vitamin B_{12}	Calcium	Phosphorus
	mg/lb	mg/lb	mg/lb	mg/lb	mg/lb	mcg/lb	%	%
Menhaden	0.3(5)	2.2(23)	—	25.4(8)	—	34.8(3)	5.49(50)	2.81(27)
Tuna	—	2.5(36)	—	53(36)	—	115(36)	5.32(9)	3.07(8)
Mackerel	—	2.4(1)	—	27.1(1)	—	174.4(1)	—	—
Herring	—	4.1(9)	5.2(8)	40.4(7)	1820(19)	99.4(8)	2.94(37)	2.20(36)
Sardine	0.2(2)	2.7(24)	4.2(4)	28.2(4)	1345(7)	78.2(8)	4.09(5)	2.80(7)

* Results on "as fed" basis. Figures in parentheses are number of samples analyzed.
From "Composition of Concentrate By-product Feeding Stuffs," National Academy of Sciences, Washington, National Research Council, publication 449, 1956.
Results on tuna reported in *Com. Fisheries Rev.*, **19,** No. 5a, 17 (1957).

TABLE 20.3. AMINO ACID COMPOSITION OF PRINCIPLE U.S. FISH MEALS*

Species	Arginine % feed	Histidine % feed	Isoleucine % feed	Leucine % feed	Lysine % feed	Phenylalanine % feed	Threonine % feed
Menhaden	4.0(4)	1.6(4)	4.1(4)	5.0(4)	5.3(5)	2.7(4)	2.9(4)
Tuna	7.0(2)	—	—	—	6.2(3)	—	—
Herring	4.0(10)	1.3(9)	3.2(8)	5.1(8)	7.3(12)	2.6(8)	2.6(8)
Sardine	2.7(10)	1.8(9)	—	—	5.9(10)	—	2.6(1)

Species	Tryptophane % feed	Valine % feed	Methionine % feed	Cystine % feed	Glycine % feed	Tyrosine % feed	Cysteine % feed
Menhaden	0.6(3)	3.6(4)	1.8(5)	—	—	1.6(3)	—
Tuna	0.9(2)	2.2(2)	1.7(6)	—	—	—	—
Herring	0.9(9)	3.2(8)	2.0(14)	1.6(1)	5.0(1)	2.1(8)	1.4(3)
Sardine	0.5(2)	4.1(1)	2.0(7)	0.8(2)	4.5(2)	3.0(1)	—

* Results on "as fed" basis. Figures in parentheses are number of samples analyzed.
From "Composition of Concentrate By-product Feeding Stuffs," National Academy of Sciences, Washington, National Research Council, publication 449, 1956.

Tests for Quality

Quality of fish meals is based on their nutritional value for poultry or other animals. Consequently, biological tests are the most reliable. These have been developed to measure biological value of protein[2,10,11,16] and of individual amino acids[21] as well as of unidentified growth factors[3]. However, chemical tests are more practical for routine tests, and a number of methods have been developed for *in vitro* measurements[4].

Several factors affect quality and no one test will give complete information. Both protein and oil in the meal can be affected by processing and storage and are used for laboratory tests[14]. If the oil has oxidized, the meal will show a low ratio of ether extract to the total oil extracted by acid hydrolysis. This ratio decreases with oxidation or polymerization of the oil in the meal, and it will vary with the length of meal storage and with the species of fish used as raw material.

Several tests are used to indicate the value of the protein. The pepsin-digestibility method[8,1] is often used, but the range covered by commercial meals is too small to show most differences[12,23]. The method can be used to detect an extremely poor meal, but this rarely occurs, and noting a high amount of charred material by visual observation gives just as reliable results.

Lysine availability is sometimes used to indicate heat damage in fish meals. Although lysine usually is not the limiting amino acid, if lysine has been damaged, other amino acids will also have been damaged. An *in vitro* method for "available" lysine has been developed[7,5,6].

Digestibility of the meal is affected by physical and chemical factors and is difficult to measure. Methods for *in vitro* analysis do not give the same results as those for *in vivo* analysis. Part of the reason that knowledge of chemical composition cannot be used to predict nutritional value is that it does not give a clue to digestibility of the product for the animal being fed. However, digestibility alone cannot be used as a criterion of nutritive value.

A chick assay[21] to measure unidentified growth factor (UGF) activity was developed and used to determine correlation between processing variables and UGF activity of fish meals[22]. The UGF activity apparently was not affected by drying at 390°F for 3 hours or by storage at room temperature for 18 months. Consequently UGF activity should be stable to commercial processing and storage conditions, which are less severe than the above experimental treatments. A wide variety of fish meals and fish solubles were assayed and all had significant amounts of UGF activity.

Factors Affecting Quality

The type of raw material used will affect both composition and quality of the meal. The species of fish will help to determine the amount of oil in the meal. The amount of protein will be greater in meals from whole fish than from fillet waste. If the raw material has spoiled, the amount of protein will be less, but the biological value of the protein present will not be diminished.

After meals are removed from the driers, the oil oxidizes and the meals go through a period of heating spontaneously. If care is not taken, the meals will heat to very high temperatures, high enough to char or ignite them. Meals have a greater tendency to heat if they have a high oil content. Olafsson[19] found that for oil extracted from meal on the first day, the lower the moisture content in the meal the higher is the peroxide number of the oil. If meals are allowed to heat to high temperatures, their nutritional value is affected, due at least partially to decreased digestibility.

The problem of spontaneous heating has been practically eliminated in modern commercial operations. The meal is permitted to heat under controlled conditions that keep the temperature low and the damage to the nutritional quality of the meal at a minimum.

The temperature of drying and the method of processing have long been suspected as important reasons for variability in nutritional values of fish meals. Conflicting reports about their importance have appeared in the literature. High temperatures at the end of the drying period, when the moisture content is low, will scorch the meal. A survey of commercial menhaden meals[9] was made to determine their protein quality. The values of 97 meals varied by more than 100 per cent in these tests in which the fish meal was fed as the sole source of protein and the growth rate of chicks was measured. Although two-thirds of the meals dried at high temperatures were of good or intermediate nutritional value, one third were of poor quality. In contrast, none of the meals dried at low temperatures were of poor quality. Thus meals of good nutritional value can be dried at high temperatures under some conditions. Although temperatures of drying effect quality, other factors are also important.

Fish Solubles

The use of fish solubles in poultry diets was started about 1945[14], after a commercial process was developed to condense stickwater. These solubles are sometimes added back to fish meal to produce "whole" meal. Solubles have also been spray-dried to make them easier to ship and handle, but this is unsatisfactory because the dried solubles are hygroscopic.

Solubles are added to diets primarily for their nutritional value, although they also have the advantage of reducing dust in mash feeds. They are an important source of unknown growth factors, B vitamins, and trace minerals. Although solubles do contain amino acids, they are not a good source because the amounts are variable.

Fish Protein Concentrate

For many years dehydrated fish proteins have been suggested as an animal protein additive in areas where diets are deficient in animal protein. Fish protein has been added as a supplement to cereal flours and shown to increase the nutritional value of the vegetable protein. A high lysine content has been reported[17,20], and the protein efficiency ratio was found to be the same as egg albumin[13]. The nutritional value of several products was compared[18] and variations were found. However, if fish protein concentrate is properly prepared it will provide high quality protein.

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CHAPTER 21

Uses of Industrial Fish Oils

Edward H. Gruger, Jr.

Supply and Composition of Fish Oils

The sources for industrial fish oils produced in the United States are found in the herring, menhaden, Pacific sardine (pilchard), and tuna industries. Between 1950 and 1959 the average annual production of United States fish oils was distributed as follows: 78 per cent from menhaden, 7.3 per cent from herring, 5.1 per cent from Pacific sardine, 3.1 per cent from tuna and mackerel, and 6.5 per cent from other sources, including whale and sperm oil[44]. Excluding fish-liver and whale oils, the annual production of fish oils in the United States, from 1950 to 1960, reached a high in 1960 of over 208 million pounds. The low for this period was 118.6 million pounds in 1952. The amount of such fish oils available annually during this period for United States consumption has varied from 33.5 million to 101.0 million pounds or from 19 to 67 per cent of the total annual productions. More complete information on this is shown in Table 21.1[42].

Fish oils have not reached maximum industrial use in the United States in recent years because of preconceived ideas, among other things, of considerable variation in physical and chemical characteristics. The investigation by Simmons[46] points out certain variations in the characteristics of fish oils taken from different geographical locations and from different species during the 1956 and 1957 season. The data shown in Table 21.2 was obtained from this work.

The effect of geographical location of catch for menhaden has been

Table 21.1. U.S. Supply of Fish Oils,* 1950–1960
(Excluding liver, whale, and sperm oil)

Year	United States Production	Imports	Total Supply	Exports†	Available for U.S. Consumption
	Thousand pounds	Thousand pounds	Thousand pounds	Thousand pounds	Thousand pounds
1950	160,748	15,135	175,883	75,975	99,908
1951	133,530	17,370	150,900	49,838	101,062
1952	118,635	15,592	134,227	43,958	90,269
1953	150,668	11,955	162,623	108,465	54,158
1954	162,210	13,012	175,222	141,630	33,592
1955	185,092	10,380	195,472	142,672	52,800
1956	197,265	10,658	207,923	140,805	67,118
1957	148,192	7,252	155,444	114,938	40,506
1958	161,632	4,928	166,560	94,042	72,518
1959	187,088	6,750	193,838	144,480	49,358
1960‡	208,695	8,932	217,627	143,662	73,965

* Conversion factor: 7.5 pounds per gallon.
† Includes small amounts of nonmedicinal liver oils.
‡ Preliminary estimate from incomplete figures.

investigated from the standpoint of fatty acid composition of the commercial crude oils[17]. The relative amounts of saturated and unsaturated fatty acids coincides with the known physical properties of the crude oil. Table 21.3 summarizes the principal fatty acids from crude menhaden oils produced in the United States during the 1960–1961 season.

Chemical Modifications of Fish Oils

The industrial utilization of products derived from fish oils depends on the kinds of chemical modifications of the oils as well as the chemical and physical properties of the products. Fish oils can be chemically altered by reactions of the ethylenic bonds or so-called "double bonds" in the unsaturated fatty acid portion of the oils or by reactions of the carboxyl groups of the fatty acids from the oils (see Ref. 19). Chemical reactivity of fish oils and their fatty acid derivatives depend on the number and class of functional groups found on each molecule. Like chemical reactivity, the physical properties of fish oil products depend on the nature of chemical functional groups. Viscosity, solubility, acidity, melting point, and physical state are typical properties influenced by the nature of chemical functional groups.

Chemical modifications of the ethylenic bonds in fish oils are considered to be the most important from the standpoint of economic success because they make use of the uniqueness of these oils as compared to other natural fats and oils. A common chemical reaction of this type is that of hydrogenation. Hydrogen can react with the ethylenic bonds to cause hardening

TABLE 21.2. SOME PHYSICAL AND CHEMICAL PROPERTIES OF VARIOUS FRACTIONS OF FISH OILS COLLECTED FROM DIFFERENT GEOGRAPHICAL AREAS

Area	Type of Oil	Refractive Index				Iodine Number				Free Fatty Acid			
		No. of Samples	High	Low	Median	No. of Samples	High	Low	Median	No. of Samples	High	Low	Median
	Menhaden:											(Per cent)	
Northern New Jersey and Long Island	Whole	18	1.4724	1.4698	1.4706	18	181.5	172.1	176.6	18	2.57	0.47	0.76
	Winterized	10	1.4722	1.4711	1.4712	10	194.3	179.2	187.0	—	—	—	—
	Stearine	10	1.4700	1.4678	1.4684	10	171.3	156.4	161.3	—	—	—	—
South Jersey and Delaware	Whole	20	1.4810	1.4689	1.4711	20	190.8	166.6	182.6	20	2.89	0.56	1.40
	Winterized	14	1.4735	1.4690	1.4722	14	197.1	166.8	189.4	—	—	—	—
	Stearine	14	1.4714	1.4651	1.4688	14	173.7	134.4	163.1	—	—	—	—
Chesapeake Bay	Whole	5	1.4712	1.4683	1.4695	5	175.3	159.8	169.2	5	2.73	1.22	2.11
	Winterized	—	—	—	—	—	—	—	—	—	—	—	—
	Stearine	—	—	—	—	—	—	—	—	—	—	—	—
North and South Carolina	Whole	14	1.4699	1.4664	1.4687	14	174.0	150.5	162.8	12	3.57	0.67	1.70
	Winterized	7	1.4695	1.4701	1.4709	7	179.1	161.0	175.2	—	—	—	—
	Stearine	7	1.4689	1.4662	1.4681	7	162.9	141.4	157.4	—	—	—	—
East Coast of Florida	Whole	3	1.4680	1.4669	1.4679	3	158.6	150.0	157.5	3	2.94	1.07	2.30
	Winterized	3	1.4694	1.4684	1.4693	3	168.2	161.7	167.1	—	—	—	—
	Stearine	3	1.4674	1.4654	1.4672	3	150.9	136.4	149.2	—	—	—	—
East of Mississippi Delta	Whole	49	1.4705	1.4662	1.4673	51	182.2	140.1	152.5	51	74.20	0.77	1.70
	Winterized	31	1.4722	1.4673	1.4688	31	191.5	148.5	164.1	—	—	—	—
	Stearine	31	1.4707	1.4638	1.4663	31	168.8	123.9	139.8	—	—	—	—
West of delta to Mexican border	Whole	15	1.4706	1.4668	1.4674	15	165.2	150.7	152.7	15	3.31	1.00	1.78
	Winterized	12	1.4699	1.4681	1.4690	12	175.2	140.0	158.3	—	—	—	—
	Stearine	12	1.4664	1.4567	1.4659	12	145.8	123.2	132.7	—	—	—	—
Combined data	Whole	114	1.4810	1.4662	1.4687	126	190.8	140.1	162.8	124	74.20	0.47	1.70
	Winterized	77	1.4735	1.4673	1.4701	77	197.1	140.0	171.2	—	—	—	—
	Stearine	77	1.4714	1.4567	1.4677	77	173.7	123.2	153.3	—	—	—	—
	Tuna:												
California	Whole	12	1.4758	1.4732	1.4749	12	193.8	163.7	186.8	8	4.96	0.68	3.47
		—	—	—	—	—	—	—	—	—	—	—	—
		—	—	—	—	—	—	—	—	—	—	—	—
	Herring:												
Alaska	Whole	14	1.4672	1.4646	1.4657	14	172.8	123.1	133.5	14	3.31	0.57	2.05
	Winterized	12	1.4678	1.4648	1.4665	12	155.2	120.6	135.7	—	—	—	—
	Stearine	12	1.4666	1.4638	1.4649	12	146.4	109.4	126.5	—	—	—	—
	Salmon:												
Alaska	Whole	12	1.4707	1.4681	1.4685	12	175.1	150.8	168.6	12	3.48	1.14	2.06
	Winterized	8	1.4709	1.4680	1.4691	8	167.4	141.9	152.9	—	—	—	—
	Stearine	8	1.4693	1.4668	1.4675	6	162.8	94.1	110.5	—	—	—	—

TABLE 21.2 (*Continued*)

Area	Saponification Number				Nonsaponifiable Matter				Stearine Fraction				Gardner Color Index			
	No. of Samples	High	Low	Median	No. of Samples	High	Low	Median	No. of Samples	High	Low	Median	No. of Samples	High	Low	Median
						(Per cent)				(Per cent)						
Northern New Jersey and Long Island	18	198.3	162.6	192.1	14	1.69	0.64	0.77	16	46.1	18.0	36.2	19	12	10	11
South Jersey and Delaware	20	198.3	190.4	192.8	18	1.06	0.68	0.82	20	41.0	9.0	31.7	20	12	10	11
Chesapeake Bay	5	194.8	191.8	193.7	3	1.30	0.91	0.97	6	91.7	36.2	39.9	5	12	11	12
North and South Carolina	12	198.2	190.4	192.6	12	2.89	0.53	1.17	14	94.2	28.2	54.2	12	13	9	12
East Coast of Florida	3	196.5	193.3	193.8	3	1.29	0.75	1.24	3	62.8	48.7	61.5	3	14	10	11
East of Mississippi Delta	51	201.4	180.0	195.9	40	1.35	0.13	0.92	19	76.9	19.2	46.2	51	black	10	12
West of delta to Mexican border	15	197.5	195.1	196.4	13	1.32	0.59	0.93	15	66.0	22.1	42.8	14	12	11	11
Combined data	124	201.4	162.6	193.7	103	2.89	0.13	0.93	123	94.2	9.0	42.8	124	black	9	11
California	4	198.1	186.2	194.5	1	1.33	1.33	1.33	11	71.8	12.8	42.3	8	black	brownish red	dark brownish red
Alaska	14	195.2	186.2	188.3	13	1.74	0.77	1.01	14	72.4	26.3	42.0	12	12	7	12
Alaska	12	187.5	184.9	185.7	10	1.18	0.77	1.00	12	38.5	2.6	3.0	12	13	11	13

TABLE 21.3. FATTY ACID COMPOSITION OF COMMERCIAL CRUDE MENHADEN OILS

Location of catch	Date of Produc-tion	Fatty acid*															
		14:0	16:0	16:1	18:0	18:1	18:2	18:3	18:4	20:1	20:4	20:5	22:1	22:5	22:6	15:0 & 17:0	Others
		%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
South prodn.†	Feb. 1961	15.1	24.0	16.8	3.0	11.1	1.0	0.9	0.8	1.6	1.4	10.4	1.0	1.6	4.8	3.1	3.4
Empire, La.	May 1960	13.5	22.4	17.3	2.6	14.1	0.9	0.4	1.1	1.6	0.8	13.5	0.9	1.4	3.3	2.2	3.9
Fernandina Beach Fla.	May 1960	13.7	21.6	17.9	2.9	11.6	1.0	0.8	1.0	2.4	0.7	11.9	0.8	1.4	5.0	3.5	3.7
Beaufort, N.C.	May 1960	16.3	23.5	17.3	3.1	10.7	1.3	0.7	0.9	2.2	0.6	10.2	0.7	1.4	5.0	3.2	3.9
Port Monmouth, N.J.	May 1960	6.7	21.9	12.2	3.0	23.4	1.3	0.5	1.5	1.9	1.2	12.9	0.9	1.1	5.1	1.8	4.4
Port Monmouth, N.J.	July 1960	10.6	23.6	14.8	3.0	12.6	1.2	1.0	0.9	2.7	0.8	13.1	1.0	1.4	6.5	3.4	3.3
North prodn.†	Feb. 1961	12.5	19.6	14.1	2.4	19.3	1.2	1.1	1.8	2.0	1.3	10.3	1.0	1.2	5.6	2.4	4.1

* Shorthand notation for fatty acids: (carbon number:number of double bonds), e.g., 14:0 meaning 14-carbon-atom chain length with zero number of double bonds.

† Exact origin unknown.

or saturation of the oils. Other examples of this type of process will be discussed later.

Chemical reactions of the carboxyl groups in fish oils afford the other important class of reactions. In a saponification or "fat splitting" process, fish oils can be made to yield fatty acids and glycerine. The resultant fatty acids possess many of the chemical properties of the original oil triglycerides with the added advantage of the higher reactive carboxyl groups. The carboxyl end of the fatty acid chain can be readily converted to other functional groups, which may be more advantageous than the carboxyl group, depending on the use of the product. An example of this is in the preparation of fatty alcohols, which possess hydroxyl rather than carboxyl groups[43]. This and similar reactions will be discussed later.

A special class of reaction applicable to fish oil is one that takes advantage of the reactivity of the hydrogen atoms attached to carbons adjacent to the ethylenic bonds. These hydrogens in the "allylic position" exhibit particular reactive or acid-like properties. An example of this reaction applied to unsaturated fatty acid methyl esters is the bromination using N-bromosuccinimide[55].

Present and Past Uses of Fish Oils

Commercial fish oils are used by industry today in a variety of ways[4,23,49]. Many of the applications are not generally known because of their confidential nature to the manufacturers using fish oils. However, there are several applications that are well known and are discussed below.

Protective Coatings. Paints and varnishes are perhaps the most widely recognized industrial products from fish oils used in the United States at this time. The use of fish oils in protective coatings was reported by Mattil[36]. Crude fish oils are generally high in saturated fatty acid content (approximately 30 per cent), thereby preventing the formation of hard, tack-free films. Even a "cold-pressed" oil having iodine values of 190 to 200 and with from 60 to 70 per cent of saturated and mono-unsaturated acid groups removed results in dried films that lack hardness and strength[27]. Therefore, fish oils, such as those from menhaden, must be heat-bodied or thermally polymerized to yield products that dry faster and give harder films than untreated oils. More recently, alkyd resins produced from fish oils have provided a most versatile, durable, and economical class of film binders. Coatings produced from phthalic anhydride fish oil alkyds and cyclopentadiene copolymers of fish oils are major steps forward in the protective coating field.

Linoleum and Oil Cloth. Linoleums and oil cloths may include fish oils in their formulations. A process of linoleum manufacture involving blending of fish oil with linseed "linoxyn" is described by Fritz[10]. Here linseed linoxyn is a cement composed of a heat-treated mixture of specially oxidized linseed oil, rosin, and kauri gum. The linoleum "cement" is pressed onto burlap or other fabric to make a finished product. Bonney and Egge[7] report the removal of nonoxidized portions of blown oils to give improved quality to the linoxyn.

Cotton cloth that has been coated on one side with a drying oil, such as a bodied fish oil, and a filler material make up oil cloth. Solid fats or fatty acids serve as plasticizers to the oil cloth. Usually the finished product is coated with varnish or wax to give it a glossy surface.

Leather Treatment. The leather industry has consumed considerable quantities of fish oils as fat-liquoring agents and softening agents in the past. Presently, cod oil is the only fish oil being used in any quantity[32]. Studies have suggested that sulfonated menhaden oil may be used in place of cod oil in fat-liquoring leather[33,34,35]. Fish oils of medium unsaturation with iodine values from 145 to 165 may be used in chamoising of leather[5].

Patent leather can be manufactured in much the same manner as oil cloth from pilchard or similar oils. In this case, a specially prepared leather, rather than cloth, is used as a base.

Printing Inks. Another application of fish oils is in the manufacture of printing inks. Herring, sardine, menhaden, whale, and pilchard oils are suitable for the formulation of different kinds of printing inks by blending with linseed and other vegetable oils. Since odor is objectionable in some inks, the fish oil used is refined by cold-pressing and possibly by alkali treatment. A British patent describes a means for processing fish oils to produce products similar to those from tung oil. A portion of tung oil in a rapidly drying typographic ink can be replaced by fish oils that have been halogenated in the presence of an activator such as zinc and aluminum paste[28]. Sulfated and sulfonated fish oils are used in inks for photogravure processes[4].

Core Oils. Fish oils have been used in the manufacture of core oils used in foundries for iron and steel castings. Many pilchard oil cores made have been judged satisfactory by practical core makers[4].

Lubricants and Greases. In the field of lubrication, fish oils are used in blended oils, in the manufacture of greases and cutting oils, and in other specialized products. Low temperature lubricating oils, including polymerized fish oils, were studied by Tanaka and coworkers[54]. Synthetic oils produced with a modified fish oil were reported to meet the requirements of high grade lubricants[29]. The high titer of hydrogenated fish oil fatty acids makes them particularly suitable for the kinds of lubricating greases made from aluminum and lithium soaps[13,2]. A grease for gear lubrication can be formulated from a complex of lead and sodium soaps of fish oils[53]. Sulfurized fish oils compounded with mineral oils can be made to serve well as gear lubricants. Thread cutting oils can be prepared from fish oils, particularly whale oils; however, medium unsaturated fish oils may serve to replace whale oil. Wire-drawing compounds, for the cooling and the lubrication of dies, have also been formulated from fish oils, e.g., sulfonated whale oil[39].

Ore Flotation Agents. Fish oils have been used as collecting agents in ore flotation processes, particularly in the early days of froth flotation. Fish oil fatty acids of various degrees of unsaturation have recently been studied in the flotation of iron ores[8,25,57]. Fatty acids of greater than 110 iodine value, such as those from fish oils, are powerful and selective collectors of calcium-activated quartz and chert, when these materials are floated from iron oxides.

Insecticidal Compounding. Insecticidal applications involving fish oils have been investigated in certain horticultural sprays[20,30]. Miller[38] reported that injury to foliage as a result of treating walnut trees was almost completely eliminated by the addition of emulsions of salmon oil to the spray. Thomssen and Doner[56] presented a review of the insecticidal applications of fatty acids, soaps, and glycerides. More recently, reports have been made of insecticidal mixtures using vegetable oils, such as linseed oil, where semidrying type fish oils may possibly find application[22].

Fungicidal Derivatives. Unsaturated fatty acids and quaternary ammonium salts derived from fish oils are reportedly successful fungicidal agents[47]. The oxidation of highly unsaturated fractions from fish oil and unsaturated ethyl esters of fatty acid fractions of menhaden, pilchard, and cod-liver oils was shown to increase their fungicidal activity. The antifungal activity of quaternary ammonium salts prepared from fish oils were about 4000 times stronger than that of oxidized highly unsaturated fatty acid fractions prepared from fish oils.

Fire Retardants. Chlorinated fish oils have been examined for their fire-retardant properties toward wood. Pieces of wood treated with a chlorinated fish oil product failed to generate a flame when heated in an electric furnace[50,51,52].

Miscellaneous. In addition to the above applications, there are other specialty products from fish oils that are used as extenders and modifiers in rubber compounding, as caulking compounds, putties, brake blocks, cosmetics, and as pharmaceuticals. Other specialties include slushing compounds, wood preservatives, rust inhibitors, and fortifiers of vitamin feeding oils.

Hydrogenated fish oil fatty acids are reported ingredients in the manufacture of candles[48]. Herring oil is an ingredient in producing artificial protein fibers[1]. A combination of mixed driers and the polyethylene glycol ethers of fatty alcohols from sardine oil, as well as certain vegetable oils, have been investigated as successful water paints.

Potential Uses of Fish Oils

Much research has been done to provide additional products by chemical modifications of fish oils. These products may serve as finished materials for end uses or as raw materials for the formulation of other finished products. Sometimes products of basic research have no immediate use but only await further exploitation through an advancing technology. The remainder of this chapter will summarize a variety of different modifications of fish oils that may become important commercial assets to the fish oil industry of tomorrow.

Epoxides are important industrial materials used as protective coatings, adhesives, and vinyl plasticizers[37]. Epoxy menhaden oil has been prepared and tested as a plasticizer for polyvinyl chloride[12,31]. Test results from these studies showed good compatibility with and stability of PVC when epoxy menhaden oil is used as a plasticizer. Whale oil has also been investigated for its value as an epoxy oil[9]. Epoxidized oils have a use also in the oiling and waterproofing of leathers[3].

