

CHAPTER 18

FISHERY PRODUCTS

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THE major types of fish and shellfish harvested from North American waters and used for food include the following:

- Groundfish (haddock, cod, whiting, flounder, and ocean perch), lobster, clams, scallops, snow crab, shrimp, capelin, herring, and sardines from New England and Atlantic Canada
- Oysters, clams, scallops, striped bass, and blue crab from the Middle and South Atlantic
- Shrimp, oysters, red snapper, clams, and mullet from along the Gulf Coast
- Lake herring, chubs, carp, buffalofish, catfish, yellow perch, and yellow pike from the Mississippi Valley and the Great Lakes region
- Alaska pollock, Pacific pollock, tuna, halibut, salmon, Pacific cod, various species of flatfish, king and snow crab (*Chionoecetes opelio*)—about 90 000 000 kg annually—Dungeness crab, scallops, shrimp, and oysters from the Pacific Coast and Alaska
- Catfish, salmon, trout, oysters, and mussels from aquaculture operations in various parts of North America

Fish harvested from tropical waters are reported to have a substantially longer shelf life than fish harvested from cold waters. This may be due to the bacterial flora naturally associated with the fish. The bacteria associated with fish from tropical waters are mainly gram-negative mesophiles, whereas the bacteria that cause spoilage of tropical or other fish during refrigerated storage are usually gram-negative psychrophiles. The time required for this bacterial population shift (from mesophiles to psychrophiles) after refrigeration may account for the increased shelf life.

The major industrial fish used for fish meal and oil is menhaden from the Atlantic and Gulf coasts. In addition, the parts of fish not used for human consumption are often used to manufacture fish meal and oil.

Fish meal and oil are the principal components of the feed used in the aquaculture of trout and salmon. Meal also is a component of the diets of poultry and pigs. Fish oil is used in margarine, in paints, and in the tanning industry. It is also being refined for pharmaceutical purposes.

This chapter deals with the preservation and processing of fresh and frozen fishery products; the care of fresh fish aboard vessels and ashore; the technology of freezing fish; and present commercial trends in the freezing, frozen storage, and distribution of seafood.

See [Chapter 26](#) for additional information regarding fishery products for precooked and prepared foods.

HACCP System. Many of the procedures for the control of microorganisms are managed by the Hazard Analysis and Critical Control Point (HACCP) system of food safety. Each food manufacturing site should have a HACCP team to develop and implement its HACCP plan. See [Chapter 11](#) for additional information on sanitation.

The preparation of this chapter is assigned to TC 10.9, Refrigeration Application for Foods and Beverages.

FRESH FISHERY PRODUCTS

CARE ABOARD VESSELS

After fish are brought aboard a vessel, they must be promptly and properly cared for to ensure maximum quality. Trawl-caught fish on the New England and Canadian Atlantic coasts, such as haddock and cod, are usually eviscerated, washed, and then iced down in the pens of the vessel's hold. The offshore Canadian fleet and the fleets of Iceland, the United Kingdom, and other European countries have been icing the fish in boxes for optimum quality. Because of their small size, other groundfish (e.g., ocean perch, whiting, flounder) are not eviscerated and are not always washed. Instead, they are iced down directly in the hold of the vessel.

Crustaceans, such as lobsters and many species of crabs, are usually kept alive on the vessel without refrigeration. Warm-water shrimp are beheaded, washed, and stored in ice in the hold of the vessel; on some vessels, however, the catch is frozen either in refrigerated brine or in plate freezers. Cold-water shrimp are stored whole in ice or in chilled sea water, or they may be cooked in brine, chilled, and stored in containers surrounded with ice.

Freshwater fish in the Great Lakes and Mississippi River areas are caught in trap nets, haul seines, or gill nets. They are sorted according to species into 23 or 45 kg boxes, which are kept on the deck of the vessel. In most cases, fishermen carry ice aboard their vessels, and the fish are landed the day they are caught.

Freshwater fish in the lakes of Canada are iced down in the summertime and stored at collecting stations on the lakes, where they are picked up by a collecting boat with a refrigerated hold. Winter-caught Canadian freshwater fish and Arctic saltwater fish are usually weather-frozen on the ice immediately after catching and are marketed as frozen fish.

Line-caught fish of the Pacific Northwest, such as halibut caught largely by bottom long-line gear and salmon caught by trolling gear, are eviscerated, washed, and iced in the pens of the vessel. Pacific salmon caught by seines and gill nets for cannery use are usually stored whole for several days, either aboard vessels or ashore in tanks of seawater refrigerated to -1 °C. A small but significant volume of halibut is held similarly in refrigerated seawater aboard vessels. Tuna caught offshore by seiners or clipper vessels are usually brine-frozen at sea. However, tuna caught inshore by the smaller trollers or seiners are often iced in the round or refrigerated with a brine spray.

Fish raised by aquaculture farms are usually harvested and sold as required by the fresh fish market. They are usually shipped in containers in which they are surrounded by ice.

Icing of Fish

Fish lose quality because of bacterial or enzymatic activity or both. Reduction of storage temperature retards these activities significantly, thus delaying spoilage and autolytic deterioration.

Low temperatures are particularly effective in delaying growth of psychrophilic bacteria, which are primarily responsible for the spoilage of nonfatty fish. The shelf life of species such as haddock

and cod is doubled for each 4 to 5.5 K decrease in storage temperature within the range of 16 to -1°C.

To be effective, ice must be clean when used aboard a vessel. Bacteriological tests on ice in the hold of a fishing vessel showed bacterial counts as high as 5 billion per gram of ice. These results indicate that (1) chlorinated or potable water should be used in making the ice at the ice plant, (2) ice should be stored under sanitary conditions, and (3) unused ice should be discarded from a vessel at the end of each trip.