Fatty alcohols from menhaden oil can be readily produced[21,43]. Jangaard and Ackman[26] reported the properties and preparation of fatty alcohols by the lithium aluminum hydride reduction method from the oils of cod, cod liver, seal, herring, and dogfish liver. Preparations of fatty alcohols by this method cause the least amount of change in the ethylenic bonds from fish oils than any other method. Sardine oil fatty alcohols have been prepared and separated into several fractions of iodine values, ranging from 120 to 346[14]. Using fatty alcohols as synthetic intermediates, alkyl halides, silicones, and quaternary ammonium salts have been prepared from fish oils and certain pure fractions. Saturated alkyl bromides derived from menhaden oil and unsaturated alkyl bromides from pilchard oil have been produced along with the corresponding triethylalkylammonium bromides. Trichloroalkylsilanes have been synthesized from n-hexadecyl, n-octadecyl, and oleyl bromides, as well as from the fish oil alkyl bromides. Silicones were derived from the corresponding trichloroalkylsilanes by a two step hydration-dehydration process[15].

A heat-stable protective coating from fast drying fish oils can be postulated from such products as alkoxypolysiloxanes prepared from the corresponding polyunsaturated long chain fatty alcohols. Olsen and Christenson[40] report such polysiloxanes from soybean oil fatty alcohols.

Fish oils can be used to prepare several types of non-soap detergents. Hill and co-workers[24] reported fatty alcohols from sardine and menhaden oils in connection with their investigation of the detergent properties of fatty alcohol sulfates. One potentially important type is sulfated fatty acid monoglycerides[6]. Mono and diglycerides and their acetylated products have been prepared from the oils of menhaden, tuna, herring, sardine, and salmon eggs[18].

Polyunsaturated aliphatic aldehydes have been prepared from the methyl esters of menhaden oil fatty acids[11]. The corresponding acyloins were used as the intermediates in the synthesis. Reduction of acyloins were made to yield mixed "symmetrical" glycols from menhaden oil. Both the acyloins and the glycols are unique products of fish oil.

Investigations with fish oils lead to a novel method for the preparation of hydroxylated products. Autoxidized fish oils were shown to give hydroxylated products on treatment with thiourea. Methyl oleate hydroperoxide with a peroxide value of 6050 was converted to an oil having a peroxide value of 56 by this method[45].

Fish oil is reported to be a suitable raw material for commercially produced nitriles and amines[41].

Fish oils and fish oil fatty acids should better serve as raw materials for the synthesis of new chemical products if the raw materials are fractionated into less complex and purified mixtures. This approach has been taken to a limited extent by industry to provide such materials as select chain length fatty acid mixtures, e.g., C_{18}—C_{20} partially hydrogenated fatty acids. Similarly, industry provides destearinated fish oils, which can be considered as a partial fractionation to provide a more uniform product. Recently, Gruger[16] reported the investigation of several commercially important fractionation methods that provide purified and less complex mixtures of fatty acids from fish oils. These fractions of fatty acids from the whole oil can be put to better use through chemical modifications by employment of select reactions that take advantage of the uniqueness of the particular acids.

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PART IV

Preservation Methods

CHAPTER 22

Handling Fresh Fish

John A. Dassow

Fish is one of the most perishable of all foods and needs proper care from the time it is caught until it is served or processed. The handling of fresh fish during this interval determines to what extent deterioration takes place from three sources—enzymatic, oxidative, and bacterial. How rapidly each of these progresses during the spoilage of the fish depends upon, first, the application of basic principles of food preservation and, second, the variables of the species and the fishing methods. These basic factors in fresh fish handling will be examined before considering the various steps in commercial practice from the fishing vessel to the retail market.

Consideration is given in this chapter to the accepted fundamentals in handling fresh fish. Chapters dealing with the various species provide additional information on technological advancements and new process methods in handling fresh fish and shellfish.

Factors Affecting Freshness

It is obvious that all fish are fresh when first caught, regardless of the final disposition. On the other hand, a significant portion of the total catch of the United States fisheries, 662 million pounds from a 5.2 billion pound catch in 1961, is *marketed* fresh[7]. This includes the whole, drawn and dressed fish and fresh shellfish, but not fresh fillets, which are included with the frozen fillet total of 158 million pounds. At this point, the term "fresh" might well be defined. Actually, the consumer at either the retail or the institutional level may not know whether fishery products are "fresh" or "freshly thawed."

What is Fresh? Of all the dictionary meanings, two are implicit in the correct use of "fresh": (1) newly produced, not stored or preserved and (2) having its original qualities unimpaired, i.e., not deteriorated in any way. Fish which have been carefully frozen and thawed and are otherwise of high quality might well be considered fresh by the second definition although not by the first, since the process of freezing was used. Both aspects of the definition must be kept in mind for our consideration of fresh fish. In purchasing, careful inquiry or knowledge of the seasons for the species wanted should indicate whether the product is truly fresh.

The descriptions of fresh fish characteristics have many variations; however, the following from the Bureau of Commercial Fisheries[1] provides a basic guide:

Whole or drawn fish have the following characteristics:

(1) Flesh: Firm, elastic flesh, not separating from the bones, indicates that fish are fresh and have been handled carefully.

(2) Odor: Fresh and mild. A fish just taken from the water has practically no "fishy" odor. The fishy odor becomes more pronounced with passage of time, but it should not be disagreeably strong when the fish are bought.

(3) Eyes: Bright, clear, and full. The eyes of fresh fish are bright and transparent; as the fish become stale, the eyes become cloudy and often turn pink. When fish are fresh the eyes often protrude, but with increasing staleness they tend to become sunken.

(4) Gills: Bright red. The color gradually fades with age to a light pink, then gray, and finally brownish or greenish.

(5) Skin: Shiny, with color unfaded. When first taken from the water, most fish have an iridescent appearance. Each species has its characteristic markings and colors which fade and become less pronounced as the fish loses freshness.

Fresh fillets and steaks have the following characteristics:

(1) Flesh: Fresh-cut in appearance; the color should resemble that of freshly dressed fish. It should be firm and moist in texture, without traces of browning about the edges and without a dried-out look.

(2) Odor: Fresh and mild.

(3) Wrapping: If the fillets or steaks are wrapped, the wrapping should be of moisture-vapor-proof material. There should be little or no air space between the fish and the wrapping.

Fresh Shrimp have a mild odor, and the meat is firm in texture. The color of the shell may be grayish green, pinkish tan, or light pink. When cooked, the shells turn red, and the meat takes on a similar attractive reddish tint, with possibly some dark-red spots. When shrimp are sold as "green shrimp," this does not refer to the color or species, but is a term used in the trade to describe shrimp that have not been cooked.

Clams and oysters in the shell should be alive—the shells should close tight when tapped gently.

Shucked oysters should be plump and should have a natural creamy color with clear liquid. If oysters are in the original package or can, there should be not more than 10 per cent of liquid (by weight). Oysters with an excess amount of liquor should be avoided, as this indicates that they have been improperly handled. Excessive water results in bloating of the oyster meat, and partial loss of flavor and food value. For purchasers who use a chemical test for freshness, the pH should be at least 6.0.

Crabs and lobsters, when bought alive, should show movement of the legs. The "tail" of live lobsters curls under the body and does not hang down when the lobster is picked up.

Crabs and lobsters, cooked, should be bright red and should have no disagreeable odor. By lifting slightly the lid under the body section of crabs, it is possible to smell any strong, disagreeable odor very easily.

Species and Fishing Methods. Fish that are very active in their normal habitat, e.g., tuna and mackerel, may become excited and die in a frenzied state when seined. Similarly, certain types of gear, e.g., salmon gill nets, may kill the fish after an exhausting struggle. Such activity before death results in rapid development of *rigor mortis* followed by earlier signs of deterioration during icing. On the other hand, many salmon are caught by surface hook and line, brought to the boat swiftly, and dispatched quickly with a blow on the head. Halibut caught on a bottom hook and line usually come to the surface easily and are quickly dispatched. Such "clean kills" are significant in extending freshness and quality, as is well known in slaughtering livestock. In at least one fishery, domestic trout farming, a major operator has found that an electric shocker to stun or kill the trout pays quality dividends[2].

Physical Damage. The fishing gear and the handling of the fish when the gear is brought aboard often contribute to bruising or tearing the flesh. Transfer of fish in and out of the boat with gaff hooks, pughs, or forks takes a toll in terms of unsightly and unsanitary holes in some fish. Quick bacterial spoilage follows in these pugh marks. Rough weather on the trip back to port and excessive ice pressure in the bins accelerates the deterioration and increases the shrinkage of fish.

Dressing. Fish that are feeding actively at the time of catch show greater incidence of autolytic spoilage by digestive enzymes and need prompt dressing and icing.

It is usually desirable, where possible, that all fish be dressed, i.e., gills and viscera removed, immediately after catching. The gut cavity should be washed with clean sea water before icing. Recent tests aboard an Atlantic trawler[6] showed that use of 50 ppm chlorine in the sea water was more effective than plain sea water in rinsing the blood and slime from the fish. In some fisheries, e.g., the Pacific trawl fishery, dressing is deemed impractical for the value and size of the fish. Experience in the distant water trawl fishery of Great Britain has demonstrated the importance of gutting and washing the fish[5].

Chilling Procedures. Lowering the temperature of the fish by a prompt and efficient chilling procedure is fundamental for preservation of fish freshness. Proper use of crushed fresh water ice is the oldest and simplest method.

Use of Ice: The most significant rule in use of ice or any chilling procedure is that eventual spoilage is only retarded, not stopped[3].

Ice, when properly used in adequate amounts, aids in preservation in two ways: (1) the temperature of the fish is lowered to approximately 32 to 36°F, which slows the bacterial and enzymatic changes and (2) the melting of the ice bathes the fish in clean cold water and, with proper stowage, washes away considerable slime, blood, and bacteria.

Every pound of ice, on melting, absorbs 144 BTU of heat from its surroundings. This absorption of heat is sufficient to lower the temperature of 19 pounds of fish 10 degrees Fahrenheit (assuming that the fish has a specific heat of 0.760 and that no external heat was absorbed in the process). In actual practice, the heat transfer from the boat hold and air equals or exceeds the heat transfer from the fish.

To ice the fish correctly in the boat hold, three things should be accomplished: first, the fish should be placed with sufficient ice around them to cool them promptly and to maintain their temperature as close to the melting point of the ice (32°F) as is practical for the duration of the trip; second, the ice and fish should be arranged to allow accumulated water, blood, and slime to drain through the mass into the bilge; and third, the fish should not be subjected to great pressure from the weight of fish and ice placed above. Otherwise, the physical damage as well as the shrinkage or loss of weight by the fish will be excessive.

Every fisherman soon learns how much ice to "take on" to carry him through the trip. The expected duration of the trip, the temperature of air and sea water, the insulating value of the sides and deck head of the vessel, and the expected quantity of fish to be obtained are all factors to be considered in estimating the amount of ice to be loaded. Ice is cheap compared to the other expenses of a fishing operation; hence, no fisherman should cut short his estimated need. The exact ratio of weight of ice to weight of fish to be carried varies commonly from 1:4 to 1:1. In northern waters in uninsulated holds of wooden vessels, a ratio of 1:2 is common. More, rather than less, ice should be taken by fishing vessels because it has been found that additional ice (compared to present practice) should be allowed at the sides of the vessel and adjacent to the wing boards of each pen. Any exposure of fish at these points due to melting of ice contributes substantially to quality losses.

Correct icing requires considerable care and experience, and every vessel is a separate problem depending upon the construction, hold and pen layout, and the relative heat transfer from the water and air outside the hold. For eviscerated fish, the gut cavity or poke of the fish should be well filled with ice, taking special care to pack the ice in the gill cavity and around the nape. Preferably, each fish should be surrounded by ice or the fish placed in alternate layers such that the ice is in actual contact with the greater portion of each fish.

Preservative Ices: In efforts to improve the keeping quality of fish in ice, experimenters have incorporated a number of preservatives or germicides in the ice. Sodium benzoate, benzoic acid, chloramine compounds, fumaric acid, sodium hypochlorite, sodium nitrite, carbon dioxide, hydrogen peroxide, calcium propionate, disodium phosphate, and various antibiotics are among the many substances tried. Any such substance must meet the approval of the United States Food and Drug Administration for use with food products in this country. Proper care in the handling and storage of fish, with adequate amounts of ordinary crushed or flaked ice, will yield as much or more improvement in keeping quality than will the casual use of any preservative-treated ice tested and accepted for use with food fish to date. Any preservative ice that has been accepted for use on fish will be of greatest value only if its use is combined with the best handling practices.

The introduction of the wide-spectrum antibiotics, especially chlortetracycline (CTC) and oxytetracycline (OTC), about 1950 was followed by more extensive laboratory and commercial testing for application to fresh fish preservation than any other compounds to date. The consensus in the considerable scientific literature favors use of five to ten ppm CTC as a dip before icing or as an additive in the ice for extension of keeping quality.

In commercial operations, use of preservative ices generally add not more than two or three days to the storage life of the fish, although in some laboratory or experimental procedures extensions of up to two weeks have been reported. Regulations of the United States Food and Drug Administration provided in 1959 a tolerance of five ppm for use of CTC on certain fish products in the fresh, uncooked and unfrozen form. Much of the research on use of antibiotics in fish has been ably summarized with a good literature review by Tarr[10].

Refrigerated Sea Water (RSW): The cooling of fish in chilled, circulating sea water at 32°F is more efficient than is cooling in crushed ice under usual commercial conditions. In icing fish aboard the vessel, the best results are attained if ice completely surrounds each fish. In practice, this ideal icing is difficult to attain, and a layer of fish tends to build up through which the melt water from the ice percolates. The cooling medium in the case of circulating refrigerated sea water surrounds the fish entirely, and thus the transfer of heat from the fish is more rapid in the chilled sea water. Moderate circulation of chilled sea water through the mass of fish and past the cooling coils is essential to achieve a uniform temperature of 29 to 30°F at all times.

The problems of refrigerating a hold for sea-water storage are somewhat greater than are those of ice storage, as the hold must not only be constructed water-tight but must be subdivided into sections or tanks with suitable baffles. Large centrifugal-type pumps are needed for pumping water in or out of the separate tanks and to and from the brine chiller or heat exchanger. Special equipment must be designed for discharging and unloading the fish. The water in the tanks is precooled to about 29°F prior to being loaded with fish. Ice may be carried to supply additional refrigeration if large volumes of fish must be handled in a short time. If preferred, three per cent of salt (0.25 pounds of sodium chloride per gallon of water) may be used instead of sea water.

Comparison of keeping qualities of fish in refrigerated sea water (or three per cent brine) and ice[9] indicate that sea water has no special properties for extending the storage life if fish is of the same temperature in each case. From the viewpoint of keeping quality, the real advantage of refrigerated brine appears to be that the brine temperature can be lowered to 29 to 30°F, or just above the point at which the fish begin to freeze. The importance of this characteristic is related to the fact that bacterial and enzymatic activity are greatly depressed at temperatures slightly below 32°F and greatly increased at temperatures slightly above 32°F. For example, Canadian workers found that cod and haddock fillets kept eleven to twelve days at 31.5°F but only five to six days at 37°F. At 45°F the keeping time was only two to three days[4].

The use of the RSW system is advantageous commercially in that the fish may be transferred to tanks with far less labor than icing requires. The brine supports the fish and minimizes physical damage and pressure effects that may occur in the deep layers of iced fish; however, the effect of brine on flesh composition should be considered. The influence of salt in the brine during RSW storage of pink salmon increased the ash and sodium content greatly, whereas salmon in ice showed extensive leaching of the ash, sodium, and potassium contents[11]. The technological aspects and engineering considerations of RSW for storage and transport of fish have been covered thoroughly by Roach, Harrison, and Tarr[8].

Sanitation. Fish buyers know from experience that, under comparable conditions, the cleanest boats bring in the best quality fish. "Good housekeeping" aboard the vessel is associated with careful handling methods because the fisherman who keeps the fish hold, gear, and deck clean is likely to be quality-conscious when he ices his fish. Contamination from any source will affect fish quality. Dirt, slime, fuel oil, rust, grease, blood, scales, and bits of viscera and flesh must be removed and washed away constantly in order to keep the deck and the hold clean.

The problem of sanitation and housekeeping aboard a boat depends greatly upon its design and construction. The use of concrete, mastic, or metal (corrosion-resistant types) to eliminate the hard-to-clean corners in the holds saves many hours of labor and cleaning during the busy season. In recent trials, aluminum alloys have been found satisfactory for construction of the lining, stanchions, shelves, and pen boards in the holds of large trawlers. Bilges should be cleaned frequently during the fishing season, using a good detergent or bilge-cleaning compound to remove accumulated dirt, oil, and slime. Pen boards should be scrubbed, sanitized, and allowed to dry after each trip.

Although the cold-storage plants prepare the ice from clean potable water, ice can be contaminated with dirt or bacteria during crushing and delivery at the dock and during handling aboard the vessel. Since the ice comes in intimate contact with the fish, old ice should be discarded at the end of the fishing trip and new ice should be kept clean. Shovels, utensils, gloves, and the hold should be cleaned at frequent intervals and rinsed with chlorinated water (25 to 50 ppm) or other effective sanitizing solutions.

Steps in Commercial Handling of Fresh Fish

On the Vessel. Trips in which the fish are abundant and the weather is good provide the best opportunity for high quality fresh fish. If fishing is slow, the earlier part of the catch may languish too long in the hold while the rest of the catch is obtained. Stormy weather may bruise both the fishermen and their catch. It is well known that a stormy return trip may result in great quality loss from the physical pounding which tends to cause excessive ice loss and soft fish.

Of those factors under control by the fisherman the most important are speed in getting the fish chilled, care in handling to avoid cuts and bruises, proper dressing and washing the fish, and the correct use of ample ice for the trip conditions. In many fisheries, the fisherman returns his catch within a few hours to port or to a nearby fish buyer. Keeping the fish clean and cool for these few hours has been shown to be most important for the best keeping quality. Day fishermen frequently carry a small amount of ice for this purpose.

Unloading (Figure 22.2) is the final operation for the fishermen who must transfer the fish from the iced bins by hand, shovel, or pugh to the

Figure 22.1. Icing haddock aboard an Atlantic trawler. (*U.S. Fish and Wildlife Service.*)

unloading box or net. The ice is removed and the fish are dumped on a table or a belt for grading. Buyers grade most fish species before washing since the slime provides a quick index to the quality. The fish are generally weighed in tared carts or boxes. During these unloading and transfer operations, it is common to find that iced fish may increase several degrees in temperature.

In the Shore Plant. Following unloading, it is frequently necessary to hold the fish for later shipment or processing. In some cases the fish are left in carts holding several hundred pounds and simply topped with crushed ice. A better procedure is to spread the fish on a thick layer of crushed ice laid along a clean concrete floor provided with suitable side boards to segregate various lots along the fish house floor. An excellent procedure used in many progressive fish houses is to provide a separate

Figure 22.2. Unloading trawl fish at Boston Fish Pier. (*National Maine Coast Fisherman.*)

insulated area away from traffic for such iced fish on the floor. The greatest problem in the operation arises from gluts in which fish must be held two or three days before they can be processed. It is under these circumstances that initial high quality of the fish is most important if they are to keep well during processing delay.

Filleting. A major portion of all trawl-caught fish is sold as fresh fillets. In large operations many of the washing and handling operations are mechanized. In small operations, the fish are washed and filleted by hand on a cutting board placed next to a sink. The fillets may be washed briefly in a dilute salt solution and drained for packing or may be transferred directly from the filleting board to the flat fillet tin, which holds 15 or 20 pounds.

Mechanization of the fillet plant is becoming increasingly important because of the large volume of the operation, the relatively low yield of

Figure 22.3. Filleting Pacific ocean perch in a Pacific Coast processing plant. Note the disposal chute at the right, the incoming fish on the lower belt, and the pans of fillets on the upper or discharge belt. (*Whiz-Eardley Fisheries Co.*)

the product (e.g., 25 per cent in many flat fish), and the stiff economic competition from other protein foods and imported fishery products. A typical filleting plant consists of a mechanical washer, which may also scale the fish, a manual fillet line or a filleting machine, a washer and/or briner, a draining table or belt, an inspection area, and a mechanized packaging line.

The washer often consists of a large inclined rotating cylindrical container constructed of metal screens. The fish are tumbled in sprays of water and then pass to the fillet line. A manual filleting line usually consists of endless belt conveyors which bring the fish to individual filleters along each side and transfer the fillets to the end of the line at the washer or briner. Waste and trimmings are usually placed on the return belt of the incoming line and transferred to an outside disposal conveyor. After removal of the fillet, the skin may or may not be removed depending on whether a skinning machine is used or whether the skin is left on, as is common, for example, with Pacific ocean perch. The fillets of lean fish

Figure 22.4. Filleting room of a Pacific Coast processing plant. The filleting line is at the right and the packing line at the left. (*Whiz-Eardley Fisheries Co.*)

such as cod and haddock may be dipped in a dilute salt solution, especially in New England processing plants, to enhance flavor and control excess drip of the frozen and defrosted fish. Inspection of the fillets usually includes an examination on a glass plate illuminated from below so that both surface and internal defects or parasites may be detected and removed if objectionable.

Dressed fish, such as salmon and halibut, are shipped to wholesale markets in large volume. Whereas shipments within a few hundred miles provide no problem, the fish must be most carefully re-iced and boxed for refrigerated truck or rail shipment when greater distances are involved. Large shipments of fresh dressed fish are made daily from the large ports of both the Atlantic and the Pacific to the large inland markets. Strapped or wirebound boxes holding 100 to 200 pounds of fish and ice are used, as a rule with one part ice to one or two parts of fish depending on distance and re-icing facilities along the route.

For shipment, fresh fillets in tins are covered by a slip cover secured by a slotted strap and buried in crushed ice in 200 pound boxes. In recent years processors have found that large plastic film bags or plastic-lined

Figure 22.5. A box of fresh lake herring from the Great Lakes ready to be top-iced and closed for shipment to market. (*U.S. Fish and Wildlife Service.*)

cartons may be used quite successfully rather than the relatively expensive fillet tins. Shipments are made to wholesalers and chain stores where the fillets are repackaged in the familiar tray and film overwrap in family-sized portions. These are displayed in the retail refrigerated case and normally are sold within two to three days after repackaging. The shelf life of such fillets is not apt to be over five to six days inasmuch as the original fishing operation, process delay, and shipment have already taken the better part of the original storage life of about 14 days for properly handled trawl fish. It is at this end of the chain that the care taken along the line to assure good chilling procedures and sanitation pays dividends in terms of quality. Restaurants and institutions are major consumers of fresh fillets and are increasingly aware of the need for specifications in fillet purchases in order to assure consistent quality and satisfaction.

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CHAPTER 23

Freezing and Cold Storage

J. W. Slavin

Artificial freezing of fishery products was introduced in 1861 by Enoch Piper of Camden, Maine[44]. He used a mixture of crushed ice and salt in pans to freeze fish laid out on racks within an insulated chamber. After freezing, the frozen fish were glazed with water and transferred to an insulated chamber equipped with vertical metal tubes filled with the salt-ice freezing mixture. Patents on the freezing of fish were granted in 1869 to W. Davis and in 1875 to W. and S. H. Davis of Detroit, Michigan. Their method consisted of packing the fish in metal pans with tight fitting covers and then placing the "cans" of fish in insulated bins with alternate layers of salt and ice. Many other patents of less importance were issued during this period for the freezing of fish with eutectic ice.

The most important advance in the artificial refrigeration of fish was the use of ammonia refrigerating machines for freezing and cold storing fish in 1892 at Sandusky, Ohio. At the beginning of this century many different types of freezing equipment were introduced for fisheries application. Brine-freezing systems were developed by Taylor, Zarotschenzeff, Petersen, Kolbe, Ottesen, and others, but with the advent of packaged foods these early methods were discarded in favor of direct-contact and air-blast freezing. Freezing on refrigerated coils, or sharp freezing, was also introduced in this period, and this method is still being used to a limited degree for freezing whole fish.

The marketing of frozen fishery products began in 1926 with a shipment of frozen fish from New York to Detroit in a railroad car refrigerated with dry ice. Subsequently, many technological and engineering improvements were made in the transportation and marketing of frozen seafood, thereby making it possible to market these products on a large scale.

The frozen sea fish industry has grown considerably since Piper's first freezing of fish a century ago, and now over 350 million pounds of frozen fishery products are produced annually in the United States.

Maintenance of Product Quality

The quality of frozen fishery products is influenced by many different considerations. Among the most important are composition of fish, prefreezing handling and treatment, method of freezing employed, and the environment to which the frozen product is subjected during storage and handling. Of principal concern here is the temperature and humidity of the cold-storage area and the protective packaging or glazing afforded the product. It is difficult to pinpoint precisely how much each of the above factors individually influences the quality of frozen seafood.

Fish not readily amenable to freezing have a low resistance to adverse conditions of treatment; thus, they must be handled under almost ideal conditions. In contrast with this are those products which lend themselves to freezing and have a certain built-in resistance to malpractices. Likewise, a product of excellent quality prior to freezing will take more punishment than one of only marginal quality when frozen.

Composition of Fish. The composition of fish has a significant effect on whether or not a product can be successfully frozen. Fish with high oil content are, in general, more susceptible to oxidative color and flavor changes than are those that contain only small quantities of oil. However, oil content is not the only factor involved here. According to Stansby[43], pink salmon, containing only 6 per cent oil, develops rancid odors and flavors much quicker than does king salmon containing as much as 16 per cent oil.

The relative suitability of different fishery products for freezing and frozen storage is indicated in Table 23.1. Today, 100 years after the inception of freezing, little is known of the biochemical properties of fishery products and how they influence the suitability of the product for freezing. For example, the North American lobster cannot be frozen satisfactorily because of serious textural changes; yet the spiny lobster, or craw fish, is readily amenable to freezing. Atlantic Coast oysters, blue crabs, and clams are not generally suitable as frozen foods, but little information is known as to why this is so.

Prefreezing Treatment. The condition of the raw material to be frozen significantly influences the subsequent quality of the frozen product.

Quality changes in the fresh state take place much more rapidly than do those in the frozen condition and are quite different in nature. The former result chiefly from autolysis and growth of bacteria[5,7,8] and the latter from dehydration and oxidation[7,37,43]. Frozen fish prepared from partly spoiled fish have a much shorter frozen shelf life than fish freshly frozen. Reay[35] found that the shelf life, or quality, of frozen haddock used for smoking decreased considerably because of an increase in the storage period of the unfrozen raw material. His results are not applicable to frozen fillets since the very nature of freezing alone may seriously impair the suitability of a product for smoking. More recently, Peters[29] found

Table 23.1. Relative Suitability of Fishery Products for Freezing and Frozen Storage

Degree of Suitability		
High	Moderate	Low
Storage Life of 7 to 12 months at 0°F	Storage Life of 5 to 9 months at 0°F	Storage Life of 4 to 6 months at 0°F
Haddock	Ocean perch	Mackerel
Cod	Whiting	Tuna
Flounders	King, red, or coho salmon	Catfish
Hake	Lake herring	Sea herring
Shrimp	Red snapper	Spanish mackerel
Halibut	Smelt	Pacific sardines
King crab	Crawfish	Clams
Dungeness crab	Rockfish	Chub
Pollock	Carp	Chum or keta salmon
Sea scallops	Buffalofish	Whale meat
Blue pike	Swordfish	
Yellow perch	Pacific oysters	
	Alewives	
	White bass	

that the chilled storage age of whiting seriously affects the quality of the frozen packaged product. The results of these investigations are shown in Table 23.2.

Much work has been done on assessing quality changes in chilled fish and in frozen fish, but little information is available on the relationship of prefreezing quality to the quality of the frozen product.

Another consideration in freezing fish may be whether or not the raw material has passed through *rigor mortis*. Banks, et al.,[3,4,47] found that eviscerated cod stored in ice for up to three days after catching could be frozen satisfactorily with little loss of quality. It has also been suggested that fish frozen in a pre-rigor condition are of lower quality than fish frozen post-rigor[24]. Other investigations[14,15,28,41] report that fish frozen in a pre-rigor condition are of high quality and that this method of freezing is quite satisfactory.

There is considerable controversy regarding effects of pre- and post-rigor freezing on the quality of the frozen fish. When freezing fish at sea, the practical considerations of fast and easy product handling offset any theoretical advantage claimed for freezing in a post-rigor condition. In the same vein, fish frozen ashore are customarily in post-rigor condition, and no ill effects have been noted because of this. There are many factors that have a greater influence on product quality than do pre- or post-rigor freezing.

Freezing. The relationship of freezing to quality changes is discussed in comprehensive reviews by Dyer and Dingle[12], Heen[13], Stansby[43], and

Table 23.2. Effect of Chilled Storage Age on Shelf Life of Frozen Whiting

Period of Storage in Ice at 32°F	Shelf Life of Frozen Product Stored at 0°F
Days	Months
0	12
2	12
4	6
7	2
9	0
11	0

Reuter[36]. Fast freezing results in large quantities of very small ice crystals in the muscle, whereas slow freezing forms large crystals. However, more recently theories have been advanced contradicting the early observations that the large ice crystals formed during slow freezing mechanically damaged and ruptured the cells and were responsible for increased drip in the thawed product. Lebeaux[16] found no evidence of cell puncture during slow freezing. Love[19,20,21], in investigations based on the premise that cell rupture will liberate deoxyribonucleic acid (DNA) from the nucleus of the cell, observed some correlation of DNA with cell damage but did not conclusively demonstrate the effects of slow or quick freezing on cell damage.

Work conducted to date has been concerned primarily with the influence of the freezing rate on biochemical changes in the muscle tissue. Few investigations have been conducted to determine if the freezing rate affects the quality of the product as judged by organoleptic examinations. The author's experience indicates that there is no recognizable difference between the organoleptic quality of products properly fast or slow frozen.

Fast or quick freezing is in wide usage because of its practical advantages in expeditiously mass producing frozen seafood. Slow freezing is still used for large whole fish such as halibut, tuna, or salmon, and no ill effects have resulted because of the rate of freezing.

The method of freezing may affect the appearance or quality of the frozen product. In sharp freezing, where the product is frozen on refrigerated grids or plates, bulging or voids may occur because of the lack of outside pressure to control product expansion. Freezing in an air blast can result in excessive "freezer burn," or dehydration, because of low relative humidity or the use of air velocities of over 500 feet per minute with unpackaged or inadequately packaged products. The package will also be distorted unless devices are used to control expansion. In immersion freezing, the temperature of the freezing medium and the time of product immersion must be precisely controlled. If this is not done, the immersion solution will penetrate into the fish and may adversely affect the quality of the product. Products frozen in a contact-plate freezer contain a minimum amount of bulges and voids and are usually highly acceptable.

Temperature. Temperature and time of storage are the most important factors influencing the quality of frozen seafood. Exposure of the food to higher temperatures significantly increases the rate of quality loss. Likewise, a reduction in product temperature retards the adverse quality changes that take place in the frozen state and results in an extension of product shelf life.

It may be said that fresh frozen seafood contains a fixed amount of edible quality, the loss of which is both temperature and time dependent. The product will lose this quality over a rather long period of time when stored at low temperatures and over a proportionally shorter period of time when subjected to high temperatures. Van Arsdel, *et al.*,[45] have used a time-temperature coordinate system to mathematically estimate the quality loss of frozen fruits and vegetables subjected to a number of different temperatures for various periods of time. Slavin[42] reported that this tool shows considerable promise in estimating the loss of quality in frozen fishery products.

Many investigations conducted on the storage of frozen fishery products verify that a decrease in product temperature markedly reduces loss of quality. Notevarp and Heen[25] and Reay[34] found a great difference in the quality of fish stored for only several weeks at 14 and −4°F. Dyer, *et al.*,[10] found that frozen rose fish fillets can be kept in good condition for 4 to 5 months when stored at 10°F and for 6 to 8 months when stored at −10°F. It was also reported that frozen cod stored at temperatures of 15°F for only 3 to 14 days will deteriorate in quality quite rapidly[17].

Stansby[43] reported that oxidative changes in frozen fish were greatly retarded by lowering the temperature and that fish held at 0°F were oxidized at only about half the rate of those held at 20°F. In his review, Heen[13] reports there was no detectable change in the quality of fish stored at −256°F for 6 months. However, a noticeable decrease did result in the quality of fish stored for 6 months at temperatures as low as −103°F.

In the final analysis, the choice of product storage temperature is arrived at after weighing cost of storage, maximum storage period desired, and susceptibility of the species selected to quality changes in the frozen state. Lean fish such as haddock or cod should be kept at temperatures of 0°F or lower. Fatty fish such as mackerel, sea herring, or tuna should be stored at temperatures not higher than −20°F.

Packaging and Glazing. Frozen fishery products undergo adverse changes in quality if subjected to contact with air or loss of moisture. The air surrounding the frozen product is usually of lower moisture-vapor pressure than the product and acts as a sponge in removing moisture from the food. This loss of moisture results in dehydration of the fish flesh to a point where chalky and fibrous texture develop, discoloration takes place, and off-odors and flavors develop. Contact of air with frozen fish causes oxidation of the fats and results in "rusting," or discoloration of the flesh and development of rancid or off-odors and flavors.

The storage life of frozen fishery products can be increased significantly by using a protective shield to cover the product and thereby prevent dehydration and oxidation. This protection can be obtained by packaging, glazing, or a combination of these methods.

Packaging. The packaging of frozen fishery products has been reviewed by Peters[27] and Pottinger, *et al*[33].

The packages used for frozen fishery products must have a low moisture-vapor permeability, a low oxygen transmission rate, and be resistant to absorption of oils and also water. They must also fit the product tightly to minimize air spaces or voids. Products in a loosely fitting package will undergo rapid loss of quality because of: (1) oxidation, from the excessive air surrounding the food, and (2) dehydration, caused by a constant migration of moisture from the product to the inside surface of the package.

It is generally agreed that fatty fish lose quality more rapidly than do lean fish, and they therefore must receive added protection against the detrimental effects of oxidation and rancidity. Conventional waxed cartons, overwrapped with films containing polyethylene, waxed paper, cellophane, or combinations of these materials, are generally not suitable for packaging these fish. They are not resistant to gas transmission and do not fit the product tightly.

The use of hermetically sealed tin containers will significantly increase the frozen storage life of fatty fish or other fish and shellfish not readily amenable to freezing. However, despite these advantages, these containers are seldom used for frozen seafoods, probably because of their high cost and association with heat-processed foods. Fatty fish can also be well protected by using vacuum-pack or heat-shrinkable bags, where the air is removed from the package and the film shrunk tightly around it by immersion in hot water or passage through a steam chamber. Also, instead of vacuum packaging, the package can be purged with nitrogen gas to remove the oxygen. Pouches and bags made of polyester films coated with or laminated to polyethylene, cellophane, polyvinylidene chloride, aluminum foil, or certain combinations of these materials are quite satisfactory.

Another method of packaging fatty fish is to dip the product into a protective alginate or other solution, package it, fill all voids with the dipping solution, overwrap the carton, and freeze the product. An alternate method consists of individually freezing the product, packaging it, flooding the cartons with a glazing solution, overwrapping the cartons, and refreezing the product or putting it into low-temperature frozen storage. The above methods have been used quite successfully for packaging frozen shrimp, salmon, mackerel, smelt, and herring.

The so-called nonfatty products such as haddock, cod, certain shellfish, and precooked fish must be protected principally against loss of moisture; in some cases, however, oxidation can also be a serious problem. The packaging requirements for these fish and shellfish are less demanding than those for fatty fish; therefore, conventional cartons and overwrapping films can be used satisfactorily. Fish fillets, breaded convenience items, or steaks can be adequately protected by packaging in tightly fitted waxed cartons overwrapped with waxed bleached sulfite paper, combinations of waxed paper, polyethylene, aluminum foil, or cellophane. The new cook-in-the-bag package being used for shrimp, fillets, and other heat-and-serve seafoods offers considerable promise. Materials such as polyethylene and combinations of foil, polyethylene, and paper are being used quite satisfactorily for this purpose.

Glazing. The function of a glaze is to provide a continuous film or coating that will adhere to the product and retard loss of moisture or oxidation. Glazes are, in the main, applied to whole or eviscerated fish, although in some instances they are used for packaged fish. Application is by dipping or spraying.

Although many different types of glazes have been introduced, ice—the first one used—is still the only glaze of commercial importance.

Many patents have been issued describing the addition of various chemicals to water to reduce the brittleness or evaporation of the ice glaze. Colloids and thickeners such as Irish moss extractives, cellulose gum, and pectinates have been used to improve the effectiveness of the glaze. An alginate referred to as "Protan" is being used commercially in the glazing of packaged mackerel fillets[26]. Dassow, *et al.*,[9] reported a glaze of corn syrup solids to be effective in increasing the shelf life of frozen salmon steaks. The writer has found that water glazes containing sodium alginate or carboxymethylcellulose were not any more effective than a plain ice glaze in extending the shelf life of frozen packaged whiting and round haddock.

Antioxidants have been incorporated into dips or glazes in an attempt to reduce oxidation and rancidity of fatty fish[24,33]. Banks[1] found that ascorbic acid and ascorbates, different gallates, and other antioxidants retarded development of rancidity in different species of fish, but the effect varied greatly and was generally unreliable. Piskarev, *et al.*,[30] reported that sprats glazed with water containing ascorbic acid developed foreign taste and odor and kept no better than water-glazed fish. Bramsnaes[6], however, found that development of rancidity of fat in frozen rainbow trout could be delayed by dipping in a weak solution of ascorbic acid or other antioxidants.

The present trend is to use packaging materials wherever possible to protect the product from loss of moisture and oxidation. Glazes are still used for some whole halibut, salmon, or fresh water fish and fish steaks or portions readily susceptible to rancidity. Ice glaze is the only one used commercially. Antioxidants are seldom used in glazing materials because their influence is not significant.

Relative Humidity. The relative humidity is a comparison of the amount of moisture in the air, at a particular temperature, to that which the air can theoretically hold. Air at a certain temperature will hold only so much water; then precipitation of moisture in the form of rain or frost will occur. As the temperature of the air decreases, its ability to hold moisture also decreases. The air also exercises a certain vapor pressure, which increases because of moisture content and temperature.

Frozen fishery products contain about 80 per cent water and therefore have a relatively high moisture-vapor pressure. As the relative humidity of the storage environment is decreased, the moisture-vapor pressure of the air decreases proportionally, causing a greater difference between the moisture-vapor pressure of the product and the surrounding air. Moisture then migrates from the product to the surrounding air until equilibrium is established. The rate at which the moisture is removed from the product is a direct function of the difference in the vapor pressure between product and air.

Fishery products are subjected to storage, transportation, and handling conditions where both the temperature and the relative humidity may vary considerably. Temperature has a greater effect on product quality than does relative humidity. However, the detrimental effects of a low relative humidity should not be underestimated, particularly when storing unpackaged frozen seafoods. Slavin, *et al.*[39], found that whole tuna stored at 0°F and at a relative humidity of 70 to 80 per cent for 10½ months lost 20 times more weight than tuna stored similarly except at a higher relative humidity of 90 to 95 per cent. Results of these tests also showed that packaged seafoods will lose weight at a significant rate when stored at low relative humidities.

It is therefore important that cold-storage plants used for long-term storage of frozen seafoods be designed to maintain relative humidities of 90 per cent or higher. All evidence available clearly shows that the use of low storage temperatures and high relative humidities will significantly extend the quality of unpackaged and packaged frozen seafoods.

Theoretical Considerations in Freezing Fishery Products

The freezing of fish takes place in three steps. The sensible heat is first removed, lowering the temperature of the product to the freezing point. A change in state then takes place, and the latent heat of fusion is removed from the food, changing a major portion of the water to ice. The third step involves subcooling of the food from its freezing point to its terminal temperature. The process of freezing is basically the transfer of heat from one substance to another. The rate at which this heat flows depends on many different factors, of which the most important are: (1) the heat transfer method, (2) the temperature difference between the fish and the cooling media, (3) the size, type, and thermal properties of the product, and (4) the packaging materials and method of packing employed.

The heat transfer method is a function of the particular freezer employed. In freezing, heat is removed from the product primarily by conduction and convection. The transfer of heat from the center of the product to its outside surface is accomplished by conduction and is a function of product conductivity, temperature difference, and product thickness. The heat is generally transferred to the cooling medium, whether it be air, brine, or refrigerant circulating in contact plates by forced convection or radiation. The transfer of heat to the cooling medium varies with the velocity of the gas or liquid, its thermal properties, and, of course, its temperature.

The time of freezing is a direct function of the average temperature difference between the product and the cooling medium. Ordinarily the freezing time decreases in direct proportion to the increase in temperature difference between the product and the cooling medium.

The time of freezing is also a function of product thickness. As a rule of thumb, the freezing time may be assumed to be directly proportional to the square of the product thickness. Therefore, if it takes 180 minutes to freeze 2 inch thick packages of fillets, 281 minutes will be needed to freeze a similar product 2½ inches thick, provided, of course, that all other conditions are similar.

The type of package and method of packing also govern the time of freezing. For example, packaging materials having a low conductivity retard the transfer of heat from the product. The ideal packaging material should have a high thermal conductivity and be relatively thin to permit rapid transfer of heat from the product's surfaces to the cooling medium. The fit of the package is also very important; a loosely fitting package, with insulating air pockets or voids, will greatly increase the time and efficiency of freezing.

Table 23.3. Average Water Content and Specific and Latent Heats of Various Fishery Products

Fish	Water Content	Average Freezing Point	Specific Heat* Above Freezing	Specific Heat* Below Freezing	Latent† Heat
	%	Degrees F	Btu/Lb/F	Btu/Lb/F	Btu/Lb
Whole Fish					
Haddock, cod	78	28	0.82	0.43	112
Halibut	75	28	0.80	0.43	108
Tuna	70	28	0.76	0.41	100
Herring (kippered)	70	28	0.76	0.41	100
Herring (smoked)	64	28	0.71	0.39	92
Salmon	64	28	0.71	0.39	92
Menhaden	62	28	0.70	0.38	89
Fish Fillets or Steaks					
Haddock, cod, ocean perch	80	28	0.84	0.44	115
Hake, whiting	82	28	0.86	0.45	118
Pollock	79	28	0.83	0.44	113
Mackerel	57	28	0.66	0.37	82
Shell Fish					
Scallop meat	80	28	0.84	0.44	115
Shrimp	83	28	0.86	0.45	119
American lobster	79	28	0.83	0.44	113
Oysters and clams (meat and liquor)	87	28	0.90	0.46	125

* Calculated by Siebel's formula; for values above freezing $S = 0.008_a + 0.20$; for values below freezing $S = 0.003_a + 0.20$. a = water content in per cent, 0.20 = specific heat of solid constituents of the substance.

† Values for latent heat (latent heat of fusion) in Btu per lb, calculated by multiplying the percentage of water content by the latent heat of fusion of water, 143.4 Btu.

Calculation of Freezing Time. Information on the average water content and specific and latent heats of various fishery products is shown in Table 23.3.

The calculation of the rate of cooling solid bodies has attracted much attention, and rather complete analytical solutions have been provided. However, most of the work reported involves complex mathematical formulas requiring much labor and knowledge to solve. In 1913 Plank developed his basic equation for freezing foods, and he later modified this[31,32].

There are many modifications of Plank's basic formula. Some make the calculations unnecessarily difficult, whereas others make them perhaps too simple and inaccurate. The formulas used by Levy[18] and Nagaoka, *et al.*[23], provide for calculation of the cooling and freezing time using a straightforward equation that can be easily solved.

Plate Freezing. Extensive studies on contact-plate freezing of fish have been conducted by Watzinger, *et al.*,[46] and Slavin[38]. Application of Plank's modified formula to the freezing of 2 inch thick packages of fish fillets agree with experimental findings.

Commercial Freezing Methods

Refrigeration machines used for freezing fishery products in this country vary in design from rather simple batch-freezing units, which require considerable labor in product handling, to automatic loading and unloading units that utilize mechanical or electronic controls to regulate operation in accordance with the requirements of the product. These machines usually are classified according to their general physical characteristics as being of the sharp, air-blast, contact-plate, or immersion types.

The Sharp Freezer. The sharp freezer consists of an insulated room, usually maintained at −20 to −50°F, containing a number of shelves made from pipe coils through which cold brine, ammonia, or other refrigerant circulates. Fish frozen by this method are placed directly on the shelves or on aluminum pans or plates covering the pipe coils.

Heat is withdrawn from the fish by the combined effects of convection, conduction, and radiation. The coils or plates covering the coils remove heat by conduction; the shelf above, by radiation; and the surrounding air, by convection. The heat transfer between the refrigerant in the pipe and the fish at the point of contact is relatively high. However, the overall heat transfer rate is quite low because of the extensive surface area of the product that is not in contact with the pipes and is cooled largely by the natural circulation of the air within the freezer. The result is slow and uneven product freezing. At evaporator temperatures of −50 to −20°F, 14 and 16.5 hours are required to cool 2 inch thick and 2½ inch thick packages of fillets, respectively, from 50 to 0°F. Faster freezing can be accomplished by using lower temperatures or by forced circulation of air over the product.

The sharp freezer is largely outdated and its use is limited to round or dressed fish, such as halibut or salmon; panned fish, such as whiting, mackerel, or herring; or in some cases, institutional five- and ten-pound packages of fillets or steaks. Consumer-size packages of fish fillets undergo bulging because of the absence of a method of controlling expansion during freezing.

Excessive handling of the product is another disadvantage in the use of sharp freezers. As much as three hours are required for loading and three hours for unloading 40,000 pounds of fish fillets. Infiltration of air and accumulation of frost on the shelf coils during loading and unloading are problems. In a New England plant, handling requirements and air infiltration have been reduced by utilizing conveyors to carry the product from the processing room into the freezer and from the freezer to the cold-storage room. Some labor is still required, however, to transport the product from the conveyor to the freezer shelves and from the shelves to the conveyor.

Space requirements vary with the installation and with the type of product being handled. However, about one square foot of shelf space should be allotted for each $7\frac{1}{2}$ pounds of round fish or for each 10 pounds of packed fish in institutional cartons.

The Air-blast Freezer. Air-blast freezers are generally small rooms or tunnels in which cold air is circulated by one or more fans over an evaporator, cooled by ammonia, brine, or Refrigerant 12 or 22, and around the product to be frozen. The freezers are usually fully loaded at one time by rolling or pulling a rack of shelves of fish into the insulated room. More recently, conveyors have been used to move fishery products continuously through the blast room or tunnel. Most freezers of this type operate at air temperatures of −30°F or lower. The velocity of the air moving over the product generally varies between 500 and 1000 fpm to give the most economical freezing. Lower air velocities result in slow product freezing, whereas at higher velocities the freezing costs per pound of fish frozen per hour increase considerably.

Dehydration of product, or "freezer burn," may occur in freezing unpackaged whole or dressed fish in blast freezers unless the velocity of air is kept to about 500 fpm and the period of exposure to the air is controlled. Consumer-size packages of fish fillets or fish fillet blocks requiring close dimensional tolerances undergo bulging and distortion during freezing. In blast rooms or tunnels, where the product is frozen on trucks, the use of specially designed freezer trucks enabling distribution of pressure on the surfaces of the package will remedy this condition.

The Contact-plate Freezer. The contact-plate freezer consists of horizontal movable plates stacked vertically within an insulated cabinet or in an insulated room. The refrigeration effect is furnished by cold brine, ammonia, or Refrigerant 12 or 22 circulating in connected passageways in the plates. This freezer was designed for freezing packaged food products. It is used extensively in fast freezing fishery products packaged in consumer-size cartons and in five- and ten-pound institutional-type cartons. Among packaged fishery products frozen in the plate freezer are fillets, steaks, shrimp, fish sticks, fish blocks, and scallops. Fish to be plate-frozen should be properly packaged to keep air spaces in the package at an absolute minimum. In addition, during freezing, spacers should be used between the plates to prevent crushing or bulging of the package. For most products the thickness of the spacers should be about $\frac{1}{32}$ to $\frac{1}{16}$ of an inch less than that of the package. Where very close package tolerances are required, as in the manufacture of fish fillet blocks, a metal tray is employed to hold the packages of fish during freezing. The tray is generally the width of the package and is as long as the width of the freezer plates.

Contact-plate freezers in commercial use in the United States are of three types: batch, semi-automatic, and automatic. In the batch freezer, as the name implies, products must be loaded manually between the plates and then removed after freezing. High labor requirements have been reduced by using a specially designed rack of shelves, spaced at the same intervals as the freezer plates to enable transfer of the trays of product to and from the freezer.

The semi-automatic freezer is similar to the batch freezer, except that it has a mechanism that enables operator-controlled loading and unloading of the product. In a typical installation, packaged fish fillets are fed to the freezing unit on a conveyor belt. When a predetermined number of cartons accumulates, the machine operator presses a button, causing a horizontal bar to push the packages off the conveyor into the waiting slot between the two freezer plates. As a row of warm packages enters at the front of the freezer, previously frozen packages advance one row, causing the back row of frozen product to be ejected from the freezer onto a conveyor belt. The product is then conveyed to the freezer. After one plate is loaded, a counting device inactivates the feeder and lifts the freezer plates to the next station, at the same time closing the plates on the product just loaded. The loading cycle is then repeated until all the plates are full.

The automatic plate freezer is similar to that described above, except that the loading and unloading are controlled automatically by a series of microswitches and electrical relays. In this freezer, the loading time can be varied to suit product freezing requirements.

Immersion Freezers. Immersion freezers are not standard in design and vary considerably with each application. Fundamentally, the process involves pumping a continuous stream of brine or other similar refrigerant over the products to be frozen or, in reverse, moving the product through the cooling solution. Immersion freezers are ideally suited for use in freezing unpackaged fish on the vessel, where compactness of equipment, fast rate of freezing, and high efficiency of operation are of prime importance.

The cooling solution is the heart of the immersion-freezing system. To be acceptable, the solution directly contacting the food must meet Food and Drug requirements and be easy to renew, relatively inexpensive, and of low temperature and viscosity. These demanding requirements are not easy to fulfill, and sodium chloride brine is still the solution used primarily in the immersion freezing of fish. More recently, solutions consisting of 20 per cent glucose and 20 per cent salt in water have been used successfully in the freezing of shrimp on the vessel. Glycol and glycerine solutions are being used in freezing packaged poultry; however, they are not being used for seafood.

Tuna are frozen on the vessel in brine wells lined with galvanized pipe coils on the inside. Direct expansion of ammonia into these coils cools the brine, which is circulated by a pump over the coils and the fish. In some cases a heat exchanger or brine cooler is used to obtain more rapid cooling of the brine and, consequently, the fish. In commercial operation the fish are placed in sodium chloride brine in the wells. Then, after freezing, the brine is pumped overboard and the pipe coils used to keep the well refrigerated to 10 or 15°F. Prior to unloading, the wells are filled with brine to thaw the fish for processing at the cannery.

Commercial equipment is available for the freezing of shrimp aboard the vessel[22]. One system in general use consists of a stainless steel tank containing a pipe-coil evaporator. A glucose-salt brine circulates within the tank over the evaporator coils, which are cooled by Refrigerant 12 or 22, and over shrimp contained in wire baskets of 50- or 25-pound capacity. About 15 minutes is required to freeze the product satisfactorily.

A brine immersion-freezing system for freezing groundfish at sea has been developed by the U.S. Bureau of Commercial Fisheries and put into experimental use on the *MV Delaware*. Researchers at the Bureau's Gloucester Technological Laboratory found that groundfish such as cod and haddock could be put whole into cylindrical baskets in the freezing tank, the baskets moved through the cold brine, and the fish frozen very rapidly. After freezing, the fish could be stored, until processed, at 0°F in the vessel's hold and in a frozen storage plant ashore. The frozen fish can be water-thawed, filleted, and the fillets refrozen and marketed through regular distribution channels.

Cold-storage Design and Equipment

A cold-storage plant, or refrigerated warehouse, consists essentially of an envelope of insulation enclosing partitioned rooms that are cooled with mechanical refrigeration. It may contain space for freezing and, in some cases, glazing or packaging products; receiving and delivering products; refrigeration and other machinery; and offices, lockers, etc.

Today some refrigerated warehouses, particularly those located in the major fishing ports, are built especially for fisheries applications. But in most cases refrigerated warehouses are the general custodians of many different types of packaged frozen foods, all of which vary considerably in storage and handling requirements. The trend to automation has resulted in modern, low-story palletized warehouses arranged so that the products can be taken off rapidly or put on refrigerated trucks or railway cars servicing the storage facility. There is a definite tendency to limit activities to the storing of frozen foods, thereby leaving to others the specialized treatments of glazing or packaging or even, in some cases, freezing.

Temperatures of 0°F or lower generally are used in the newer cold-storage warehouses and in many of the older ones for the storage of frozen fish. The trend in recent years has been to construct refrigerated warehouses that will maintain temperatures of -10°F. In some warehouses, temperatures as low as -20°F are being used for storing frozen fish.

Many of the older refrigerated warehouses that are used for storing frozen fish are of multistory construction. Bare pipe-coil evaporators generally are used in these installations. Brine or flooded ammonia systems are used to provide the refrigeration effect. The refrigeration machinery is comprised of large slow-speed ammonia compressors. These warehouses were designed for nonpalletized operation, but conversion to palletized operation has been accomplished by using light-weight mechanical lift trucks. This conversion has reduced the labor necessary for product handling by 50 per cent. In the last decade, many new refrigerated warehouses have been constructed for storing fish and other foods. These warehouses are one or two stories high and are palletized throughout. Location and design of the loading facilities in these plants permit mechanical unloading of frozen fish from refrigerated railway cars or trucks directly into the cold-storage rooms. A modern warehouse located on the eastern seaboard is situated so that frozen fish can be unloaded from refrigerated vessels into the frozen-storage area. Air-operated freezer doors and hydraulic ramps for unloading trucks facilitate handling of products.

Cold-storage plants which handle whole or dressed fish usually contain facilities for washing, glazing, packaging, and storing the fish. Halibut and salmon are usually washed with fresh water, then laid out to freeze on the shelves of a sharp freezer similar to those described previously. After freezing, the fish may be placed into a wire pallet box and carried by a fork lift truck to a glazing tank. There the pallet box, or, if one is not used, the individual fish, are connected to a hoist and dipped several times into the water. After the fish have been coated with a sufficient glaze, they are transported to a storage room, either individually or in the pallet box, and kept at 0°F or lower. At intervals of storage the glaze on the frozen fish is renewed by spraying them with fresh water or by redipping them in the tank of glazing water.

Mackerel, chubs, or herring are usually washed, placed into metal pans, and frozen in a sharp or air-blast freezer. After freezing, the pans are dipped into fresh water and the fish removed. The remaining blocks of fish are then dipped in or sprayed with water to acquire a sufficient ice glaze and packaged in wooden boxes lined with kraft paper or in cardboard cartons.

Fishery products may be glazed by dipping them into a tank of fresh water, as referred to above, or by spraying them. Dipping is the most effective method. The glazing room should be 20 to 25°F. The temperature of the glazing solution should be kept just above its freezing point, and the length of each dip should be about 30 seconds. It is necessary that the product be dipped into the solution several times in order to build up a sufficient ice glaze.

Packaged seafoods (fish fillets, precooked fishery products, scallops, shrimp, etc.) may be frozen at the cold-storage plant in a contact-plate, air-blast, or in some cases a sharp freezer, then master cartoned, and stored on skids or pallets in storage rooms of 0°F or lower. Many of the cold-storage plants used to store packaged seafoods are not equipped with facilities for freezing and packaging the product. These plants are designed mainly to provide storage and fast in-and-out movement of already frozen products.

Space Requirements. The size of a cold-storage plant is generally rated in cubic feet of gross refrigerated volume, which includes wall to wall and floor to ceiling. In a large palletized warehouse, the product piling area will comprise 70 to 80 per cent of the total refrigerated floor area, the remaining area being for aisles of 8 to 12 feet in width. The product piling heights for modern single or double-story warehouses may vary from 16 to 20 feet, or 70 to 90 per cent of the floor-to-ceiling height. The older multistory warehouses have relatively low product piling heights of 7½ to 10 feet. This permits the stacking of products by hand or with small lift trucks. The aisles are less frequent in number and only about half the width of those found in the more modern palletized warehouse. Because of this, the ratio of product storage space to gross refrigerated space is usually much higher for the nonpalletized warehouse.

The space required for storing frozen fishery products varies with the density of the product involved. Precooked or breaded packaged seafoods such as fish sticks, shrimp, or fish portions have space requirements of about 25 to 30 pounds per cubic foot. Packaged fish fillets or fish blocks have higher densities of 55 to 60 pounds per cubic foot. Round or dressed fish stored in wooden boxes or stacked individually within the freezer have densities ranging from 30 to 35 pounds per cubic foot. In storing round fish, average weight 10 pounds, on shelves, about 1 square foot of shelf space should be allotted for each 7½ pounds of fish. In the case of 10-pound, 2½-inch-thick packages of fish fillets, about 1 square foot of shelf space should be allocated for each 10 to 11 pounds of fish.

Temperature. The cold store is maintained at the desired temperature by natural or forced circulation of air over an evaporator located in the room. If the refrigerant used in the mechanical refrigeration system is circulated directly through the evaporator, then the system is referred to as being of the direct type. However, when a secondary cooling medium such as brine is circulated through the evaporator, then the system is of the indirect type. Ammonia is used almost universally in large installations because of its excellent thermodynamic characteristics. However, the use of nontoxic Refrigerant 12 and 22 is increasing.

The evaporators used consist of bare-pipe coils, finned-pipe coils, refrigerated plates, or blower-type unit coolers. The unit coolers are not satisfactory for storing unpackaged seafoods because of excessive product dehydration resulting from circulation of the air.

Relative Humidity. To maintain a high relative humidity the temperature of the evaporator cooling coils must be as close as possible to the room temperature. If warm moisture-laden air enters the storage room—through cracks in the insulation or by continual opening of the doors—then frost will accumulate on the evaporator surfaces, retarding heat transfer and causing a lower coil and dew point temperature. Widely fluctuating air temperatures within the storage room will also have a similar effect.

In designing new installations, the temperature of the evaporator coils should be 5 to 10°F lower than the room temperature. Heat transfer from the evaporator coil to the surrounding air is rated in BTU per hour, per square foot of coil surface area, per degree Fahrenheit temperature difference between the coil and the room. Therefore, the difference between coil and room temperature can be decreased proportionally by increasing the evaporator surfaces.

In conventional designs, economic considerations limit the relative humidity to a range of 70 to 80 per cent. A jacketed-type cold-storage room has been designed, however, for maintaining almost constant room temperatures and relative humidities as high as 90 to 95 per cent. Cana-

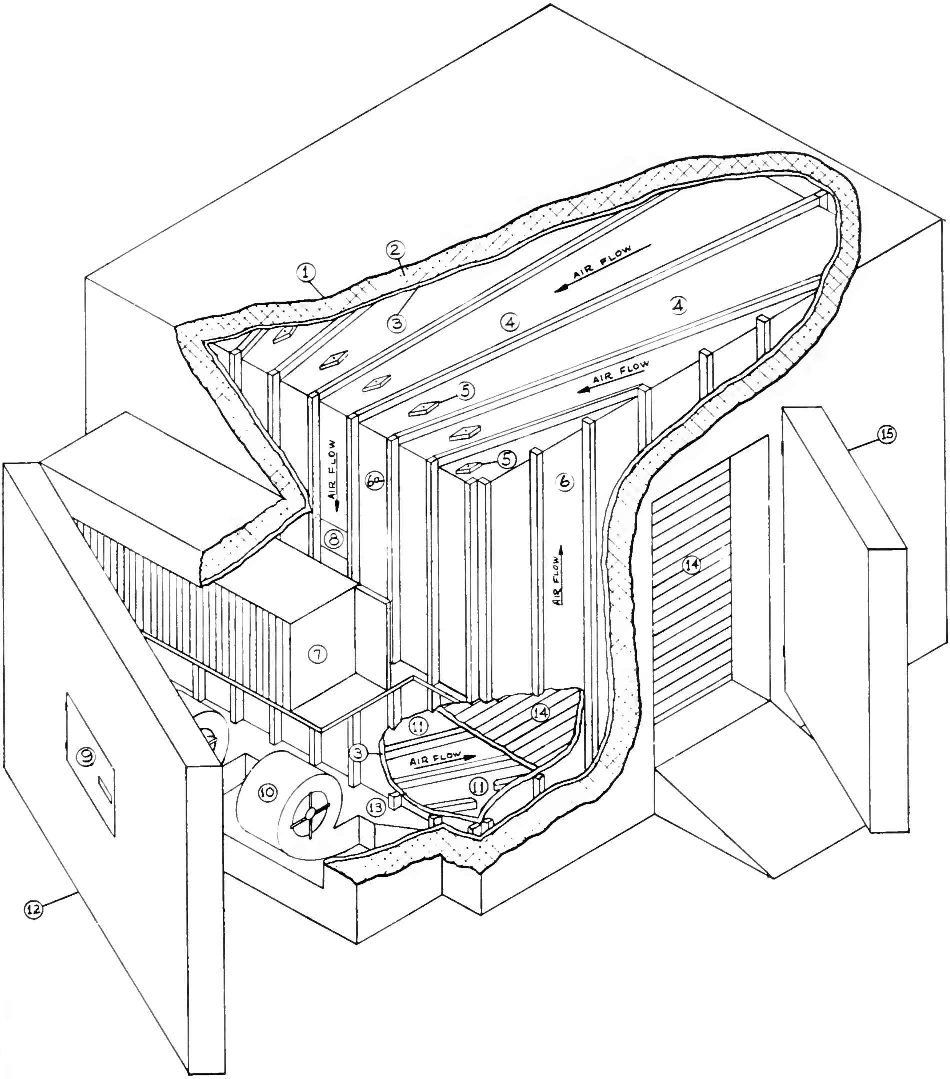

Figure 23.1. Cross-sectional view of jacketed cold storage room.

1. Vapor seal and emulsion
2. Cork insulation
3. Marine plywood
4. Jacket ceiling ducts
5. Dampers
6. Jacket wall ducts
7. Evaporator coil
8. Door connecting jacket with room
9. Inspection door
10. Centrifugal fan
11. Jacket floor ducts
12. Removable panel
13. Fan discharge duct
14. Tongue and groove fir flooring
15. Overlap freezer door

dian, American, English, and Russian workers report that this type of storage room is very satisfactory for storing both unpackaged and/or packaged seafoods[2,17,37,39,40].

The jacketed system, as proposed by Canadian workers, consists of a storage room placed within an insulated enclosure, with an air space between the outside surfaces of the storage room and the inside of the insulated walls. This annular space, referred to as the jacket, is lined with wooden members to direct the flow of cooling air around the outside of the walls, ceiling, and floor of the storage area. The jacket is a closed duct system containing a set of finned or bare-pipe cooling coils and a fan to circulate the air. The cold air circulating through the jacket ducts maintains the inner storage room at a predetermined temperature by removing the heat migrating through the insulated walls, ceiling, and floor before it can enter the refrigerated storage area. With proper air flow, the difference between the temperature of the walls, ceiling, and floor of the storage room and the heat of the storage room can be kept as small as 2°F, making it possible to maintain relative humidities as high as 98 per cent in the storage space.

An experimental fully jacketed cold-storage room constructed by the U.S. Bureau of Commercial Fisheries is shown in Figure 23.1. This room, which was similar to that described above, operated quite satisfactorily, maintaining relative humidities of 90 to 95 per cent.

An experimental −20°F jacketed cold store is being used at the Torry Research Station, Aberdeen, Scotland. In this design, insulation is used to form both the inner and outer surfaces of the jacket; whereas in the Canadian and American installations insulation is used only on the outer surfaces of the jacket and plywood or similar material is used on the inner jacket surfaces, which comprise the walls, floor, and ceiling of the storage room. Insulation of the inner walls of the room minimizes room temperature fluctuations.

In the Soviet Union, a large commercial six-story partially jacketed cold store has been constructed. The plant has a total capacity of 27,240 tons of frozen products and 8,260 tons of chilled food. The outside walls of each cold-storage room are jacketed, but the ceilings and floor are not. The jacket for each storage room is two feet deep and contains refrigerated cooling grids. Natural circulation of air over the cooling coils results in relative humidities of 97 per cent in the storage area.

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CHAPTER 24

Canned Fishery Products

R. G. LANDGRAF, JR.

History of Canning

The preservation of fish for use during the off season is an age-old idea. The drying and smoking of fish are processes developed shortly after the discovery of fire. Salting dates back to the stone age and pickling to the Greeks and Romans. The modern day application of these methods of preservation, which are referred to as "curing," are covered in Chapter 25.

As compared to curing, canning, by far the most important method of preservation, is relatively new, dating back only 150 years. The father of the canning industry is generally recognized to be Nicolas Appert, a French chef, who began working on canning in response to a Napoleonic government offer in 1795 of a prize of 12,000 francs to anyone who could find a new method of adequately preserving foods for France's fighting men. Although initial success was obtained in 1804, his method was not completely developed until 1809. His results, after being investigated, were published under the terms of the award in 1810[4]. Appert's method was simple. He merely sealed his products in glass, immersed them in boiling water, and "processed" them for a time sufficient to keep them in edible condition. The length of the process was determined strictly through trial and error.

Canning in the United States began in 1820, with Ezra Draggett and Thomas Kensett canning oysters in New York and William Underwood packing lobster and fruit in glass in Boston. However, it was not until 1844 that true commercial quantities of oysters were produced by

Draggett and Kensett. Other products followed with fishery products such as salmon and crab being among the first.

Although Isaac Solomon introduced the use of calcium chloride to raise the temperature of the "process" water to a high of 240°F in 1860, it was not until 1874 that the real beginning of modern canning came with A. K. Shriver's introduction of the pressure kettle or retort[6]. Prior to that time, all processing had taken place in boiling water, although Appert had experimented with an autoclave in his original work. The canning industry grew. The first canning trade association, formed in Baltimore in 1872, was followed by a national association in 1890 which ultimately influenced the adoption of the Pure Food Act of 1906. The National Canners Association was formed the following year.

From these meager beginnings the canning industry in the United States has grown to giant proportions. According to the 1954 census report[5] over 3500 plants were involved in the canning, preserving, and freezing industries, employing almost 200,000 people and producing products with a value approaching four billion dollars. While the canning of fishery products is only a small portion of the total canning industry, in 1960 accounting for only 2.6 per cent of the total of 4.8 million tons of metal consumed in "tinplate" cans[3], it is big business, producing products in 1960 having a value of over 387 million dollars[2]. The canning of fishery products is also a growing industry; from 1940 to 1960 product value quadrupled.

Containers

Appert performed his original canning experiments in glass with specially designed cork stoppers. In 1810 an Englishman, Peter Durant, conceived and patented the idea of using containers of glass, pottery, tin (tinplate), or other suitable materials for canning. Not until 1900 was the handmade, hand-soldered "hole in cap" can replaced by the modern "sanitary" or open top can of today[1]. Initially, the "hole in cap" cans were made at speeds of 60 cans a day by the expert tinsmith. Today the can-making industry is one of the most highly automated industries in the world, with round, open-top tinplate cans being manufactured at speeds up to 1000 cans per minute. Can-making speeds of 400 cans per minute are common.

The vast majority of processed fishery products canned in the United States today are packed in three-piece open top tinplate cans. Drawn tinplate cans are used for sardines, mackerel, anchovies, and certain specialty items. Glass containers are not used in substantial quantities for fishery products, other than for limited quantities of specialty products and fish roe.

Drawn aluminum cans, while used almost exclusively in some European countries for fishery products, are not used commercially to any extent at this time for processed fishery products in the United States. This has been primarily due to economics; until recently the price of aluminum has made it unable to compete with tinplate in the United States. This economic picture is changing and within a few years drawn aluminum containers should be used in significant quantities for canned fishery products in the United States.

Can Making. Open top or sanitary cans for fishery products are made from tinplate sheet ranging in actual gauge from .006 to .0105 inch or in base weight* from No. 55 to No. 95 plate, depending on the size of container and the process to which it is subjected.

The stages involved in the manufacture of three-piece open top cans are shown schematically in Figure 24.1. Generally these may be described as follows: Tinplate sheet is enamelled in the flat by passing it through a roll coater and applying a suitable organic protective coating at film weights ranging from two to ten mg per sq in. The enamelled sheet is then slit into body blanks of the proper dimension; the body blanks are fed into a bodymaker which automatically feeds the blanks through a series of stations during which the blank is rolled, notched, fluxed, side seam hooks are formed, engaged, bumped, and soldered. The cylindrical body is conveyed automatically to the flanger which flares out the edges of the body to allow double seaming. The flanged body is fed automatically to a double seamer which applies the bottom end of the can at speeds up to 1000 per minute. The finished can is automatically air tested for possible leakers and packaged in bulk shipping cartons, paper bags, or in reshipping cartons, depending upon the request of the packer.

The steps in end manufacture are also shown in Figure 24.1. The plain or enamelled tinplate sheet is scroll sheared so as to obtain maximum metal utilization. The scroll blanks are placed in a hopper on the end press, the ends punched out and curled. Sealing compound is applied in the channel of the end unit (Figure 24.2) and dried. The finished ends are stacked and wrapped with paper prior to shipment to the packer.

General Processing Considerations

The basis of the canning industry has been the development of suitable containers and an adequate process. For our purposes, canning may be defined as the packing of foods in hermetically sealed containers and obtaining "commercial sterility" through the use of heat processing. Commercial sterility, in turn, may be defined as that degree of sterility neces-

* Base Weight—The weight in pounds of a standard base box of plate of the desired thickness, i.e., the weight of 112 sheets, 14 × 20 inches, 31,360 square inches.

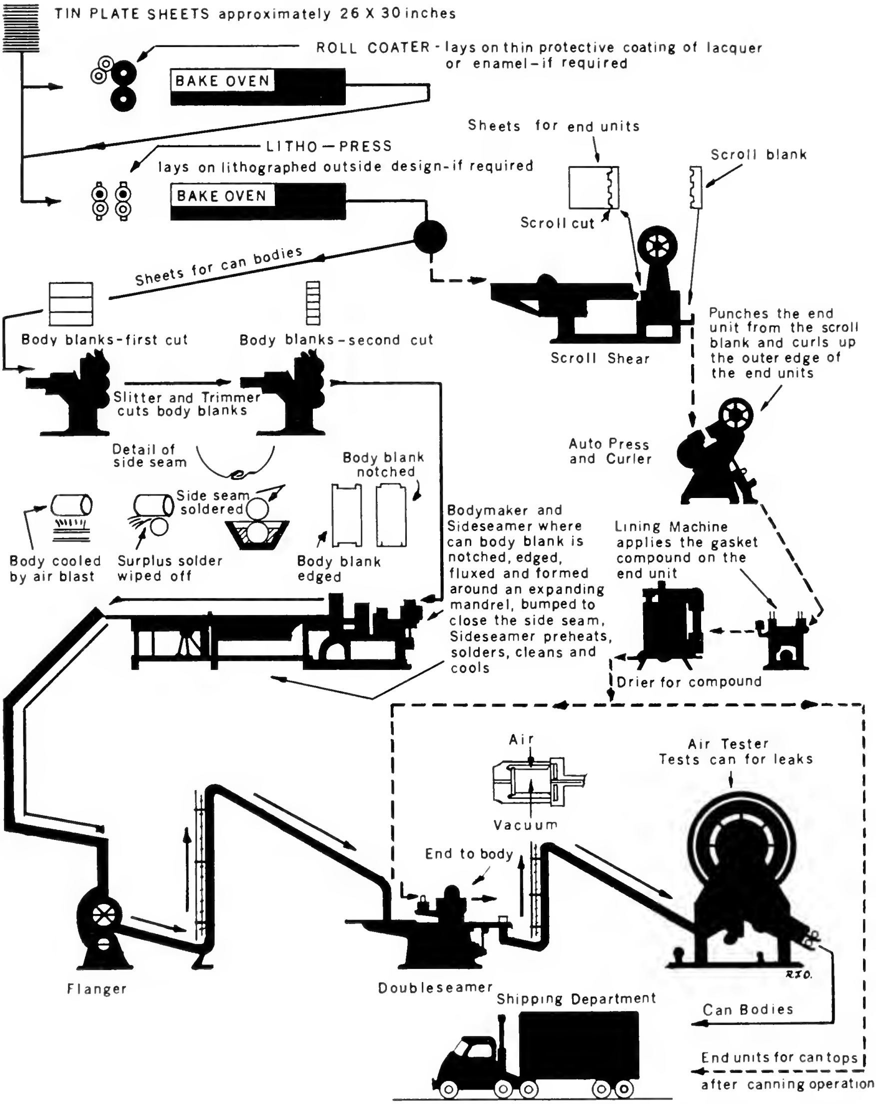

Figure 24.1. Stages in manufacture of cans. (*Continental Can Co., Inc.*)

sary to destroy the most harmful types of bacteria and prevent spoilage under normal handling and storage conditions. The time and temperature of the heat process is primarily dependent upon the pH of the product and the load of bacteria present. Other factors, such as the salt, moisture, and sugar content, as well as the type of product (solid, liquid, etc.) and the type of packing medium all influence the process required.

What is heat processing? From the standpoint of processing requirements, foods may be divided into two categories: the "acid" foods (pH below 4.5) and the "low acid" foods (pH 4.5 and above)[1]. While the spores of food spoilage bacteria may be easily destroyed in acid foods because of the effect of pH, similar spores in the low acid foods require substantially greater heat treatment to render them harmless. Since the heat resistance

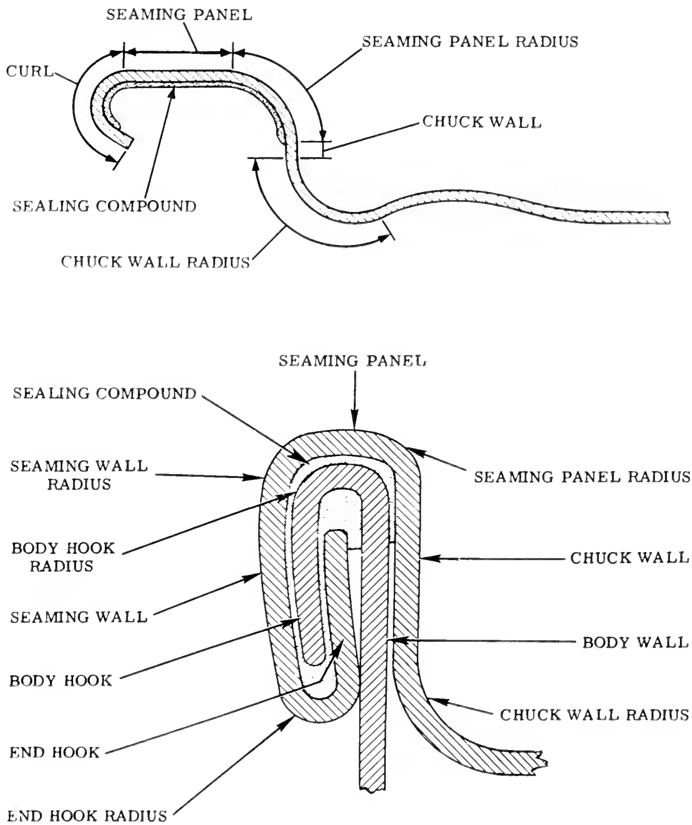

Figure 24.2. End unit and double seam terminology. (*Continental Can Co., Inc*).

of food spoilage bacteria varies widely, it is necessary first to determine the thermal death time or the lethality necessary to destroy the spores in question. It is then necessary, in order to determine the process (time and temperature of cook necessary to render the product in question commercially sterile), to measure the rate of heat penetration into the slowest heating portion of the container of food. The rate of heat penetration is determined by inserting thermocouples into the container of food and measuring the time necessary for the heat to penetrate to the slowest heating portion. In order to simplify this subject, let us say that once the thermal death time or the lethality necessary to destroy spoilage bacteria is known and the rate of heat penetration determined, a sufficient process may be calculated for the canned food in question.

With "acid" foods, processing may be accomplished in boiling water; however, for "low acid" foods the time necessary to accomplish sterility at the relatively low temperature of boiling water would be extremely long. Hence, for "low acid" foods, it is necessary to process under superimposed steam pressure at temperatures substantially above 212°F to accomplish the required lethality in a practical length of time. Since the length of process decreases with increasing temperature, the limitation of the temperature of processing then becomes dependent upon two factors: equipment and the effect of temperature on product quality.

For fishery products, normally having a pH range of 6.0 to 7.5, 240 to 250°F processes are most commonly used, the length of time being dependent upon the size of the container in which the food is packed and the type of pack. Suggested processes may be found in NCA Bulletin 26L[7].

Correct processing is nothing to be taken lightly and recommended processes should not be modified without careful determination of the modification's effect on sterility. Research organizations, such as the National Canners' Association, the major can and glass companies, and processing equipment manufacturers may be consulted for detailed information on processing.

Other methods of processing such as aseptic canning—in which a presterilized product is filled into a sterilized container and sealed under aseptic or sterile conditions—are a commercial reality for certain products, primarily liquids. Methods such as radiation sterilization are still in the experimental stages. While many new methods of processing are being investigated, the basic method remains that of retorting or processing under superimposed steam pressure either in batch or in continuous cookers.

Production of Canned Fishery Products

In 1959, the world catch of fishery products amounted to almost 78 billion pounds[8]. The United States catch of fishery products in that year, 6.4 billion pounds, may be broken down as follows: fresh market—43 per cent, cured—20 per cent, reduction to meal and oil—17 per cent, canned—9 per cent, freezing—8 per cent, and miscellaneous—3 per cent.

In the United States there were over 360 plants canning fishery products in 1960, and although some 100 various fishery products were canned, the following were the most common (listed in the order of total value of the canned product): tuna, salmon, animal or pet food, sardines, shrimp, clam products, oysters, mackerel, and crab meat.

While the total value of canned fishery products in the United States in 1960 was in excess of 387 million dollars[8], tuna (45 per cent) and salmon (22 per cent) accounted for over two-thirds of this value. Salmon and tuna along with the remaining products listed accounted for almost 96 per cent of the total. Table 24.1 summarizes information on United States production of the more important canned fishery products in 1960.

TABLE 24.1. SUMMARY OF PRODUCTION—1960[a] OF SELECTED CANNED FISHERY PRODUCTS

Products	No. of Plants	Standard Cases[b]	Pounds Per Case	Production ÷ 1000 Pounds[b]	Value[b]
					(dollars)
Tuna:					
Solid	35	3,558	21	74,708	49,007
chunk	28	10,145	19.5	197,831	112,629
flakes & grated	27[c]	1,602	18	28,849	11,043
tuna, total	37	15,305	—	301,338	172,679
Salmon	107	2,834	48	136,049	88,197
Animal or Pet Food	52	8,787	48	421,772	43,979
Sardines:					
Maine	32	1,998	23.4	46,744	16,700
Pacific	15	616	45	27,714	4,659
Shrimp, natural[a]	45	951	15	14,268[e]	17,233
Clam products: (whole, minced, chowder, juice)	36	2,057	15–30[f]	50,605[f]	13,676
Oysters, natural[d]	31	411	14	5,747[e]	5,640
Mackerel	15	935	45	42,064	5,804
Crab meat, natural[d]	41	211	19.5	4,115	5,457

[a] Data from U.S. Department of Interior.[2]
[b] The 000's have been omitted from these data.
[c] Exclusive of duplication.
[d] No specialty products are included.
[e] Drained weight.
[f] Drained weights are given for whole and minced clams and net can contents for other clam products. Whole and minced clams are figured at 15 pounds per case while chowder and juice are figured at 30 pounds per case.

Raw Product Handling

While the methods of catching, holding, and preparation of fishery products for canning may vary widely with species, equipment, etc., one point is common to all canned products. The ultimate canned product will be of no better quality than the raw material from which it comes. While this statement is certainly self-evident, its importance cannot be overemphasized. With the exception of tuna, which is usually held frozen until canned, most other species are held in ice or refrigerated sea water from catch to can. The length of time and the temperature of the fish or shellfish during this holding period is of extreme importance to the ultimate canned product quality.

It is generally recognized that the canned product produced from fish held for long periods, either iced or in refrigerated brine or sea water, will be inferior in quality to that canned from absolutely fresh fish. Degradation (chemical, bacteriological, and/or autolytic) which occurs in fishery products during this holding period may manifest itself in many ways in the canned product—off odors and flavors, rancidity, forms of product and container discoloration, poor texture, and, in extreme cases, incipient spoilage.

Changes at elevated or deck temperatures will be even more rapid than those which take place under iced conditions. Ideally, therefore, fish should be canned as soon as they are taken from the water. More practically, the time between catching and processing should be kept to an absolute minimum.

Fish Canning Procedures

The actual canning procedures for individual fishery products are given in the chapter covering the specific species of fish. We will consider here only the differences in the canning procedures as related to the various general classifications of fishery products.

Standard Fish Packs. Fish may be divided into two broad categories in relation to the amount of preparation necessary prior to filling: (1) packed raw, i.e., no precook, and (2) those species which require a precook of some sort prior to filling.

No Precook. Under this classification the whole fish is washed, butchered, cut to can height pieces either mechanically or by hand, filled with added salt, closed, and processed. Fish canned by this simplest of methods include salmon, mackerel, shad, and alewife or river herring.

Precooked. The best example of this class of fish is tuna, which is eviscerated, then precooked prior to butchering, cleaning, cutting, and filling. The precook, which will vary from 2 to 12 hours at 216 to 220°F, depending on the size and species of tuna, is one of the most important parts of the tuna operation. Its purpose is threefold: first, to remove or cook-out a portion of the natural oil; second, to loosen the meat on the bones so that subsequent cleaning operations may be carried out more efficiently; and, third, to obtain proper texture in the final canned product.

Other fish in this class are sardines, herring, anchovies, and related species and are categorized by a high oil content which must be minimized prior to canning. With the exception of tuna, the pre-cook may be accomplished after the fish is filled into the can by a short steam exhaust followed by inversion to drain.

Shellfish. The canning of shellfish differs from that of fish in that all shellfish are precooked to some extent prior to filling and, in addition, usually require further treatment such as brining, acidification, blanching, or a combination of these. Clams and oysters are steamed to open the shell, firm the meat slightly, and ease removal.

Crabs, which must be alive when the canning procedure begins, are butchered by removing the carapace or back shell, eviscerated, washed thoroughly, and then precooked 10 to 15 minutes in boiling water or steam prior to picking. In addition, crab meat is usually dipped and/or packed in a citric acid brine to prevent product discoloration. Shrimp, which after being peeled are blanched for 5 to 7 minutes in a boiling brine prior to packing, are also packed in brine. This brine may also contain citric acid if product discoloration is a problem.

Another difference between the canning of fish and shellfish is the packing media; fish usually are packed dry or with oil while shellfish are normally packed with added brine.

Specialty Products. Specialty products may be defined as high-priced, limited volume items which usually require more than the normal amount of preparation.

Specialty fishery products canned in the United States in 1960 are tabulated in Table 24.2.

A specialty product usually requires additional preparation and treatment such as brining, smoking, grinding, addition of ingredients other than fish, and special packing and processing techniques. The procedure for canning a specific item is usually developed by the packer and the details of the method are not usually publicized.

Canning Equipment

Since the basic butchering, cleaning, cutting, and filling equipment used today is discussed under the chapter relating to the specific species, we will discuss here only closing equipment, methods of obtaining vacuum, and retorts. Related canning equipment such as track work, unscramblers, labelers, and casing equipment, which is many instances are designed for a specific plant operation, will not be discussed.

Can Closing Equipment. Closing equipment or double seaming equipment may vary tremendously in appearance, size, design, number of seaming heads, and speed, depending on the manufacturer and the specific canning operation for which such equipment is intended. Seamers may vary from a hand-operated, laboratory style to a simple single station machine operating at speeds of 30 to 60 cans per minute or to multiple station, oil-driven equipment, operating at can closing speeds of over 1000 cans per minute. In all cases, however, the basic purpose is to hermetically seal the container, thus precluding leakage so that the low acid foods, such as fishery products, once sterilized will remain so throughout the shelf-life of the product. Figure 24.2 shows schematically an end unit and a double seam along with applicable terminology.

All closing equipment has the following basic components: The *seaming head* which carries the seaming rolls, cans, and gears which rotate the

TABLE 24.2. CANNED SPECIALTY SEAFOOD PRODUCTION—1960

Product	Number of Plants	Quantity	Value
		(Std. Cases)[a]	(dollars)
Fish:			
fish cakes	4	77,930	1,068,631
fish flakes, pastes & spreads	8	15,877	442,858
gefilte fish	5	234,937	4,396,000
smoked salmon	12	844	62,189
smoked sturgeon, shad & sablefish	10	405	26,944
tuna specialties[b]	6	60,621	456,508
other specialties[c]	14	75,510	877,938
Shellfish:			
crab specialties[d]	7	8,078	116,277
lobster specialties[e]	7	7,516	236,243
shrimp specialties[f]	7	4,178	61,339
clam specialties[g]	10	36,598	507,765
conch meat and chowder	4	6,042	130,270
smoked oysters	8	1,414	135,940
oyster stew	8	122,100	1,517,374
oyster bisque and soup	3	2,234	21,722
squid	3	15,637	73,638
terrapin & turtle meat, chowder	3	13,455	237,526
other shellfish specialties[h]	6	1,676	38,845

[a] Standard case equals 48 one-pound cans.
[b] Tuna specialties include tuna with noodles, sherry, beans, creamed sauce and smoked tuna.
[c] Other fish specialties include anchovies, salted cod, creamed finnan haddie, thread herring, Pacific herring, Atlantic mackerel, salmon livers, wahoo, whitefish, fish appetizers, and fish chowder.
[d] Crab specialties include crab cocktail, deviled crab, soft shell, spread, smoked, soup, and newburg.
[e] Lobster specialties include meat, spread, dip, thermidor, soup, and stews.
[f] Shrimp specialties include cocktail, soups, and stews.
[g] Clam specialties include dips, fritters, spread, sauce, soups, and stews.
[h] Other shellfish specialties include crawfish bisque, sea mussels, abalone trimmings, scallops in sauce, gumbo, and bouillabaise.

rolls about the top of the can and cover and cause them to approach and recede from the chuck in a measured sequence. The *first and second operation seaming rolls* which engage, form, and flatten the cover and body hooks against the *seaming chuck* that lies at the center of the seaming head between the rolls. A *base plate* on which the bottom of the can rests. A *spring loaded plunger* which carries the base plate up during the seaming cycle so that the can and cover come in from contact with the seaming chuck and roll in proper sequence and down after the cycle is complete so that the can may be withdrawn from the chuck. A *knockout rod and pad* to control the cover prior to its contact with the chuck and finally a *turret* or timing device to control the can as it passes through the closing machine. The sequence of operations involved in seaming a can end onto a can body are shown in Figure 24.3.

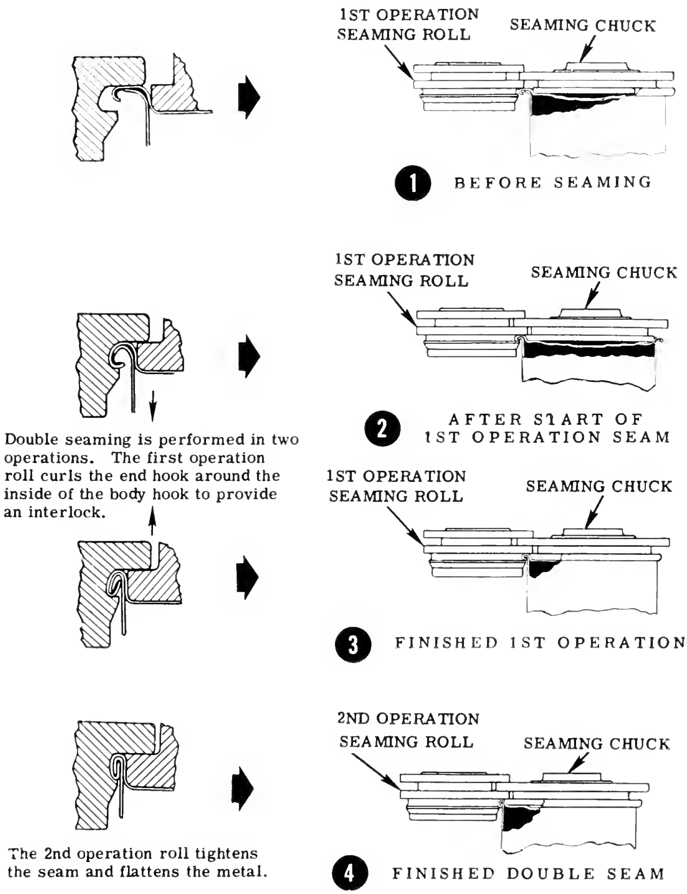

Figure 24.3. Sequence of operations for seaming a can end on to a can body. (*Continental Can Co., Inc.*)

In addition, a cover feed mechanism is built into the closing machine to feed, transfer, and index the cover with the can body at the point of assembly.

Methods of Obtaining a Vacuum. Besides obtaining a hermetic seal, it is also highly desirable to obtain a vacuum in canned foods to minimize internal corrosion by the elimination of as much air as possible from the canned product, to prevent end bulging which may be caused by changes in altitudes, and to extend the shelf-life of the product.

A vacuum may be obtained in canned fishery products in a variety of ways. Perhaps the oldest method and one which is still in use in certain operations is the steam exhaust. In this method the cover is usually clinched loosely on the can, and the packed can is then either preheated or passed through an exhaust box to heat the contents of the can and drive off the air, replacing it with steam. The can is then sealed while hot and processed. During cooling, a partial vacuum is created by condensation of the water vapor in the headspace and by product contraction.

A related method of obtaining partial vacuum is hot filling the product or a portion of the product, such as the added oil or brine. Another method is the "steam-vac" closure. Here a steaming device built into the closing machine blows steam, under 5 to 10 pounds pressure, into the headspace area of the can prior to closing, thus evacuating the air and replacing it with steam. This method is still used to a large extent on canned salmon and is often used in combination with a hot oil or brine fill.

The best and most consistent method of obtaining can vacuum is through the use of vacuum closing equipment. Here the can is actually sealed in a vacuum chamber built into the closing machine. The addition of the vacuum chamber to the closing equipment necessarily complicates and raises the cost of such equipment.

Retorts. A retort is a chamber in which canned foods may be processed under superimposed steam pressure. There are two basic types of retorts—still (nonagitating) and agitating. In addition, retorts may be either batch type or continuous. The vast majority of fishery products are processed in still, batch-type horizontal or vertical retorts. While the size, design, and capacity will vary, depending on the application, all retorts should have the following related equipment:

Automatic Controller to accurately maintain processing temperatures.

Indicating Thermometer with corresponding pressure scale suitably adjusted so as to compensate for altitude.

Recording Thermometer for establishing accurate records of actual processing.

Pressure Gauge for accurate knowledge of internal retort pressure during processing and cooling. The separate pressure gauge also provides a means for cross-checking the thermometers.

Retort Crates, Baskets, Trays, or *Gondolas* for holding stacked cans during processing. These crates are made of strap iron or perforated metal and should be so designed as to allow uniform steam flow.

It is also important that cans are stacked or jumble packed into the crates so that free circulation of steam is possible; otherwise, low temperature regions or "cold spots" will develop.

Vents, large valve-controlled openings, necessary to eliminate air from the retort during the "come-up" period; i.e., as the retort comes up to the desired processing temperature. The number and placement of vents vary with retort size and design and should be studied carefully. Proper venting is of extreme importance in obtaining accurate processing temperatures. Retorts are normally vented until the retort temperature reaches 215 to 220°F, at which time the valves are closed and the processing cycle is begun.

Bleeders, small valve openings in the retort usually 1/8 inch in size, left open during the entire process to assure steam flow.

Steam Spreaders to allow uniform distribution of steam throughout the retort.

Drain Valves to allow rapid removal of water from the retort following cooling.

By-Pass steam valve to allow manual operation of retort during the come-up and cooling cycles and in case of failure of the automatic controller.

Safety or *blow-off valve* to prevent excessive pressure in the retort.

As mentioned early in this chapter, the development of adequate processing techniques and equipment was the basis of the canning industry. A typical processing is described briefly for information purposes, but it is important to remember that only recommended processes and techniques such as those recommended in the N.C.A. Bulletin 26L be followed.

After the cans have been filled and closed, they should be processed or retorted as soon as possible to preclude excessive bacterial growth and product degradation. The cans are then stacked or jumble packed in retort crates and the crates placed in the retort. The retort door or cover is closed, sealed, and the steam turned on. The drain valve is closed, and the vents and bleeders are left wide open. As the retort reaches 220°F, the venting portion of the cycle is complete so the vents are closed, the by-pass valve is closed, and the automatic controller put into operation.

The come-up part of the cycle is completed when the retort reaches the prescribed processing temperature. The process is then begun for the recommended time; for example, 75 minutes at 240°F for 307 $\times$ 201.25 cans of salmon. At the end of the recommended process time, the automatic controller is turned off, the vent to the outside is opened, and cooling water is allowed to enter the retort. After the cans reach about 110 to 120°F (warm to touch), the drain valve is opened and the cans removed from the retort and allowed to cool to room temperature. Some products are not water cooled and are removed from the retort following the blow-down and are allowed to air cool. With larger sized cans, retorts are normally designed to allow pressure cooling in water under superimposed air pressure. This is done to prevent buckling of large size end units.

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CHAPTER 25

Cured Fishery Products

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Cured fish include those products in which preservation is achieved by reducing moisture content or by the addition of chemical preservatives including salt, vinegar, or smoke. The common cured fishery products are salt fish, smoked fish, pickled fish, dried fish, and certain specialty products such as lutefish.

At one time, even in the United States, curing was the principal method of preservation of fish, production exceeding that of products preserved by refrigeration, freezing, and canning. Cured fish were prepared during the main fishing season and were the chief form in which these particular species were available during the remainder of the year.

Cured fishery products, for the most part, possess flavors and textures quite different from those of the original fresh fish. These changes result from the presence of added preservatives which impart foreign flavors, from irreversible changes such as alteration in texture, and from failure of the curing method to completely preserve the fish, which in some cases leads to off flavors such as rancidity. New methods of preservation, such as canning and freezing, make possible a product much more closely resembling fresh fish. In the more industrially developed countries, canning and refrigeration have gradually displaced curing as the principal preservation method.

In the United States, cured fishery products are little used as the main course of a meal. Except for certain ethnic usage, such products as smoked or pickled fish are used principally as snacks or side dishes. The average consumer has preference for fresh fish or fish resembling fresh fish as closely as possible. This has resulted in a considerable decline in the consumption of cured fishery products in the United States. In some other parts of the world, however, salt fish and other cured fishery products remain the principal form of fish available.

Production in the United States of smoked, salted, and pickled fish is shown in Table 25.1. Smoked fish with an annual domestic production of

TABLE 25.1. ANNUAL PRODUCTION OF PRINCIPAL CURED FISHERY PRODUCTS IN UNITED STATES IN 1959[6]

Species	Production in Millions of Pounds			
	Smoked Fish	Salt Fish	Pickled Fish	Total
Herring, sea	1.9	0.4	18.0	20.3
Salmon	11.3	5.8	0.4	17.5
Alewife	—	6.3	1.6	7.9
Chub	6.5	—	—	6.5
Herring, lake	0.3	4.2	—	4.5
Sablefish	3.7	0.1	—	3.8
Whitefish	2.4	—	—	2.4
Cod	0.5	1.5†	—	2.0
Mackerel	0.1	0.7	—	0.8
Whiting	0.8	—	—	0.8
Mullet	—	0.7	—	0.7
Lake trout	0.2	—	—	0.2
Cisco	0.2	—	—	0.2
Haddock	0.2	—	—	0.2
Other	0.4	0.8	—	1.2
Total	28.5	20.5	20.0	69.0‡

† In addition, 1.3 million pounds of lutefish were manufactured.
‡ Not included in this total is dried fish, amounting to about one-half million pounds.

about 28½ million pounds is followed by about equal volumes of 20 million pounds of salted and pickled fish. Only relatively small quantities of dried fish amounting to about a half million pounds, mostly shrimp, are produced in this country. The total value of all domestically produced, cured fishery products in 1959 was 40 million dollars.

The production figures do not give a true picture of the total consumption of cured fishery products in the United States since a somewhat larger quantity is imported than is domestically produced. Table 25.2 gives figures on such imported cured products. These figures, when compared with the domestic production, reveal that on a consumption basis the order of importance in the United States is salted fish, pickled fish, and smoked fish.

Salt cod is the most commonly consumed cured fishery product in this country, followed by pickled herring. A considerable part of the salt cod, however, is consumed in the territory of Puerto Rico. Of the smoked fish, salmon is the leading species, followed by certain lakefish, principally chub; sablefish also has a sizable production. The total annual cured fish consumption in the United States of about 150 million pounds represents only about 5 per cent of the total human consumption of fishery products.

TABLE 25.2. IMPORTS OF CURED FISHERY PRODUCTS INTO THE UNITED STATES[6]

Item	Quantity	Value
	Millions of Pounds	Millions of Dollars
Dried cod, haddock, and other bottom fish	1.23	0.49
Dried fish, miscellaneous species	0.35	0.20
Pickled and salted cod and other bottom fish	45.83	8.28
Pickled and salted herring	30.01	3.92
Salted mackerel	3.17	0.58
Pickled and salted fish, miscellaneous species	0.62	0.28
Smoked cod and other ground fish	3.15	0.83
Smoked herring	3.07	0.50
Other smoked fish	0.77	0.59
Total cured products	88.20	15.67

Cured fish were formerly produced largely at the site of landing since the curing was a necessary step in preservation. Today with more modern refrigeration and transportation available, much of the curing is carried out near important population centers throughout the country.

Principles of Curing Preservation

Preservation of fish by curing is achieved quite largely by retarding the action of bacteria and, to a lesser extent, of enzymes which otherwise would greatly limit the storage life of the fish to only a few days at room temperature by decomposing protein and other nitrogenous components of the fish. The oils contained in cured fish are not at all completely preserved by the curing process. Cured oily species, therefore, if held for any length of time, are commonly quite extensively oxidized with rancid oils being present, and ordinarily the flavor of such oxidized oil is considered a characteristic of the flavor of the cured product.

By far the most important effect achieved in curing is the removal of moisture from the fish. Lowering of the moisture content alone greatly retards bacterial spoilage of the fish. Moisture is removed both by air drying (either naturally by exposing to the air and sun or in more modern operations by controlled dehydration in dryers or smoke houses) or by the osmotic action occurring during salting whereby moisture is removed at the same time that salt enters the fish. To a very great extent, the preservative effect resulting in both salted and smoked fish, and to a lesser extent with pickled fish, is due to the reduction in moisture content.

The action of specific chemicals in retarding bacterial spoilage is the second most important factor. Except in the case of pickled fish, this effect is often of minor importance. With pickled fish the presence of considerable acetic acid (vinegar) lowers the pH of the flesh to a point where bacterial action is largely arrested. Salt possesses some bacteriostatic action, although a few organisms grow readily in its presence. Other components of wood smoke or spices added in pickling have a mild retarding effect on bacterial spoilage but are usually not the major factor in extending the storage life of the product.

Drying. Drying is carried out not only to prepare dried fish but even more important in this country as a preliminary step in producing smoked and salted fish. In drying fish, important variables include humidity of the air, air velocity past the fish, and temperature during drying. Natural sun drying requires a climate with reasonably low humidity and also either a fairly high temperature or a windy condition. Uniformity in drying requires use of artificial dryers which give more or less complete control of these variables. The humidity of air is frequently reduced by first chilling it, which reduces the moisture content (cold air dissolves at saturation much less moisture than warm air), and then reheating. Heating during the drying of fish is commonly carried out by a heat exchanger in the air supply, by fires under the fish (in connection with smoking), or sometimes by infrared heating. In some cases moisture removal is also achieved by pressing the fish, especially after moisture has been partially released as during salting.

Salting. In the salting of fish the objective is to rapidly remove moisture and, at the same time, to cause salt to penetrate uniformly into the flesh. The principal preservation action is achieved by the lowering of the moisture content. This is enhanced by the fact that at high salt concentrations most bacterial action is halted or at least greatly retarded, although the halophilic bacteria are not so affected.

In salting fish it is generally highly important to select methods which facilitate rapid removal of moisture and penetration of salt; this is especially important in hot climates where onset of spoilage is rapid unless the preservative effects of the salting process are expedited.

Penetration of salt into the fish is more rapid when relatively pure sodium chloride is used than when impurities are present. Excessive quantities of magnesium salts, such as the sulfate, which are often present in commercial salt, are especially harmful in retarding penetration of the salt into the fish. On the other hand, some of these impurities bleach the fish and yield a whiter product. The temperature of the fish and brine during salting is another important factor. Raising the temperature accelerates the rate of penetration of salt into the fish. It also, however, increases the rate of bacterial spoilage. The salt concentration outside the fish is, of course, also an important factor with more rapid osmolysis and removal of moisture taking place at higher salt concentrations. Tressler[8], in studying factors important in achieving rapid salt penetration before onset of spoilage during the salting of fish, found that the method of dressing of the fish is of considerable importance. Removal of all blood is of special importance.

Smoking. Smoked fish is produced by a combination of salting, drying, and smoking processes. In lightly smoked fishery products, which include the more important varieties produced in the United States, some of the most important changes occur during the salting and drying steps. Thus, much of the increased storage life of lightly smoked fish comes from the preservative action begun during the brining and largely effected during drying before the smoking process begins. The smooth sheen which gives the fish the glossy appearance and results in formation of a surface pellicle is produced during the brining and drying steps. The smoking adds mostly color and flavor except in heavily smoked products where the quantity of formaldehyde, phenols, and other substances deposited on the fish from the smoke may be sufficient to account for an important part of the preservative effect.

Pickling. In pickled fish the preservative action comes largely from the combined action of the salting, and hence lowered moisture content, and from the much lower pH resulting from the use of vinegar. Pickled fish generally also contain added spices or other flavoring components, and these may contribute some to the keeping quality.

Processing Salt Fish

Dry Salt Process. Salt fish are commonly prepared by one of two general methods—the dry salting process or the brine pack process. In the dry salt process, the fish are salted in such a way that the moisture withdrawn by the salt and the brine formed are removed from contact with the fish during or before the end of processing, leaving a fairly dry product which may be further dried by artificial methods. The usual salt cod is an example of this type. In the brine pack process, the brine formed during salting is left in continual contact with the fish until the salted fish are sold or converted to another form. Mild cured salmon and salt mackerel are of this type.

Cod is the principal species salted by the dry salt process, and the following description of its production typifies that used for other species. Most of the cod salted in North America is produced on the Atlantic Coast in the Maritime Provinces of Canada, and much smaller quantities are produced in the New England states. The method described is typical of that used in these areas. Canada is, in fact, the leading producer of salt cod; most of its production is exported to countries in the Carribean, to South America, and to Southern Europe.

The cod are eviscerated at sea and preserved in ice until landed. The fish are graded as to size, beheaded, and split down the back, leaving the bone in one side of the fish. After thorough washing, the fish are generally salted by the pickle cure in wood or concrete tanks or in butts or hogsheads. A layer of salt is placed at the bottom, followed by layers of the split fish, flesh side up, each fish having been given a light sprinkling of salt. The tanks or butts are filled above the level of the container with fish, using a heavier amount of salt at the top. About 17 pounds of salt per 100 pounds of fish are employed. The fish gradually sink down below the top of the container as the brine forms from the moisture withdrawn from the fish. As this process continues, salt is added to the top layer to hold the fish beneath the brine and to keep it fully saturated with salt. Fish remain in the vats for three weeks or longer.

When fish are salted aboard vessel, the "kench" curing method is used whereby the fish are piled in the hold of the vessel without use of containers of any kind. This method can also be used ashore if the climate is quite cool.

The fish are next removed from the brine and "waterhorsed." In this process the fish are piled flesh side down in stacks about three feet high. The weight of the fish in the pile presses brine from the fish. Sometimes the piles are weighted down to increase the pressure and to remove additional moisture. Over a period of a day or so the piles may be rearranged to put the fish previously at the bottom of the pile at the top.

The cod at this stage are "green salted" and still contain too much moisture, the excess of which is removed by drying. This was formerly done entirely by sun drying on racks. Currently artificial dryers in which humidity and temperature can be controlled independent of weather conditions are displacing sun drying methods.

In outdoor or sun drying, the fish are merely spread on wire netting supported by wooden frames in the open air and allowed to remain until the moisture content has been sufficiently lowered. The rate of such drying will depend, of course, upon the relative humidity of the air, its rate of movement, and the temperature. Drying is generally more rapid in the spring or fall than in the summer because of the lower humidity.

Conditioned air dryers, which are now in operation in a large part of the North American salt fish industry, consist of tunnel-type dryers in which the salt fish is spread on wire mesh trays and dehumidified air blown across the fish at a temperature of about 80°F and at a velocity of about 300 to 400 feet per minute. The air is dehumidified either by first cooling it or sometimes by a chemical process. The relative humidity of the air during drying is adjusted to about 50 per cent or slightly less. Heavily salted fish which are to be reduced to about 43 per cent moisture content can be dried in from 30 to 60 hours, depending upon the size of the fish. With larger fish two or three drying periods of about 20 hours may be interspersed with waterhorsing (press piling).

Yields and Salt Content. Beatty and Fougere[2] report that the salt content of salt cod varies from 4 per cent for a very lightly salted product with a curing time of 2 days to 20 per cent for a heavily salted product cured for about 21 days. The lightly salted cod will have about 74 per cent moisture content and are subsequently dried to about 35 per cent moisture. The loss of weight during salting is about 17 per cent. The heavily cured cod will have a moisture content of about 57 per cent before drying and a loss in weight of about 30 per cent. The heavily cured salt cod is generally dried to about 40 per cent moisture content. One hundred pounds of split cod will yield about 49 pounds of heavily cured dried product.

Brine Pack Process. In the brine pack process which is used for salt preservation of various oily fish such as herring and salmon, the fish are kept beneath the surface of brine until they are used. This helps to minimize oxidation of the oils in such fish by keeping oxygen away to a large extent.

Principal species of fish which are salted by the brine pack process in the United States are salmon (mild cured) and lake herring. The river herring, although cured in brine, are eventually packed as a dry salt product and should be so classified[5]. The production of mild cured salmon, an intermediate product preliminary to smoking, has been discussed briefly in the chapter on the salmon fisheries. The production methods for brine packed lake herring will be described briefly here. For greater detail concerning brine pack methods the reader is referred to Jarvis[5].

The lake herring are salted principally in Wisconsin and Michigan. The fish are cleaned and dressed, including beheading, upon arrival at the shore plant. They are then thoroughly washed in a tank of water and drained. The fish are salted by rubbing them with dry salt and packing in kegs (half-barrels of 125 pound capacity). The lake herring are packed belly side up in layers of about 25 fish with dry salt between layers. The barrel is filled to about four inches above the top to allow for initial shrinkage. After about 24 hours, the barrel is headed. In seven to ten days the cure is completed. The herring may be held in chilled storage until they are repacked. The fish are drained, packed in layers, back down with a small amount of salt added (3 pounds per 100 pounds of fish). The containers are then filled with 100° salinometer brine and held in refrigerated storage unless they can be sold within a month or so. Because lake herring have very low oil content (one or two per cent) rancidity is not a great problem, and the brine packed fish can be held in chilled storage for up to a year's time.

Properties of Salt. Beatty and Fougere[2] indicate that the most suitable salt for the commercial salting of fish is a mixture of equal volume of coarse salt (particles up to 1/4 inch diameter) and fine evaporated salt. The former possesses advantages in facilitating even spreading on the fish and has less tendency to cake; the latter strikes more rapidly into the fish. The salt should be free of halophilic bacteria and should contain little impurities, particularly compounds of magnesium, iron, and copper. Very small quantities of magnesium compounds may yield a whiter salt cod, but presence of more than a few tenth per cent will retard penetration into the fish.

Processing Smoked Fish

Equipment. In the United States a variety of equipment is used in the smoking of fish. In older installations a common type of smokehouse which is still quite generally used, shown in Figure 25.1, consists of a vertical shaft of rectangular cross section extending upward through several stories of the building. Doors at the lowest level lead to the fire pit, at higher levels to areas where the fish are hung for smoking, and to ventilators at the highest level. Such smokehouses have no provision for controlling humidity and only approximate temperature control.

In more recent installations both humidity and temperature can be closely controlled. In many such operations the drying is carried out in a chamber which is separate from the area where smoke is applied. The fish are hung in a room into which air is admitted which has previously been chilled and reheated to give the desired humidity and temperature. The air velocity can also be adjusted. Smoke is then applied either in a conventional older type smokehouse or sometimes by use of electrostatic equipment[4,1].

In other installations the controlled drying and smoking operation is carried out in one smokehouse. Much research at Torry Research Station in Scotland has resulted in design of the Torry controlled fish smoking kiln[3] which has been adapted to many commercial installations in Great Britain and elsewhere.

The type of wood used for smoking is not critical, most non-resinous varieties being suitable. In various areas such woods as hickory, oak, or alder are used.

Types of Smoked Products. Several types of smoked fishery products are prepared. These can be classified by the temperature during smoking

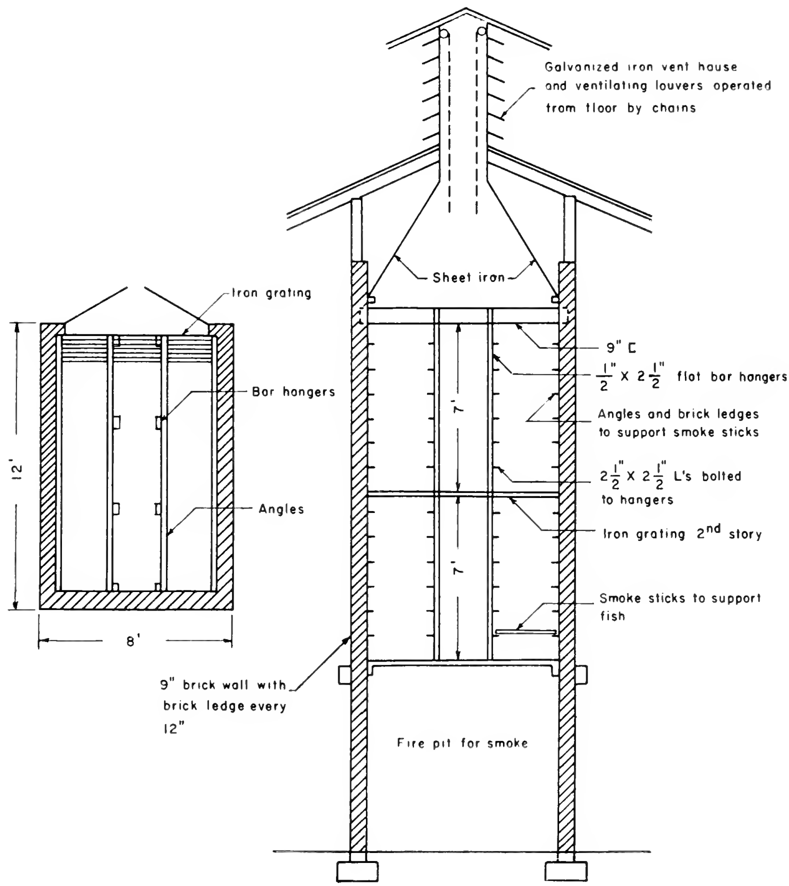

Figure 25.1. Diagram of common type of smokehouse.

(cold smoked or hot smoked) and the duration of smoking and/or drying. In cold smoked fish, the smoke is applied to the fish at a low temperature (under 100°F, usually about 75°F). This is achieved in older types of smokehouses by hanging the fish a considerable distance above the fires so that the smoke is cold when it reaches the fish. Cold smoking may continue for a short period of a few hours to produce a lightly smoked fish such as finnan haddie or kippered herring or for a period of days or even weeks to prepare such products as hard smoked herring or salmon. Alternately, fish may be smoked in a hot smoke by hanging the fish close above the fires. Use of temperatures of 150 to 250°F results in a barbecued or cooked product. Such fish are smoked for a short time, usually two to four hours. "Kippered salmon" and barbecued sablefish

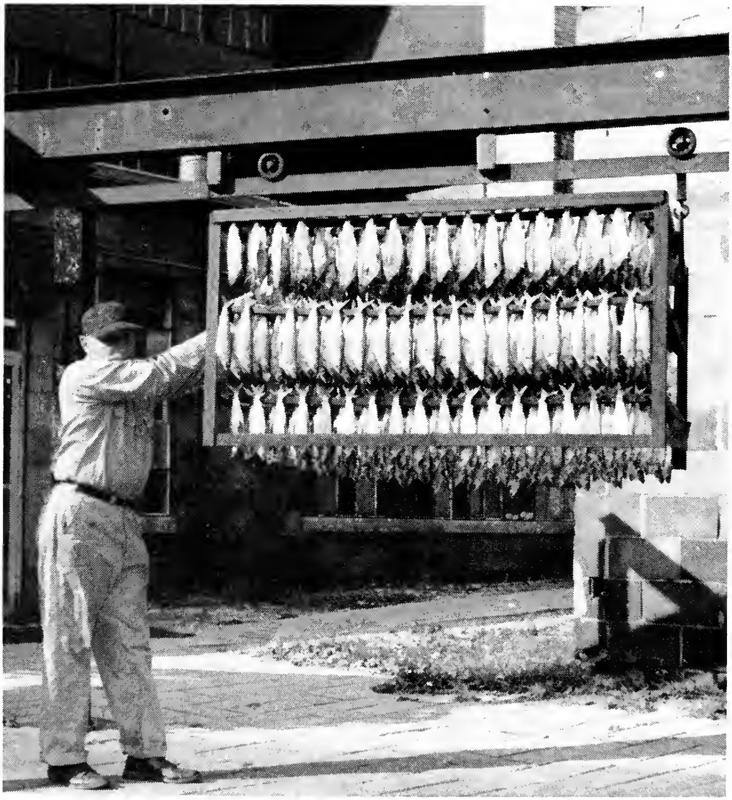

Figure 25.2. Lake chub on sticks and being wheeled on rack to smokehouse. (*U.S. Fish and Wildlife Service.*)

are examples of this type of product. In the United States, cold smoked products are much more important than hot smoked or barbecued fish.

Salmon. Salmon is the most important species which is smoked in the United States. Most salmon is cold smoked, employing mild cured salmon. The mild cured salmon is either soaked overnight in fresh water or freshened by immersion in running water for about ten hours, washed, drained, and trimmed. The salmon is then smoked at about 75°F (never above 90°F) for 24 to 48 hours in a light smoke. The density of the smoke is then increased and the smoking continued for another period of 48 hours or longer.

In recent years some thawed frozen salmon has been used in place of mild cured fish for smoking. Smoked salmon made from frozen fish has a milder flavor due to the absence of salt. Most smoked salmon is sold in piece form but some is cut into thin slices. Small quantities of salmon are smoked in other ways, the most important of which is hot smoking to produce kippered salmon.

Chub. Chub, the second most important species of fish smoked in the United States, is a small oily fresh-water fish taken in the Great Lakes, particularly in Lake Michigan. The fish are caught during a short summer season and are generally frozen and stored during the year, being smoked just before marketing. The thawed fish are dressed, split, and thoroughly washed. After draining, the chub are brined for several hours, drained, threaded on sticks, and placed in the smokehouse. Air is first blown through to dry the surface, and the fish are then smoked for about five hours in a light smoke at 80 to 90°F. The temperature is then increased to 170 to 180°F, and the fish are smoked for an additional one to two hours.

Sea Herring. Sea herring are not smoked in large quantity in the United States, but on a world-wide basis this is the most important smoke-cured species. Important centers for producing smoked herring include Germany, the Netherlands, Scotland, England, and Norway. A wide variety of smoked herring are produced, including bloaters, a lightly dried, cold smoked, whole fish (a product having a short keeping time); kippered herring, a dressed, split, lightly cold smoked product; and hard-smoked herring (sometimes smoked after skinning and boning) which is given a long cold smoke that imparts relatively long keeping quality. For details concerning methods of producing the different types of smoked herring the reader is referred to Jarvis[5].

Processing of Pickled Fish

Pickled fish are prepared largely from herring or the related alewife (river herring) in the United States. The fish are either local varieties obtained from Maine, Chesapeake Bay, and Alaska or often are imported from Canada, Iceland, Norway, or Great Britain. The fish are generally received in the salted state at the plant where the pickling operation takes place. Sometimes a preliminary pickling is carried out at the original producing site. In such cases the headed and eviscerated herring are cured from three to seven days in 80 to 90° salinometer brine containing 2½ per cent 120 grain distilled vinegar. The herring are then packed in barrels with 70° salinometer brine containing a little vinegar and shipped to such pickling centers as New York, Chicago, Detroit, or Los Angeles. Generally the fish are first cut into some form, depending upon the ultimate product to be prepared. This may be fillets, the backbone may be removed or, in other cases, left in. The cut herring are then stored in dilute vinegar and 35° salinometer brine at about 34°F until the final processing operation takes place.

For the final processing, the fish may be soaked overnight in a tank of fresh water or for a shorter time in running water. They are then generally held for about 72 hours in a salt-vinegar solution which usually consists of about three per cent white distilled vinegar and six per cent salt. The herring are then cut into final form, consisting of strips, or various shaped pieces, or left in the original dressed state. They are finally packed, usually in glass jars, with the curing and flavoring ingredients.

A wide variety of pickled herring products are prepared in the United States. As examples of some of these, the preparation of three will be described briefly. For more detailed description of the pickling of these and other products the reader is referred to Jarvis[5].

Cut Spiced Herring. This product is prepared from pieces of herring one to two inches wide cut across the body of the fish. The slices are packed in 8, 16, or 32 ounce glass jars with mixed spices and with diluted vinegar ($2\frac{1}{2}$ per cent of the acid) containing about $\frac{1}{2}$ pound sugar and $\frac{1}{4}$ pound salt per gallon. Various spices are employed and may include combinations of the following: mustard seed, oil of cardamon, white pepper, black pepper, allspice, cloves, and bay leaves. In some cases slices of onion, lemon, or pieces of bay leaf or pimento may be added. Cut spiced herring are also packed in tubs for distribution through wholesale markets.

Rollmops. This product consists of vinegar-cured herring fillets wrapped around pieces of dill pickle or pickled onion, cured in a spiced vinegar sauce, and generally packed in glass jars.

Bismark Herring. This product is somewhat similar to cut, spiced herring except that instead of using cut pieces of herring, the herring is boned and trimmed with head removed but leaving the two sides attached along the back. The fish are then cured for about ten days at 40°F in the vinegar-spice mixture before packing vertically in glass jars containing three per cent acidity vinegar and usually a slice of lemon or a piece of bay leaf.

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PART V

Food Science Applications

CHAPTER 26

Composition of Fish

MAURICE E. STANSBY AND H. S. OLCOTT

Importance of Composition of Fish

A knowledge of the chemical composition of fish is of paramount importance to evaluate it as regards nutritive value. In industrial processing of fish, a knowledge of composition of fish is important in several ways. Information on oil content of certain species and how the oil content varies with season or with area of capture is needed to evaluate the possibility for its utilization in manufacture of oil. Knowledge of proximate composition and especially moisture and oil content are important to determine the yield of such products as fish protein concentrate, fish meal, or other fishery products where drying or oil extraction eliminates moisture and oil in the manufacturing process. A knowledge of the kind of oil or protein, i.e., a knowledge of the fatty acid make-up of a fish oil or the amino acid content of a protein, are important for several applications. Thus presence of high proportions of saturated fatty acids in a fish oil will render it less valuable as a drying oil. The pattern of amino acids in a fishery product will be important in determining whether a resulting meal made from it will be suitable as a protein supplement for a stipulated use such as for poultry feed.

Some General Properties of Fish

Fish are dressed by removal of head, tail, fins, and viscera. Table 26.1 gives some information on the proportions of some of the resulting segregated parts. Species having a large head such as ling cod give much lower yields of dressed fish than fish having a small head and slim contour such as salmon.

TABLE 26.1. YIELD FROM SEVERAL SPECIES OF FISH*

Species	Dressed Fish	Liver	Viscera Less Liver	Other Trimmings
	%	%	%	%
"Average" species	65	2	8	25
Flounder	67	1	7	25
Ling cod	54	1	8	37
Sockeye salmon	73	2	6	19

* Values for this table and others in this chapter have been arrived at by considering data from a wide variety of sources.

Fish are commonly filleted, and the yield of fillets will vary with the type of fish between 20 and 40 per cent. Fillet yields in the range of 30 to 35 per cent are most common. When steaks are cut from fish the yield is between 60 and 75 per cent, most usually between 65 and 70 per cent. Dressed fish averages about 73 per cent flesh, 21 per cent bone, and 6 per cent skin.

Proximate Composition of Fish

The proximate composition of fish varies widely from species to species and even within the same species from one individual to another. Table 26.2 gives the range in values for proximate composition for fish in general.

TABLE 26.2. PROXIMATE COMPOSITION OF EDIBLE PORTION OF FISH

Statistic Calculated	Moisture	Protein	Oil	Ash
	%	%	%	%
Average	74.8	19	5	1.2
Range	28–90	6–28	0.2–64	0.4–1.5
Ratio high to low	3.2	4.7	320	3.8

In this and succeeding material when the term "edible portion" is used it will designate the skin and bone free fillet of the fish. Whereas extreme values for the moisture, protein, and ash of fish vary by only three to five times, for oil a variation of over three hundred-fold occurs. These figures apply for the variation in a component covering all species of fish. Even within the same species of fish the oil content of one individual may be more than ten times greater than that of another. These individual variations are observed to correlate with such factors as the season of the year when the fish was caught, the geographical area in which it was taken, or with such factors as age, sex, and size of the fish. These factors are not primary causes for composition variation. The primary causes are ones such as the feed intake of the fish and the degree of energy expenditure. Thus salmon caught during the late summer and fall months are found to have much lower oil content than those taken during the spring. This is due to the fact that salmon taken during the late summer and fall seasons have not been feeding and that they have been migrating during their late summer and fall spawning season which has required unusual expenditure of energy. This energy, of course, is obtained from depot deposits of oil or fat which were stored up at an earlier period when the fish were feeding. Variations in oil content of fish taken in different geographical areas are often due to differences in availability of feed in the different areas.

Because of the wide variation in the proximate composition of fish, average values have little meaning. It is better to classify species of fish according to one or more of several fairly well-defined categories into which most species fall. Table 26.3 lists five such categories.

TABLE 26.3. TYPES OF FISH

Category	Type	Oil Content	Protein Content	Prototype
		%	%	
A	Low oil-high protein	under 5	15–20	Cod
B	Medium oil-high protein	5–15	15–20	Sockeye salmon
C	High oil-low protein	over 15	under 15	Siscowet lake trout
D	Low oil-very high protein	under 5	over 20	Skipjack tuna
E	Low oil-low protein	under 5	under 15	Clams

Category A is the most common type. Fish in this category are characterized by a high protein content between 15 and 20 per cent and a low oil content of less than 5 per cent. Many species in category A have oil contents near the bottom of this range, i.e., nearer to 1 or 2 per cent than to 5 per cent.

Category B is the second most common type. Here the fish retain high protein (15 to 20 per cent) but have a medium oil content in the range of 5 to 15 per cent.

Category C represents a much less common type of fish having a high oil content (over 15 per cent). When the oil content is high, usually the protein content is lower (under 15 per cent).

Fish in category D have low oil content (under 5 per cent) and very high protein content (over 20 per cent). Although not many species fall in category D several which do (e.g., most tuna and halibut) are quite important commercially.

Category E includes fish having both a low oil content (under 5 per cent) and low protein (under 15 per cent). Most species in category E are shellfish such as clams and oysters.

TABLE 26.4. TYPES OF COMPOSITION FOR SOME IMPORTANT SPECIES

Species	Primary Category	Secondary Category
Anchovies	B	C
Bullheads and catfish	A	—
Carp	A	B
Clams	E	—
Cod	A	—
Crab	A	—
Flounder	A	—
Haddock	A	—
Hake	A	—
Halibut	D	—
Herring, lake	A	—
Herring, sea	B	C
Mackerel	B	C
Menhaden	B	C
Mullet	A	B
Ocean Perch	A	—
Oysters	E	—
Pollock	A	—
Rockfish	A	—
Salmon, Atlantic	B	A
Salmon, chum	B	A
Salmon, king	B	C
Salmon, pink	B	A
Salmon, silver	B	—
Salmon, sockeye	B	—
Sardines, California	B	C
Scallops	A	—
Sheepshead	B	A
Shrimp	A	D
Tuna, albacore	D	B
Tuna, bluefin	D	B
Tuna, skipjack	D	—
Tuna, yellowfin	D	—
Whiting	A	—
Yellow pike	A	—

Some species, especially those having more than the minimum oil content, vary in oil from one batch to another to such an extent that although they will ordinarily fall in one category, occasionally (such as at certain seasons of the year) they may fall into another. This is particularly the case for species in category B, some of which occasionally fall in category A while other species of category B may occasionally fall in category C. The latter category, in fact, contains few species which contain enough oil (over 15 per cent) to fall predominately in this category, and most of the species which are of type C are those which more usually fall in category B but at certain seasons of the year are of type C. Table 26.4 lists fish by categories, and where a species may fall into more than one category, the primary categories are shown.

Proximate Composition of Parts of Fish

The proximate composition of the edible flesh (skin-less, bone-less fillets) varies from one part to another. There is a tendency for segments near the head of a fish to have a higher oil content than those near the tail, and this difference may be quite pronounced. Thus in salmon there may be nearly twice as much oil in a slice near the head as in a slice from the same fish near the tail (see Table 26.5).

TABLE 26.5. PROXIMATE COMPOSITION OF SLICES OF A PINK SALMON (*Oncorhynchus gorbuscha*) TAKEN AT 3 POSITIONS

Location of Slice	Moisture	Protein	Oil	Ash
	%	%	%	%
Near head	75.9	18.8	4.8	1.1
Center	76.2	19.8	3.5	1.2
Near tail	77.2	19.9	2.6	1.2

Fish contain two types of muscle, the light which predominates and the dark flesh which occurs usually in small areas, such as beneath the skin at the lateral line. There is a difference in composition between these two types of muscle, with the dark flesh generally having a higher oil content and a lower protein content. Sometimes this difference, particularly that in the oil content, may be considerable (see Table 26.6).

TABLE 26.6. PROXIMATE COMPOSITION OF LIGHT AND DARK TISSUE OF EDIBLE FLESH OF PINK SALMON (*Oncorhynchus gorbuscha*)

Type of Tissue	Moisture	Protein	Oil	Ash
	%	%	%	%
Light	77.4	20.4	2.1	1.25
Dark	69.9	17.5	12.5	1.20

The trimmings of fish (all of the fish except the edible flesh) usually have a considerably higher oil and ash content and lower protein content than does the edible portion. These differences may be quite pronounced (see Table 26.7).

TABLE 26.7. PROXIMATE COMPOSITION OF WHOLE FISH, EDIBLE FLESH AND TRIMMINGS OF DOVER "SOLE" (*Microstomus pacificus*)

Material Analyzed	Moisture	Oil	Protein	Ash
	%	%	%	%
Whole fish	81.9	3.5	12.7	2.7
Edible flesh	83.6	0.8	15.2	1.1
Non-edible portions (all parts except flesh)	81.2	4.4	11.7	3.5

Major Components of Fish

Water. Water is the principal component of fish, amounting to as much as 80 per cent of the edible flesh. Usually there is an inverse relationship between oil and water content of fish muscle, such that the sum of the two is close to 80 per cent.

The water in fish does not freeze at 32°F. Rather, it starts to freeze at about 30.5°F. As the temperature of the fish is lowered, the amount frozen at successively lower temperatures increases. Even at 22°F only about 90 per cent of the water is frozen. Substantially all is frozen at about −30°F.

The moisture in fish tissue is held tightly by colloidal as well as chemical forces so that fresh fish subjected to high pressures do not release much of it. This retention of water by the fish can be measured by centrifuging the fish and determining the amount of fluid which separates after applying a stipulated centrifugal force for a stated period of time. This water retentivity of fish flesh is greatest in freshly caught, untreated fish. Either storage at ice temperatures or freezing of the flesh results in reduced water retentivity.

Protein. Protein, although second to water in quantity of the components of fish, ranging from 6 to 28 per cent but usually amounting to 18 to 20 per cent, is the most important component of fish.

Proteins are very large molecules which can be broken down to alpha-amino acids by treatment with acids or enzymes. The principal amino acids are shown in Table 26.8 with their abbreviations and content in various fish proteins. Those capitalized are essential for the nutrition of man.

The assortment of amino acids, the various orders in which they may be combined and the manifold possibilities of distribution in space (as long threads or globules or any intermediate form) account for the almost infinite variety of functions which proteins perform. In fish the skin

TABLE 26.8. AMINO ACID CONTENT OF FISH PROTEINS

Name*	Symbol	Approximate Amount in g/100 gm Flesh	Myosin†	Actin†	Collagen
Alanine	Ala	7.1	6.5	5.4	10.4
Arginine	Arg	6.9	6.7	7.4	9.1
Aspartic acid	Asp	11.2	11.5	9.7	7.5
Cystine	Cys	1.4	0.9	1.4	0
Glutamic acid	Glu	16.9	21.7	13.3	11.3
Glycine	Gly	5.1	3.4	5.0	28.2
Histidine	His	3.6	2.1	3.3	1.2
Hydroxylysine	—	0	0	0	1.0
Hydroxyproline	—	0	0	0	9.0
ISOLEUCINE	Ileu	5.0	4.6	7.7	1.7
LEUCINE	Leu	9.2	9.4	6.6	3.2
LYSINE	Lys	10.6	10.6	6.5	3.7
METHIONINE	Met	2.7	3.0	4.1	2.0
PHENYLALANINE	Phe	4.7	3.9	4.6	2.0
Proline	Pro	4.4	3.5	6.0	12.4
Serine	Ser	5.8	4.9	5.9	7.9
THREONINE	Thr	5.5	4.3	6.9	0.6
TRYPTOPHANE	Try	1.4	0.8	1.6	0
Tryosine	Try	4.1	2.7	6.0	0.6
VALINE	Val	5.8	5.3	5.9	2.3

* The capitalized amino acids are those now recognized as essential for the human. Histidine is also essential for laboratory and stock animals. Arginine can be synthesized but only slowly so that its addition to the diet of young growing chickens accelerates growth. Cystine may replace part of the methionine requirement, and tyrosine may replace part of the phenylalanine requirement.

† Myosin and actin account for 50 per cent and 20 per cent respectively of the total protein of white muscle. They combine to form actomyosin during muscle contraction.

and fins, the working parts of the muscles, the enzymes and hormones, the blood and muscle pigments, the masses of liver and kidney cells, and the linings of the intestinal tract are mostly or entirely protein in nature.

It is convenient to divide proteins into classes based upon their solubilities or on the non-protein components which in some instances are integral parts of the substances. Water-soluble proteins are called albumins, salt-soluble proteins are called globulins. Ten to 20 per cent of the proteins of fish muscle are albumins, and 70 to 90 per cent are globulins. It is possible to dissolve almost all of fish muscle with the proper combination of salts and water. Insoluble proteins are keratins and collagens. An appreciable part of the structure of fish is made up of collagens which are characterized by their transformation in hot water to gelatins or glues. The structural components of tendons, cartilage, skin, and the eye are collagens, as are also the skeletons of sharks and rays. Fish eggs contain appreciable amounts of lipoproteins in which the protein is combined with fat-soluble components. Heme-proteins contain the red colored heme as an integral part of the structure. Hemoglobin is the red protein of blood; myoglobin is the red protein of dark muscle. These contain small amounts of iron. Other metals and phosphorus are present in small amounts in some specialized types of proteins.

The approximate amino acid composition of fish proteins is very similar to the composition of mammalian flesh; hence consuming of fish proteins represents an efficient way to supply the amino acid requirements of man and other animals. In particular, it is necessary to furnish those amino acids which cannot be synthesized by the animal organisms. These "essential" amino acids occur in abundance in fish.

Lipids. Fish body oils are composed primarily of triglycerides which differ from those of animal and vegetable origin in two ways. Whereas animal and vegetable oils contain only very small quantities of fatty acids having more than 18 carbon atoms, the chain length of as much as ⅓ of the fatty acids of fish body oils exceeds this value. Most of these long chain fatty acids of fish oils consists of C_{20} and C_{22} fatty acids. Very small amounts of C_{24} fatty acids occur in some oils. The fatty acids of fish oils also contain more double bonds than is the case with animal and vegetable oils. Thus a large part of the C_{20} fatty acids of fish oils is a pentaene (five double bonds) and a large part of the C_{22} fatty acids is a hexaene (six double bonds). Vegetable and animal oils contain almost no pentaenes or hexaenes.

In spite of the high content of these polyunsaturated fatty acids in fish oils, the content of the classical essential fatty acids, linoleic, linolenic, and arachadonic acids, is relatively low as compared to the content of these acids in oils from animal or vegetable sources. Although fish oils are low in these classical essential fatty acids, evidence available would indicate that most of the polyunsaturated fatty acids of fish oils, while unable to cure dermal symptoms such as linoleic and arachadonic acids will do, are members of the linolenic acid family (first double bond at the three position counting from the terminal methyl group end) and, as such, will adequately support growth.

The depot fats of fish consist primarily of triglycerides. Much of the lipid associated with the cells of the flesh occurs in non-triglyceride forms. In some species of fish such as haddock and cod, where the amount of total lipid content in the flesh is of the order of 0.6 per cent, the vast majority of the lipids occur as phospholipid and in other non-glyceride forms. Thus Olley and Lovern[3] report the lipids of haddock flesh to consist of lecithin, 42.8 per cent; unidentified lipids, 15.2 per cent; waxes and alcohols, 10.5 per cent; free cholesterol, 6.1 per cent; free fatty acids, 6.1 per cent; phosphatidylethanolamine, 5.4 per cent; inositol lipids, 4.4 per cent; cholesterol esters, 3.4 per cent; triglycerides, 2.4 per cent; hydrocarbons, etc., 2.0 per cent; and plasmalogens, 1.7 per cent. Olcott, *et al.*[2], have reported that the phospholipids of albacore tuna consist of about 65 per cent phospatidyl choline, 25 per cent phosphatidyl ethanol-amine and phosphatidyl serine, 5 per cent sphingomyelin, 1 per cent phosphoinositides, and lesser amounts of sterols, cerebrosides, and unidentified components. Large proportions (nearly half) of the fatty acids in these phospholipids consisted of the very highly polyunsaturated C_{20}—5 double bonded and C_{22}—6 double bonded fatty acids.

Fish liver oils sometimes contain relatively high proportions of non-triglyceride components which make up the unsaponifiable portion of these oils. For example, many shark-like fishes contain alkoxydiglycerides. In the common dogfish such compounds occur in amounts up to 15 per cent and in the ratfish to an even higher proportion. These alkoxydiglycerides consist of a glyceryl ether at the ether linkage, principally selachyl

TABLE 26.9. INORGANIC ELEMENTS IN THE EDIBLE FLESH OF FISH

Mineral	Average Content
	mg %
Potassium	300
Chloride	200
Phosphorous	200
Sulfur	200
Sodium	63
Magnesium	25
Calcium*	15
Iron	1.5
Manganese	1
Zinc	1
Fluorine	0.5
Arsenic	0.4
Copper	0.1
Iodine	0.1

* Values are much higher (about 200 mg %) for calcium in canned fish if the bone is included.

alcohol, batyl alcohol, or chimyl alcohol. Not only are these glyceryl ether components less unsaturated than are the fatty acids of most fish oils but also the fatty acids esterified to the diglycerides portion are less unsaturated, containing considerable proportions of monoenes[1].

Some shark liver oils also contain very considerable quantities of some hydrocarbons, particularly squalene (an unsaturated C_{30} hydrocarbon with 6 double bonds). Basking shark liver oil contains nearly 50 per cent squalene.

Inorganic Components. Fish probably contain, at least in very small amounts, practically all of the elements occurring in sea water. Table 26.9 lists those occurring to the greatest extent. In addition, trace, yet appreciable, quantities of aluminum, barium, chromium, cobalt, lead, lithium, silver, strontium, titanium, and vanadium are known to be present.

Minor Components of Fish

Only brief treatment of the many minor components of fish such as nonprotein nitrogen compounds, carbohydrates, and vitamins is possible here. Discussion of such components as hormones and enzymes is beyond the scope of this book.

Vitamins. Table 26.10 gives the vitamin content in the wet tissue muscle of fish. Values are given as ranges and averages for all species. While considerable variation occurs among species of fish, our knowledge and data on vitamin content by species is not complete enough to warrant tabulation by species. The last column in Table 26.10 gives values for the "usual range." Some extreme values occurring in certain commercially unimportant species have been eliminated.

Table 26.10. Vitamin Content of Edible Flesh of Fish

Vitamin	Units	Content Per 100 Grams Average	Usual Range Low	High
Vitamin A*	μg	25	10	100
B Vitamins				
Thiamine	μg	50	10	100
Riboflavin	μg	120	40	700
Nicotinic acid	mg	3	0.5	12
Vitamin B_{12}	μg	1	0.1	15
Pantothenic acid	mg	0.5	0.1	1
Pyridoxine†	μg	500	50	1000
Biotin†	μg	5	0.001	8
Folic acid†	μg	80	71	87
Vitamin C	mg	3	1	20
Vitamin D*	μg	15	6	30
Vitamin E*† (total tocopherol)	μg	12	4	35

* For fish of medium or high oil content.
† Based on very scanty data.

Miscellaneous Components. Up to 1/10 or more of the nitrogen of the teleost fishes and 1/3 of that of the elasmobranch fishes occurs in forms other than protein. Trimethylamine oxide is one such component. It occurs in elasmobranch fishes in quantities up to 275 mg per cent. In teleost fishes somewhat less occurs. Marine fishes contain variable quantities usually in the range of 40 to 100 mg per cent. Certain of the bottom-feeding fish like cod and hake contain up to 150 mg per cent. Fresh water fish generally contain less trimethylamine oxide than marine fishes, with amounts generally in the range 5 to 20 mg per cent.

Freshly caught fish generally contain only a very small part of their amino acids in the free form, although free amino acids may form *post mortem* in a very short time after the fish are caught. An exception occurs in tuna which has an unusually high content of free histidine in the flesh.

Urea occurs in elasmobranch fishes in fairly high amounts. In sharks and rays, the urea content may amount to 2 per cent of the flesh. In the teleost fishes urea occurs in quantities of only about 0.05 per cent.

Creatine occurs in teleost and elasmobranch fishes in about equal amounts, averaging about 0.5 per cent in the wet muscle. Carnosine occurs to an extent of about 0.1 per cent to 0.4 per cent and anserine about 0.04 per cent.

The principal carbohydrate occurring in fish is glycogen, averaging about 0.6 per cent maximum. When the fish has undergone severe struggling just prior to capture, a lactic acid content of several tenths per cent may occur and the glycogen content will be reduced accordingly. Free glucose occurs in fish in concentrations in the range of 1 to 75 mg per cent.

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CHAPTER 27

Bacteriological and Chemical Basis for Deteriorative Changes

JOHN LISTON, MAURICE E. STANSBY, AND H. S. OLCOTT

From the moment fish is taken from the water a series of deteriorative changes start to occur which eventually will render the fish unmarketable. These changes occur relatively rapidly, such that fish is probably the most perishable of all flesh foods.

These changes occur as either the result of microbiological action or can be classified as being some form of more or less pure chemical change. In most cases, the deteriorative changes resulting from microbiological action are the most extensive. Hence a large part of this chapter is devoted to bacteriological considerations.

Proteins, the most important food component of fish, undergo various chemical changes and these will be described. In some special cases, notably in cold storage of frozen fish, largely chemical alteration in the lipids is involved so that a consideration of such changes, especially those involving oxidation, is included.

Microbiological Changes

Bacterial Populations on the Living Fish. More or less large populations of bacteria are constantly present on the external surfaces of all marine animals. In the case of free-swimming fish, the numbers of bacteria on the skin range from 10^2 to 10^6 per square centimeter, on the gills from 10^3 to 10^5 per gram, and in the intestine from very few in nonfeeding fish to 10^7 or more per gram in feeding fish. Less information is available for shellfish, but bacterial populations of the same order of magnitude can be anticipated for these animals, too. The tissues and internal organs of healthy fish and shellfish appear to be sterile.

In general, the bacteria found on living fish are predominately psychrophilic (growing significantly at 32°F), sea water loving (though not necessarily absolutely halophilic), aerobic, and attack proteinaceous materials more actively than carbohydrates.

Representatives of most of the genera of heterotrophic true bacteria reportedly have been isolated from living fish. In many cases, however, it is probable that the species described represent casual contaminants or transient strains not normally present on the fish. Genera repeatedly found to be present on fish to a greater or lesser extent include *Pseudomonas, Achromobacter, Vibrio, Flavobacterium, Corynebacterium, Alcaligenes, Photobacterium, Micrococcus, Mycoplana, Proteus, Bacillus* and (in the intestine) *Clostridium.* Most recent reports, however, indicate an overwhelming preponderance of gram negative rod-shaped organisms of the genera *Pseudomonas, Achromobacter,* and *Vibrio* in fish and shellfish floras. *Flavobacterium, Corynebacterium,* and *Micrococcus* also seem to occur consistently but at much lower levels of incidence. Fish and (particularly) shellfish living in water polluted from terrigenous sources may carry significant numbers of bacteria normally associated with land animals, though even under these conditions such bacteria never occupy a preponderant position in the total associated bacterial flora. However, the occurrence of such types is important from the sanitary and public health standpoint.

Bacteriological Changes Post Mortem. *Quantitative.* During the lifetime of the fish or shellfish there is no effective penetration of the tissues by the bacteria present on the body surfaces and in the intestine, and a balanced situation seems to exist whereby the numbers of these bacteria remain at a rather stable level. On the death of the fish (or other animal) the humoral defenses against bacterial invasion cease to operate and the mechanical barriers such as skin and membranes gradually lose their impermeability. As a result of these and other changes *post mortem,* the balance between bacteria and host animal is upset, and qualitative and quantitative changes in these bacterial populations soon become evident.

Very little is known concerning the nature and extent of these changes when the dead fish remains in its natural environment, but considerable information is available on the changes which take place in dead fish stored in ice. Technologically, these changes in the bacterial flora are of enormous importance since, together with associated endogeneous biochemical and perhaps physical changes in the fish tissue, they lead to the process of spoilage and ultimate decay and dissolution of the cadaver.

For a short period after death, corresponding rather closely to the onset, duration, and resolution of *rigor mortis*, there is little change in the numbers of bacteria present. This period has been likened to the classical lag phase observed in newly inoculated laboratory cultures of bacteria. It is succeeded by a period of gradually accelerating growth associated with organoleptic changes in the fish, typified by a loss of the characteristic fresh fish flavor. Next the bacterial population enters a phase of more or less exponential growth corresponding to the initial appearance of such well known spoilage indicator substances as trimethylamine and other related bases. This phase is of short duration and is succeeded by a more or less stationary terminal growth period, during which there is little change in numbers among the surface bacterial populations. Despite the absence of quantitative bacterial change, this is the period of maximum spoilage activity terminating, practically, when the fish is approaching putridity.

It is well established by experiment and observation that this classical growth sequence occurs in all fish and shellfish samples held under chilling conditions (i.e., greater than 32°F, less than 50°F) and applies equally to whole fish and to fillets or pieces. Of course special treatments, such as pasteurization, antibiotic ices, nitrite, etc., may affect the timing of events and perhaps lengthen part of the growth curve (usually the lag and accelerating growth phases.)

Qualitative. The qualitative alterations in the bacterial populations which accompany these quantitative changes are not well established. However, recent work has provided some information on this point. The predominant gram negative rod floras of living fish are frequently altered by the handling procedures which precede stowage in ice so that gram positive organisms such as *Micrococcus* and *Corynebacterium* attain a temporarily important quantitative position in the surface bacterial populations. This is also frequently true in the case of filleted products. However, during the apparent lag period and the phase of accelerating growth, qualitative changes in the flora re-establish the predominance of the gram negative rod forms so that by the time logarithmic growth is under way usually over 90 per cent of the total bacteria present are of this type.

At the same time changes occur in the balance of physiological types among the gram negative organisms. The comparatively slow-growing *Achromobacter* and *Flavobacterium* show a steady decline in relative significance and the rapidly growing *Pseudomonas* (more correctly perhaps "*pseudomonad*") types become completely predominant. By the time the lag phase is well advanced *Pseudomonas* types may constitute from 70 to almost 100 per cent of the total population present. There is also apparently a shift in balance among *pseudomonad* types themselves, typified by a reduction in the relative occurrence of typical marine forms and an increase in the proportion of types of *Pseudomonas* (*P. fragi*, *P. putida* and similar species) commonly found on all spoiling "animal protein" foods held under refrigeration, i.e., meat, turkeys, etc.

Penetration of Tissues. The degree of penetration of the surface bacteria into the tissue of the fish is not well established. Three possibilities exist: movement inwards from cut surfaces such as belly flaps and from gills—possibly mainly via the major blood vessels, movement outwards from the gut or gut cavity, and movement inwards from the skin surface.

The small amount of experimental evidence available indicates that while all three possibilities may be realized to some extent, general penetration from the surface inwards is most significant. Some evidence strongly suggests that significant penetration through the belly wall may also take place. However, movement of bacteria into tissues is apparently a slow process and multiplication within tissues is not very rapid. Even when the fish is clearly spoiling, only small numbers of bacteria can be found in the deep muscle. Consequently, the most widely accepted view is that most of the primary activity of the spoilage bacteria occurs in the surface layers of the fish, and the total effect is largely due to secondary diffusion of bacterial enzymes and products into the deep tissues.

Penetration of bacteria into cut fish and fillets is certainly more rapid than in the case of whole fish but is still sufficiently slow to justify the application of the above theory to these products also. It is possible that the reason for the primary surface action of the spoilage flora is its obligate aerobic nature.

Bacterial Metabolites. While comparative experiments with sterile and contaminated fish muscle samples clearly confirm that bacteria are responsible for the gross changes in fish associated with spoilage, the actual relationship between bacterial activity and chemically detectable changes is by no means clear. This may, in fact, be a reflection of our inadequate understanding of the chemistry of spoilage. Even in the apparently clear-cut situation of trimethylamine oxide (TMO) reduction, which has been attributed to the activity of bacterial triaminases, there must exist some doubt since (a) the total percentage of bacteria in the spoilage flora able to reduce TMO is very small and (b) there is no evidence of an increase of TMO reducing bacteria during spoilage. The predominant *Pseudomonas* types constituting the spoilage flora do attack peptides and similar sub-protein N-containing substances very vigorously, yielding amounts of NH_3 and other amine substances. However, there is some question concerning their ability to attack native fish protein. Typical end products of protein degradation are significantly absent from spoiling fish, appearing only after putrefaction has set in. Moreover, there is no apparent increase in the proportion of casein and gelatin digesting bacteria present in the spoilage flora during storage of fish in ice.

Handling Effects. The influence of handling procedures on the bacterial populations in fish is fairly evident from the outline description of the normal situation given above. Rough handling of the fish which results in breaks in the skin barrier or crushing of tissues will facilitate primary penetration of the tissues by bacteria and will hasten spoilage. Dirty ice, re-used ice, or ice stored for long periods in fish rooms will harbor large numbers of psychrophilic fish spoilage bacteria and, therefore, the use of such ices can bring about a shortening of the lag-acceleration phase of bacterial growth again leading to more rapid spoilage. A similar effect will be obtained by exposure of fish to improperly cleaned boxes, pen boards, etc.

Of all the physical and chemical factors which affect bacterial growth, temperature is probably the most important. The psychrophilic bacteria, which normally cause fish to spoil, grow many times faster at temperatures close to 70°F than they do at temperatures close to 32°F. Indeed, as Hess[5] pointed out many years ago, the effect on bacterial growth of raising the temperature a few degrees in the region of 32°F is out of all proportion to the effect of raising the temperature through the same number of degrees in the region of 70°F. Any laxity in temperature control (e.g., through use of insufficient ice or poor brine cooling) will result in accelerated bacterial growth and more rapid spoilage.

Filleted and steaked fish are particularly susceptible to the deleterious effects of bad handling since the naked flesh provides an excellent medium for bacterial growth. Theoretically, a fillet carefully prepared from a fresh fish should be nearly sterile, since all bacteria are initially present only on the exterior surfaces of the fish. However, filleting knives, tables and boards, filleter's gloves, static wash water, etc., rapidly accumulate large populations of fish bacteria if proper sanitary precautions are not observed. Transposition of these bacteria to the virgin flesh surface can bring about very rapid spoilage of the cut fish.

Effect of Processing on Fish Bacteria. The primary aim of all processing is to interfere in some way with the activities of the spoilage bacteria. Most processes can be defined in terms of three objectives: partial inhibition, complete inhibition, and sterilization.

Partial Inhibition. Partial inhibition is most commonly achieved in practice by maintaining the temperature of the fish or other seafood close to 32°F by the use of ice or refrigerated brine. As was noted earlier, the effect of such low temperatures is to reduce very greatly the rate of multiplication of the spoilage bacteria and thus to delay the onset of the logarithmic growth phase and the corresponding development of gross spoilage.

Chemical additives, such as nitrites, benzoates, etc., operate in a somewhat different manner, bringing about a partial inhibition of the sensitive portion of the bacterial flora, but yield the same end results as chilling—a delay in the rate of increase of the spoilage population. These substances are in fact usually used in association with chilling, and the combined inhibitory effect is additive in nature. Antibiotics of the tetracycline group, though very much more potent inhibitors than the other bacteriostatic chemicals, also produce only a temporary remission of bacterial activities. However, chlortetracycline, oxytetracycline, and tetracycline have been shown to yield considerable extensions of "storage life" of round and filleted fish at chilling temperatures when applied at levels up to about 10 ppm in ice or as dips yielding residual concentrations of about 7 ppm on the fish surface.

Analyses of the bacteria present on fish stored in antibiotic ices have shown that the antibiotics initially exert a highly selective effect, greatly reducing the proportions of "spoilage types" present in the early storage period and maintaining the total bacterial populations at a low level. However, after an extended lag and acceleration phase, the normal logarithmic growth ensues and spoilage then becomes evident. The spoilage flora which ultimately develops is similar to that present in normally iced fish, except that its members are mostly insensitive to the antibiotic when tested *in vitro*.

Pasteurization, whether effected by heat or by high energy irradiation, is also a partial inhibition process which by its selective effect on sensitive bacteria slows down the development of the spoilage flora and delays, but does not prevent, spoilage.

Most modern smoking processes ensure only partial inhibition of bacteria. The preliminary brining and drying procedures may produce some reduction in the numbers of bacteria and probably exert a selective antibacterial effect. Smoking deposits phenolic and other substances on the fish surface which are mildly antiseptic. The combined effect of these factors is to retard the development of the spoilage flora and thus extend keeping time slightly.

In general, partial inhibition processes are most effective when applied very soon after the death of the fish. Once the spoilage flora has entered the period of logarithmic growth such processes are of little use.

Complete Inhibition. Freezing, salting, and drying (including freeze drying) provide good examples of complete inhibition processes. Though each of these processes may produce considerable mortality among the bacteria on fish, their primary preservative effect is due not to this but to the production of conditions in the seafood which makes bacterial growth impossible. In each of the quoted cases the effect is produced by removal of available water. In the frozen product, water is unavailable because it is converted into ice; in the salted product free water is bound by the sodium chloride or removed by osmotic action; and in the dried product free water has been removed more or less completely. Heavily smoked products which keep for a long time owe their stability to the removal of water partly as a result of the preliminary salting and partly during the smoking process itself. Bacteria are unable to metabolize in the absence of free water because their assimilative processes are dependent on the presence of dissolved nutrients.

In the case of salted products, the osmotic effects of high salt concentrations is also important. However, salted products may be subject to a peculiar type of spoilage due to the activities of halophilic bacteria and molds which produce the conditions known as "Pink" and "Dun" respectively. These organisms are capable of growing in nearly saturated solutions of sodium chloride. The red pigmented bacteria responsible for Pink are commonly present in solar salts and are difficult to eliminate once they have established themselves in a salt fish processing plant. Some degree of control of Dun can be obtained by use of the fungistatic chemical, sorbic acid, which may be applied to salt fish in the form of a dip.

The complete inhibition processes are characterized bacteriologically by their reversibility. This is most clearly seen in the case of frozen seafoods which when thawed immediately show the usual pattern of spoilage as the inhibited bacteria regain their normal capabilities.

Fermentation and pickling processes occupy a position intermediate between complete inhibition and sterilization. Fermented and pickled products are usually not sterile but have been subject during processing to more or less irreversible changes which preclude the re-establishment of the normal spoilage flora. In each case, the inhibiting substances are acids produced in fermentation by the action of selected microorganisms and in pickling by direct addition of acid or by partial fermentation. Low pH is, like low temperature, a potent general inhibitor of bacterial growth, but microorganisms (particularly yeasts and fungi) exist which can grow at fairly low pH levels and these can cause deterioration of acid fish products.

Sterilization. There is actually only one commercial seafood processing method which is designed to achieve the objective of sterility. This is canning. However, the experimental technique of high dose irradiation is also designed to achieve sterility. In each of these cases the bacteria on the seafood are killed and the spoilage process can only be reinitiated by recontamination of the foodstuff from an external source. To prevent this, the food is enclosed in a hermetically sealed container prior to sterilization.

Spoilage of such a food can only result from faulty processing or a flaw in the container. Faulty processing must be understood to include faulty sanitation in the plant since heavy contamination of filling lines, etc., with certain types of resistant spore-forming bacteria can result in spoilage of canned seafoods subject to thermal processing which would be perfectly adequate for foods carrying their normal bacterial populations. Indeed, it may be noted here that most of the bacteria normally present on fresh seafoods are extremely sensitive to heat.

Food Processing Hazards. Processes which bring about a complete change in the bacterial flora of foods, usually by virtual elimination of the naturally occurring bacteria and their replacement by adventitious forms which may be derived from human or animal sources, introduce the problem of potential food poisoning hazards. Fresh and frozen seafoods, other than shellfish, have only very rarely been indicted as the source of food poisoning incidents. Fresh molluscan shellfish offer a peculiar problem due to their natural method of feeding and their growth in coastal waters which may be exposed to terrigenous pollution. However, the very effective control measures which are practiced in most countries have virtually eliminated the food poisoning hazard implicit in this situation.

The other fresh seafoods owe their freedom from food poisoning risk to three factors. These are: (a) the absence of food poisoning bacteria in the natural floras (in contradistinction to fowl in which *Salmonella* occur naturally), (b) the normal practice of holding fish products at low temperatures, and (c) the controlling influence of the normal and putrefactive spoilage flora on stored fish. The first point needs no comment. The importance of the second point is closely related to the third. Food poisoning organisms will not, in general, grow significantly at low temperatures (i.e., below about 50°F), but the normal flora, since it is primarily psychrophilic in nature, will grow quite actively. In situations where the temperature is high enough to permit growth of dangerous organisms, the natural flora will, in most cases, grow very much faster so that the potential pathogens are swamped and eventually die out. There may even be a positively lethal effect on such pathogens from the competitive growth of the spoilage flora.

In precooked seafoods such as fishsticks, fish dinners, etc., the extremely heat-sensitive natural flora is largely wiped out and may, under poor sanitary conditions, be replaced by an essentially mesophilic (temperature optimum about 100°F) contaminant flora which may contain significant numbers of bacteria from human sources. The dangers in such a situation are obvious. Very much higher standards of plant sanitation and operator personal hygiene are necessary in plants producing these types of foods than in normal fresh fish processing plants.

Chemical Changes

Early Post Mortem Changes. Ordinarily the most important *post mortem* change in fish is the changing of the muscle metabolism reactions largely to irreversible ones with the resulting accumulation of lactic acid in the tissue and a decline in its pH. The pH of the living fish muscle is not far from 7.0; as a result of *post mortem* accumulation of lactic acid, pH values in the range of 5.8 to 6.2 are reached at peak *rigor* development. The minimum pH attained varies somewhat with the species of fish, being a function of the initial glycogen content, the buffer capacity of components of the fish tissue, and the rate of the various *post mortem* reactions which result not only in accumulation of lactic acid but also in its subsequent oxidation and disappearance. Shellfish, such as oysters and clams, which contain relatively large quantities of glycogen attain a much lower pH as a result of *post mortem* changes with values of pH 5.0 or even lower being not uncommonly reached.

The lowering of the pH is important as a means of decreasing the rate of bacterial multiplication, thus in effect prolonging the keeping quality of the fish to a considerable extent. The pH of the fish at the time of freezing affects the texture of the frozen product because of its relationship to ice crystal formation and cell damage which causes variation in expressible fluid[7].

A second immediate *post mortem* change important only in certain cases occurs where the fish have been feeding upon certain types of food (e.g., "red feed," usually a microscopic shellfish such as *Callanus finmarchicus*) which have activated the digestive enzymes to a high degree. When this occurs, an extensive proteolysis of the fish tissue adjacent to the digestive tract occurs such that in extreme cases all of the flesh adjacent to the backbone, and sometimes extending for a considerable distance into the muscle, is completely liquefied. This form of autolysis, resulting from action of digestive enzymes, is the only one having serious consequences in the practical handling of fish.

There are other early *post mortem* changes which occur in fish tissue as a result of enzymatic changes in the protein and other components. Thus it has been shown that there is a small but definite increase in free amino acids which occurs early in the storage of freshly caught fish[6]. Other early changes result in some as yet unresolved alteration in flavor components which cause a decrease in the normal species flavor characteristics.

Changes in Proteins. The nature of proteins has been discussed briefly in the previous chapter. These high polymers are affected in a number of ways by environmental conditions. The primary peptide bonds which hold the amino acids together may be hydrolyzed by acids or alkalies or by enzymes. Mild conditions of hydrolysis break only a few bonds with the formation of heterogeneous mixtures of large polypeptides. Heat disrupts secondary bonds which hold proteins in their stable configurations. With soluble proteins the change in properties called "denaturation" is observable as subsequent coagulation. Denaturation also occurs in the presence of certain chemical reagents, such as detergents or urea. The changes in texture which occur in frozen fish during storage or in freeze-dehydration are ascribed to denaturation of the labile fish protein.

The various side chains of proteins may also enter into other types of reactions. Thus, the disulfide bond (—S—S—) of cystine may be converted to the sulfhydryl (—SH) of cysteine by reducing agents. The reverse reaction can also occur if oxidizing conditions are present.

The free amino groups of proteins are available for reactions with reducing sugars or with some of the products of oxidation of lipid material. The end result of a complicated series of reactions is the formation of brown colors and changes in flavors. This reaction is called "non-enzymatic" browning or the Maillard reaction or the carbonyl-amine reaction. The browning which occurs during cooking or during storage of dried fish products under adverse conditions or the "rusting" of fatty fish during long-term cold storage are probably all of this nature. The brown products of proteins and carbonyl compound reactions are usually indicative of a loss in acceptability. Foreign odors and flavors accompany the color changes.

In cod, browning or rusting has been carefully studied by Burt and Jones[3]. A number of reducing sugars and nitrogenous substances may be involved. Their relative importance depends upon their concentration, and this may be dependent upon the nutritive state of the fish, how long it was held in cold storage, etc. The browning reaction can be inhibited by low temperature, by low moisture content (in dehydrated products), and by the addition of sulfites. The latter has, however, undesirable side effects in meat and fish.

Changes in Oils. Fish oils hydrolyze to form free fatty acids as occurs in other food lipids. Probably owing to the long chain fatty acids which predominate and which, because of relatively high vapor pressure, are without flavor or odor, hydrolyzed fish oils do not present the problem which occurs with butter, for example, where butyric acid and other short chain fatty acids can occur. Oxidation of the fatty acids giving rise to numerous carbonyl types of products is the chief cause of rancidity in fish oils.

Although little research involving the mechanism of fish oil oxidation has been carried out, there is little reason to believe that such mechanism differs markedly from that of other lipids involving hydroperoxide autoxidation[12]. In fact, it was an observation by Farmer[4] on autoxidizing fish oil fatty acids which led to the development of the modern theories on nonconjugated polyunsaturated autoxidation. Such theories will not be discussed here, but some minor deviations in the behavior of fish oils from that of other lipids during oxidation will be noted. The course of oxidation is often quite different in extracted fish oils than when the oils remain in the fish tissue so that these cases will be discussed separately.

Oxidation of Extracted Fish Oils. Extracted fish oils oxidize at a considerably greater rate than do most vegetable oils or animal fats, and this is scarcely surprising in view of the much greater content of highly polyunsaturated (five and six double bonded) fatty acids. In most cases the induction curve for the oxidation of fish oils is considerably flattened with not such a pronounced break in the curve at the end of the induction period. This is particularly the case with crude, unrefined fish oils. Antioxidants which give high protective factors with many other lipids sometimes give much lower protective factors for fish oils. There seems to be in many cases a lack of consistency between the effect of antioxidants on fish oils as reported by different workers or even as found by the same worker at different times. Some of these discrepancies can be explained on the basis of the effect of such naturally occurring impurities in crude fish oils as free fatty acids and amines which, as reported by Olcott, *et al.*[8,9,10], exert respectively a negative antagonistic and a positive synergistic action on the effectiveness of certain antioxidants on the oxidation of fish oils. The situation is quite complex such that a given substance may act as a synergist with one antioxidant and as an antagonist with another.

Oxidation of Oil in Fish Tissue. Oil in fresh fish tissue held at refrigerated temperatures above freezing seldom exhibits any marked tendency toward oxidation or development of rancidity. In almost every instance the fish has become inedible from bacterial spoilage before any indication of rancidity appears. This surprisingly great stability of fish oils in the tissue of fresh fish would appear to be caused by something more than the mere overshadowing of the onset of rancidity by the much more rapid development of bacterial decomposition. It has been suggested[1,11] that this behavior, which has also been noted in the case of bacon stored just above and just below the freezing point, may be due to bacterial action in the chilled product limiting the oxygen tension and hence greatly retarding the rate of potential oxidation of the oil.

When fish is stored at above-freezing temperatures and the bacterial decomposition is reduced or eliminated by such techniques as dehydration, salting, or irradiation, then the oxidation proceeds at a rate which would normally be expected and the oil may become extremely rancid.

When fish is stored at sub-freezing temperatures, the oil slowly oxidizes and becomes rancid. Under such circumstances the development of rancidity does not follow a typical induction type of curve but rather usually occurs as a more or less straight line relationship between time and degree of oxidation of the oil.

The oil in the areas of the fish known as the dark meat such as occurs, for example, along the lateral line and at other portions of the fish, oxidizes at far greater rates than occurs in the light meat portions of the fish[2]. This difference in oxidation rate in the dark and light meat portions of the fish, which may be as much as 100 fold, is due to the presence in the dark layer of fish muscle of haematin compounds which act as powerful prooxidants.

Antioxidants added to fish to be frozen usually add considerably less protection against oxidation than would be predicted from model system experiments employing either the pure oil or suspensions of the oil with other fish tissue components. This disappointingly small effectiveness of antioxidants to retard rancidity development in frozen fish is in part due to difficulty in getting adequate penetration of the antioxidant to reach and protect the oil in the tissue. Other factors must also be involved such as differences between component substances and arrangements of the substances at a cellular or histological level in the fish tissue as compared to model systems of a relatively simple type where the antioxidants function much more effectively.

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CHAPTER 28

Nutritive Value and Quality of Fish

KATHRYN L. OSTERHAUG, JOHN DASSOW, AND MAURICE E. STANSBY

Nutritive Value of Fish

Fish is as good a source of animal protein, vitamins, and inorganic components as are other flesh foods such as meat and poultry. The amino acid balance in the protein is unexcelled by that of any other foods. The B vitamin content approximates that of meat, and the mineral content is richer in iodine than that of any other foods. The calcium content of canned fish containing softened bone is much higher than that of other foods so that, if the bone is not removed before eating, such fish as canned salmon and sardine represent the richest natural source of calcium. Those species of fish falling in category A (see Chapter 26) having a low oil and high protein content and which represent a majority of all species, contain lower calorie content per unit of protein than do meats or poultry. Thus these lean fish are an ideal source of animal protein for use in reducing diets.

On the other hand, fish having somewhat higher oil content in the range of 5 to 15 per cent oil (category B, Chapter 26), while of medium oil content for fish, correspond to an average *lean* meat with respect to fat content. Furthermore, the fish contains up to $^{1}/_{3}$ of its oil in a highly polyunsaturated form with four, five, and six double bonds per fatty acid.

This type of oil has been shown[3] to be effective in lowering blood cholesterol. Such fish oils are effective even when included in the diet with much larger quantities of saturated fatty acids.

Both the flavor of fish and many of its nutritive components are soluble in water; therefore, thawing unwrapped fish in water or boiling fish in water that later is discarded are wasteful practices. Some vitamins are destroyed by excessive heat and fats are oxidized at high temperatures; therefore, moderate temperatures should be used when cooking fish to avoid overcooking them. The Test Kitchen Series published by the U.S. Bureau of Commercial Fisheries is a good source of information on the proper methods of cooking fish.

Information Needed by Consumers of Fishery Products

The most important and valuable result of the effort and skill of the fishing industry is the production of food for human beings. To produce food products that meet the aesthetic, nutritive, and convenience standards of the American public is indeed a challenge. In order to do this, the processor of fishery products must have an accurate knowledge of what these standards are. On the other hand, the consumer must be in possession of certain basic knowledge in regard to fishery products before she can apply her food standards to fish.

Species and Market Forms. Approximately 240 species of fish and shellfish are available on the markets in the United States. In addition, innumerable processed and ready-to-eat forms of these species are available to the consumer. The development of convenience foods is growing at a tremendous rate. This development is particularly important in fish marketing as many consumers lack confidence in their own ability to prepare palatable dishes from these products.

The variety of species and market forms that is available in the field of fishery products precludes any danger of monotony for people who wish to eat or serve fish often.

Fish for Special Diets. The nutritional characteristics of fishery products make them valuable for use in both normal and special diets. Species of fish can be chosen to fulfill specific nutritive requirements.

The high content of complete protein combined with the extremely low fat content of many species of fish make them ideal for inclusion in weight-reduction diets. The section of the fish from which the serving portion is taken influences fat content. For instance, slices of fish taken from near the head contain up to several times as much fat as the tail portion.

Two factors that are often controlled in special diets are type of fat and sodium content. The high degree of polyunsaturation found in fish oils and the low sodium content of many species of fish make them especially useful in therapeutic diets.

The fact that fish and shellfish are readily available sources of generous amounts of complete protein and of a great variety of protective vitamins and minerals makes them a most valuable food for women during pregnancy and lactation, for children during their periods of growth and maturation, and for our growing population of senior citizens.

Seasonal Factors. The informed consumer is influenced in the choice of species by the season of the year. Many species are available fresh only during a relatively short season. Out-of-season fish may have been held for a long period in frozen storage. These fish may have developed rancidity in such oily areas as the belly flaps or along the lateral line. Often, such fish can be improved by removing the rancid areas before cooking.

Cost to Consumer. The price per pound of fish varies in relation to availability and the amount of labor invested in its preparation for market. The availability of a particular species is determined by its abundance, the proximity of the area where it is caught, and the consumer demand for the product.

Fillets of fish represent from 20 to 40 per cent of the weight of the whole fish. The consumer can thus afford to pay considerably more per pound for fillets than for the whole fish. In fish production areas there will always be the opportunity for the consumer to save labor costs by purchasing fish in the round and dressing them herself.

Quality Criteria

Flavors and Odor. The odor of iced fish ordinarily changes from the moment of capture through storage to the point of inedibility following a general pattern as shown in Table 28.1. At stage 1, most fish possess an odor and flavor characteristic of the species. These odors and flavors

TABLE 28.1. USUAL PATTERN OF ODOR STAGES FOUND IN FISH STORED IN ICE

Stage	Name	Description
1	Fresh	Normal odor characteristic for species predominating
2	Flat	Absence or decrease of normal species characteristic odor
3	"Fishy"	Onset of first faint decomposition odors often associated with fish but without any connotation of undesirability
4	Sweet	Continuation of build-up of odors associated with stage 3 but still without any connotation of undesirability
5	Stale	Arrival at stage where "off" odors are considered undesirable but fish may still be barely acceptable
6	Putrid	Stage where fish is definitely unacceptable for human consumption

are frequently delicate, perhaps quite faint, and certainly only transitory. By stage 2, much if not all of the natural species characteristic odors and flavors have disappeared. Unfortunately, the largest part of the fish consumed has reached or passed stage 2 so that the pleasing natural flavors and odors are often absent.

At stage 3, a group of perhaps quite unrelated odors and flavors, which are referred to as "fishy,"[4] begin to accumulate. At this stage these odors and flavors may be so faint as to be quite vague, almost indescribable. During stage 4, these odors often develop to a quite definite, characteristically sweet type if the fish is well refrigerated; yet, the odor is still not considered in any way objectionable. At stage 5, various amine and other odors and flavors have given the fish definitely undesirable properties which, while perhaps not rendering it entirely inedible, have certainly drastically lowered its quality. At stage 6, where sulfide and other obnoxious odors and flavors predominate, the quality of the fish has sunk to such a low level that by most standards it is considered to be quite inedible.

Another type of odor and flavor which results from oxidation and rancidification of the lipids of fish is more important with certain preserved (especially frozen) fish than with the iced fish product. These rancid flavors and odors of fish oils range from a bland, almost tasteless form in the fresh oil through various vague "fishy" stages to a fairly typical rancid flavor having a sharp, sometimes acrid taste and possessing a strong after-taste.

As has been noted by Stansby[4], the odors and flavors associated with bacterial decomposition, primarily of the nitrogenous components of fish, are not necessarily distinct and separate from those associated with fish oil oxidation. On the other hand, it has been shown[1,2] that nitrogenous components may combine in some fashion with lipid and during oxidation develop certain characteristically "fishy" odors in oils. On the other hand, fish spoiling primarily in a bacteriological pattern may contain carbonyl or other such compounds which may have arisen from the fish oil.

Texture. Normal fish texture may vary over a fairly wide range and still be considered to be entirely acceptable, depending upon the particular product. Thus halibut is normally of a flaky, moist texture wherein presence of stringiness would be considered abnormal; yet, halibut cheeks are prized by the connoisseur for just such a stringy texture. For most fish the texture characteristics considered normal and desirable include moistness, flakiness, and absence of toughness. The typically desirable fish from a texture standpoint when chewed has a moist feel in the mouth, but, as pressure is applied in chewing, there is not an excessive pressing out of moisture from the tissue. As a result of deteriorative changes during handling, texture tends to deviate from this norm in one of two ways. At one extreme, the fish appears dry and tough when eaten and little moisture can be felt at the surfaces. This condition is encountered with frozen fish which has been stored for too long or in an improper manner. It results from several types of changes which may occur including dehydration, formation of drip during thawing which is not readsorbed before cooking, or by denaturation of the protein during storage.

At the other extreme is a mushy condition whereby during chewing excessively large quantities of fluid are expressed from the fish. This condition is generally caused by proteolysis during refrigerated, above-freezing storage prior to any subsequent handling (such as freezing).

Quality Specifications and Standards

In buying and selling fishery products some type of product specification and an accepted level of quality are essential. To determine the product quality one must consider systematically the characteristics that determine its value to the buyer.

Determining Quality. Detailed purchase specifications (with inclusion of applicable standards) may be used by an exacting buyer with independent inspection checks to assure compliance and the desired level of quality. The purchase order is the obvious place for specifying product species, form, size, or unit package, and delivery requirements. Therefore the simplest type of quality inspection is an assurance of compliance with purchase requirements. The buyer often assumes the quality to be wholesome and merchantable, but quality may fluctuate with supply and demand. Availability of fishery products is frequently dependent on uncontrolled factors of season, weather, and fish distribution; therefore, shortages or gluts may provide problems.

Legal requirements include compliance with applicable regulations of the U.S. Food and Drug Administration and state or local governments. Product identity, fill of container or net weight provisions, assurance of wholesomeness, and proper labeling are key factors. Sanitation requirements for the product usually imply exclusion or limitation of microorganisms of public health or food quality significance. Exclusion of objectionable, foreign, and filthy material or origin must be assured. In shellfish sanitation, special recognition should be given to the certification program of the U.S. Public Health Service which has administered the provisions for many years through the public health programs of the individual states. In recent years the necessity of quality control requirements has increased sharply in relation to plant sanitation, bacteriological standards for foods, and use of food additives. Federal, state, and municipal regulations have become so extensive that consultation of both the regulations and the standard references is advisable (see bibliography Chapter 30).

Specifications. A specification is an accurate description of the technical requirements for a material, product, or service and includes the procedure by which it will be determined that the requirements have been met. Specifications are best known through their extensive use by the federal supply agencies; the General Services Administration has issued specifications for almost every commodity. Private buyers, institutions, local governments, and state purchasing agencies make extensive use of federal specifications in their purchasing, often with the addition of supplementary requirements. The form of federal specifications and their application in fisheries is most important for these reasons.

Grade Standards. Inasmuch as a specification or a legal standard describes a product on the basis of minimum acceptable characteristics, grade standards are desirable for many products. The broad category of products meeting the minimum standard is further segregated into two or three grades on the basis of accepted quality factors. Factors important to the desirability and market value of the product are used, e.g., flavor, color, texture, uniformity of quality, and physical defects. Food standards are developed primarily by the federal government, by the U.S. Department of Agriculture for most foods, and by the Bureau of Commercial Fisheries of the U.S. Department of the Interior for fishery products. Such standards may be mandatory as is the case of meat standards or voluntary as is true of fishery standards. Since the inception of the fishery standards program in 1954, twelve fishery product standards have been developed and promulgated to meet marketing requirements. During 1961 such standards were used under a system of voluntary government inspection on a continuous plant or lot basis to inspect and certify 185 million pounds of fishery products.

Objective Quality Criteria. Application of present fishery specifications and standards has demonstrated the need for objective criteria and methods to measure varying degrees of freshness and keeping quality. In the case of actual spoilage of fishery products, chemical determination of one or more spoilage breakdown products, such as indole in shrimp, trimethylamine in cod fillets, and total volatile acids in canned fish, produces useful results. The major problem still largely unsolved appears to be the practical measurement of the rather subtle but nevertheless important factors that enhance the palatability and, therefore the value, of really fresh fish and shellfish. Essential knowledge of the chemistry and reactions of odors, flavors, and textures of fresh fish is needed. Modern research tools such as gas chromatography, spectrophotometry, mass spectrography, and electrophoresis are proving helpful in this research and may provide the newer techniques of quality control for production of the highest quality fishery products.

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CHAPTER 29

Analytical Methods

MAURICE E. STANSBY

In this chapter will be discussed only those aspects of methods for analyzing fish where special considerations apply which are different from those for other foods. No attempt will be made to give procedures for all the various analyses. These can be found in standard analytical chemistry reference works. Attention will be paid primarily to sampling methods and to methods for determining freshness of fish.

Sampling Fish for Analysis

Owing to wide differences in composition of fish even within a small batch (see Chapter 26) and to differences in spoilage rates of individual fish from the same catch it is necessary, even in a fairly homogeneous lot of fish, to use several fish to make up a composite sample to be representative of the lot. A minimum sample size of six fish is necessary, even in quite homogeneous lots of fish, in order to be at all sure that the sample is representative of the lot. Where a large batch of fish involving several variables is involved, much larger samples are required. For example, in a vessel load of fish some fish will have been stored from the start of the catching period, possibly for several weeks, others perhaps for only a few days. A representative sample for freshness determination would then require at least six fish from each sub-lot, representing the different storage periods.

Similarly, if data on the proximate composition of fish are desired and if these are to be representative of the species as a whole, then sometimes representative samples of many different lots of fish representing such differences as fish caught at different times of year, in many different geographical areas, and in different years would be required. In such an instance, a minimum sample of six fish from each of as many as 100 different batches representing the different seasonal and geographical variables would be needed to establish the range and average proximate composition.

Because of the relatively great heterogeneity of the composition of fish, proper sampling is often the major criteria as to whether the analysis is meaningful. Errors in achieving representative samples are usually many times greater than those involving the analytical procedure itself. Careful consideration of proper sampling is, therefore, mandatory if results having any real meaning are to be obtained.

After selection has been made of a suitable number of fish for a representative sample, the problem of mixing the individual fish to give a suitable sample for chemical or other analysis is posed. Where the entire fish is to be sampled, the problem of reducing the flesh, skin, and bones to a homogeneous mass presents a problem involving use of suitable grinding and mascerating techniques. Large bones (in head or backbone) can, in particular, cause difficulties. Where cooking of the fish will not affect the resulting analyses, a steam processing to soften the bones will often solve this problem. Otherwise, rather powerful, large grinders of the hammermill or similar types are needed for preliminary grinding of bone, skin, and flesh. Skin may pose a problem with some types of grinders since it has a tendency to strip off and wind around conveyer screws.

For reducing fish flesh, free of skin and bone (or whole fish which has been given a preliminary treatment in a suitable mill) to an impalpable, homogeneous state, suitable for analytical use, a grinder adapted to cutting up pieces of tendon and connective tissue prevalent in fish is needed. For this purpose cutting-type grinders, such as are sometimes used in making sausages, are preferable to the type employing a wheel revolving against a plate with small holes (such as the ordinary kitchen meat grinder). The cutting type is better adapted to homogenizing small pieces of connective tissue, skin, and tendon.

For very soft materials such as fish liver and, in some cases, skin- and bone-free fish flesh, the blender type of equipment is suitable especially where a slurry is to be made and water or other liquid can be added.

An alternate method which sometimes has proved to be useful in sampling fish for chemical analysis is the use of "press juice." The fish (usually the flesh) is placed in a small hydraulic press inside canvas and pressure exerted. The resulting fluid is used for analysis. Use of press juice is usually satisfactory for determining water soluble components.

Results are usually somewhat different than when the entire flesh is used. This procedure is useful particularly when relative rather than absolute values are involved (for example, it is useful for preparing samples for comparison of the freshness of two batches of fish but where no legal or other standard is involved).

Proximate Composition

Proximate composition of fish is generally determined by standard procedures such as those of the A.O.A.C[2]. The only component under proximate composition which may present special problems with fish is that of determination of the oil content. Fish oils are highly susceptible to oxidation. Oxidized oils may be only slowly extracted by conventional fat solvents. In some cases, also, the fish oils in fish flesh or other fishery products may be combined with protein or other components and are then only partially extracted by ethyl or petroleum ether. This is the case, for example, with fish meals which have been stored for a long time. Use of acetone[2] or acetone containing acid (which partially hydrolyzes the complex lipids)[11] is helpful in such cases. Or a mixed solvent such as chloroform and methanol[4] can be used. Certain portions of fish such as roe and milt have most of their oil in phosopholipid or similar complex form. Such products must be analyzed using one of these techniques if the total oil content is to be determined.

Freshness Tests

Under this section will be considered tests for deteriorative changes in the nitrogenous portion of fish (mostly as a result of bacterial decomposition). Tests for rancidity are discussed in the section on fish oils.

While many chemical and bacterial tests have been proposed as giving a measure of the freshness of fish, none of these are universally applicable. Actually such tests usually are expected to correlate with various organoleptic conditions such as flavor and odor. Flavor and odor are subjective tests and their organoleptic measurement suffers all the limitations such as lack of reproducibility that are common to such tests. Nevertheless, these organoleptic evaluations are the ultimate standard against which any scientific tests for freshness must be compared. In particular, flavor and odor, which are the most important criteria for fish freshness, are dependent upon the presence or absence of not one but many chemicals. It is not surprising, therefore, that no single freshness test has been found which is both an accurate measure of freshness of fish and fairly universally applicable. Chemical freshness tests for fish can be classified[12] as specific tests (tests for a single chemical component) and group tests (tests for a group of related substances). From what has just been said, it is evident that group tests involving a determination of several different substances, each of which contributes to odor and flavor, may be more reliable than specific tests.

Group Tests for Freshness. These group tests include (a) total volatile base[13] in which ammonia, trimethylamine, and other basic substances are aerated or distilled from a mildly alkaline fish extract, collected in standard acid and determined, (b) total volatile acid[5] in which formic, acetic, and other volatile acids are steam distilled into a standard base and determined, (c) volatile reducing substances[9] in which permanganate reducing organic substances are aerated from neutral fish press juice or extract and the volatiles passed through standard alkaline permanganate at room temperature and determined, (d) pH, a measure of accumulated acids, bases, or both.

Of these tests, that for total volatile base is quite generally applicable; it usually gives reasonably good correlation with organoleptic freshness, and it can be carried out without the use of special equipment. Of the above listed tests it has the most advantages and if a single test is to be applied for freshness, except when special circumstances pertain, it is generally the author's choice. Following is a brief description of a simplified volatile base method[13]:

Blend 40 grams fish in a liquidizer (such as a Waring Blender) with 100 ml ethanol for 5 minutes. Centrifuge and decant into a 250 ml volumetric flask. Wash the precipitate twice with 25 ml portions 60 per cent ethanol, decanting the wash solutions into the volumetric flask after centrifuging each. Make to mark and transfer to a 500 ml Kjeldahl flask. Add 4 glass beads, 0.5 ml caprylic alcohol, and 5 gm powdered borax. Connect immediately to Kjeldahl distillation equipment and distill 100 ml distillate into 50 ml 0.05 N hydrochloric acid. Run a blank at the same time using 60 per cent ethanol in place of fish extract. Back-titrate excess of acid using methyl red as indicator. Calculate results as mg volatile base nitrogen per 100 gm of fish.

Total volatile base values for different degrees of freshness of fish expressed as above generally are about as follows: fresh fish, 12 or less; slight decomposition but entirely edible, 12 to 20; borderline edibility, 20 to 25; badly decomposed and inedible, above 25.

Total volatile acid gives as accurate correlation with freshness of fish as any test (including total volatile base). It is a somewhat tedious determination to carry out, requiring considerable attention to keep the steam distillation rate constant. The volatile reducing substances test requires special equipment and in the hands of some operators fails to give reproducible results. A measurement of pH is unreliable for most species of fish because end products of spoilage of both alkaline and acidic nature tend to neutralize each other. With shellfish, particularly oysters where the initial primary spoilage substance is lactic acid, pH is a simple, fairly reliable freshness test.

Of the many specific tests for single chemical substances used as a measurement of freshness, that for trimethylamine[3] has been most widely used. While the trimethylamine measured during spoilage of fish contributes little to the fishy odor, with some species of fish there is a fairly consistent increase in trimethylamine with spoilage. The test has proved to be useful principally with certain low-oil content marine species such as cod and haddock. Among the many other specific tests which have been used for fish freshness are those for histamine[6], hydrogen sulfide[1], acetoin[7], and certain free amino acids[8].

Many of the chemical freshness tests are successful in correlating with deteriorative changes occurring at the middle and late stages of spoilage where such spoilage is usually fairly obvious from organoleptic odors. Few, if any, of the tests provide a sensitive measure of early deteriorative changes before onset of the obvious spoilage changes.

Total bacterial counts are sometimes carried out as an indication of spoilage. While such total counts do include non-spoilage bacteria along with those which are responsible for spoilage, plate counts are nevertheless useful, at least in cases where relative rather than absolute values are to be used. Standard plate count methods such as are used for other foods are employed for fish. Where a measure of spoilage is desired, plate incubation temperatures of 20 or 25°C should be used rather than 37.5°C which is suitable mainly where counts are concerned with sanitary practices.

Methods for Fish Oils

When fish oils are to be extracted for subsequent examination, it is important to use extraction procedures which will not result in oxidation or polymerization during extraction. The method of Bligh and Dyer[4], employing a cold shaking extraction with a chloroform-methanol mixture is useful for this purpose.

The oxidative changes in fish oils which lead to rancidity can be followed by measuring total oxygen adsorbed (by use of a Warburg apparatus or by weight increase[10]), by measuring the amount of intermediate peroxide content[14], or by measuring the amount of certain end products[15].

The first of these methods (oxygen adsorption) is of an accelerated type, whereby the rate at which oxygen is adsorbed by the oil is measured. The other methods are tests for products formed by oxidation of the oils. They also can be applied to measurement of the rate of oxygen adsorption by aerating the oils and, at suitable intervals, running the test in question. Tests of this type, where the rate of oxygen uptake is measured, permit estimation of the induction period—the period of time when relatively little oxidation is taking place but after which rapid oxidation and rancidity develop. Measurement of the induction period is generally more desirable and useful than is the determination of a single value on the curve.

None of the methods based on a single test are at all reliably correlated with the organoleptic flavor of the oil. Depending upon such factors as the storage temperature of the oil during oxidation or whether or not an antioxidant was present, the values for a given test corresponding to a certain degree of rancidity may be quite different. If all these possible sources of discrepancy are kept in mind, it is possible to use successfully any of the tests by closely calibrating results from time to time with organoleptic rancidity. Of the tests mentioned, the procedure for peroxide number (which is very simple to execute) and the test for T.B.A.[15] are perhaps most widely used. The limitations of these tests must be constantly kept in mind if their use is not to result in misleading conclusions.

Fish oils are more unsaturated than any other common oils and are, therefore, highly susceptible to oxidation. Special precautions are needed during their analysis to prevent changes from occurring during the analysis itself. It is advisable whenever possible to keep them under an atmosphere of nitrogen at all times during analysis. For this purpose, nitrogen of a high degree of purity (99.99 per cent or better) should be used. Oxygen, contained as an impurity in some commercial nitrogen, may cause oxidation. The nitrogen, when applied to fish oils, should be bubbled through the oil to displace oxygen dissolved in the oil as well as any in the headspace.

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CHAPTER 30

General Bibliography

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The references presented here are by no means complete. However, they include some of the more important ones. They have been classified as follows:

I. General and Miscellaneous
(Includes references on conservation and descriptions of specific fisheries)
II. Composition and Nutrition
III. Chemistry and Microbiology
IV. Spoilage, Preservation, Quality, and Specifications
V. Harvesting of Fish
VI. Handling Fresh Fish
VII. Freezing and Cold Storage
VIII. Canning and Curing
IX. Industrial Products and Animal Feeds

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Product	Specification No.	Date Effective
Clams: raw, shucked, fresh (chilled), and frozen	PP-C-401a	April 25, 1952
Crab meat: canned	PP-C-651a	Sept. 25, 1956
Crab meat: cooked, chilled, and frozen	PP-C-656a	March 6, 1956
Fish: fresh (chilled), and frozen	PP-F-381d	Sept. 3, 1954
Oysters: canned	PP-O-951	March 3, 1931
Oysters: raw, shucked, fresh, and frozen	PP-O-956	July 27, 1950
Salmon: canned	PP-S-31b	Aug. 8, 1951
Sardines: canned	PP-S-51d	April 11, 1957
Shrimp: canned	PP-S-311a	Sept. 8, 1955
Shrimp: frozen, raw, breaded	PP-S-315	(New)
Shrimp: raw, and cooked, chilled, and frozen	PP-S-316a	June 20, 1955
Tuna fish: canned	PP-T-771	March 31, 1931

* Federal Specifications available from the General Services Administration Regional Offices in Boston, New York, Atlanta, Chicago, Kansas City, Dallas, Denver, San Francisco, Seattle, or Washington, D.C.

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