Both flake ice and crushed block ice are used aboard fishing vessels, although flake ice is more common because it is cheaper to produce and easier to handle mechanically.

The amount of ice used aboard vessels varies with the particular fishery and vessel; however, it is essential to provide sufficient ice around the fish to obtain a proper cooling rate (see Figure 1). A common ratio of ice to fish used in bulk icing on New England trawlers is one part ice to three parts fish. Experiments on British trawlers in boxing fish at sea with one part ice to two parts fish demonstrated improved quality in the landed fish, and, as ice has become more plentiful and less costly relative to the value of fish, the ratio of ice to fish continues to increase. Mechanical refrigeration is employed in some vessels to retard the melting of ice en route to the fishing grounds; however, the hold temperature must be controlled after fish are taken to allow the ice to melt for effective cooling of the fish.

Saltwater Icing

Iced fish storage temperatures must be maintained close to the freezing point of fish. To obtain lower ice temperatures, the freezing point may be depressed by adding salt to the water from which the ice is made. Adequate amounts of ice made from a 3% solution of sodium chloride brine will maintain a storage environment of about -1°C. Tests conducted on the storage of haddock in saltwater ice aboard a fishing vessel showed that, under parallel conditions, fish iced with saltwater ice cooled faster and to a lower temperature than fish iced with plain ice. However, the saltwater ice melted faster than the plain ice because of its lower latent heat and its greater temperature differential. Therefore, once the saltwater ice melted, the fish stored in this ice rose to a higher temperature than those stored in plain ice. Since it is not always possible to replenish ice on fish at sea, sufficient quantities of saltwater ice must be used initially to make up for its faster melting rate.

In making ice from water containing a preservative, rapid freezing and/or using a stabilizing dispersant is essential to prevent migration of the additive to the center of the ice block. This problem is not encountered in flake ice because flake ice machines freeze water rapidly into thin layers of ice, thus fixing additives within the ice flakes. Chapter 33 describes the manufacture of flake ice in more detail.

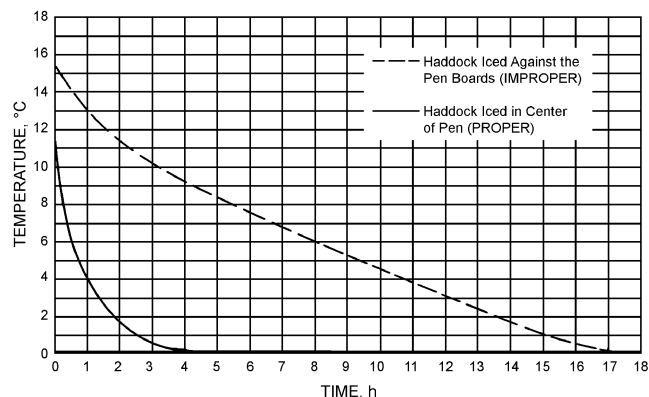


Fig. 1 Cooling Rate of Properly and Improperly Iced Haddock

Use of Preservatives

In the United States and Canada, the use of antibiotics in ice or in dips for treatment of whole or gutted fish, shucked scallops, and unpeeled shrimp is prohibited by regulation.

Storage of Fish in Refrigerated Sea Water

Refrigerated seawater (RSW) is used commercially for preserving fish. On the Pacific Coast, substantial quantities of net-caught salmon are stored in RSW aboard barges and cannery tenders for delivery to the canneries. Most salmon seiners now use RSW Systems. It is often a condition of sale. On the East and Gulf coasts, RSW installations on fishing vessels are used for chilling and holding menhaden and industrial species needed for production of meal, oil, and pet food. On the east and west coasts of Canada, RSW installations are used for chilling and holding herring and capelin, which are processed on shore for their roe. Other more limited applications of RSW include holding Pacific halibut and Gulf shrimp aboard a vessel; chilling and holding Maine sardines in shore tanks for canning, and short-term holding of Pacific groundfish in shore tanks for later filleting.

With groundfish and shrimp, RSW works well for short-term storage (2 to 4 days), but it is not suitable for longer periods because of the excessive salt uptake, accelerated rancidity, poorer texture, and increased bacterial spoilage that may result. These problems can be partially overcome by introducing carbon dioxide (CO₂) gas into the RSW; holding in RSW saturated with CO₂ can increase the storage life of some species of fish by about 1 week. Additionally, RSW reduces (1) handling that results from the bulk storage of the fish and (2) pressure on the fish as a result of buoyancy, faster cooling, and lower storage temperature.

In many RSW systems, the refrigeration effect is provided by ammonia flowing through external chillers or pipe coils located within the tanks. Best results have been achieved with external chillers.

Boxing at Sea

There are many advantages to using containers or boxes instead of bulk storage aboard fishing vessels. Known as boxing at sea, the use of containers reduces pressure on the fish while they are stowed in a vessel's hold. Because significant reductions in handling during and after unloading are possible, mechanical damage and product temperature rise may be virtually eliminated and handling costs may be reduced. Fish can be sorted into boxes by size and species as soon as they are caught. Boxed fish lend themselves more readily to mechanized handling, such as machine filleting, because they are generally firmer and of more uniform shape; fillet yields are generally better than they are with bulk-stored fish.

Boxing at sea is not generally practiced in the United States, except by some inshore vessels. The principal problems associated with converting a fishing vessel from bulk storage to boxed storage are the increased labor required by the crew for handling the boxes, the reduced hold capacity, and a relatively large investment for boxes. Many fisheries have difficulties working out the logistics for ensuring the prompt return of properly cleaned boxes to the vessel. Most of these problems have been solved in European fleets, the Canadian offshore fleet, and South American hake fishing fleets. Using nonreturnable containers for boxing at sea simplifies logistics and reduces initial capital outlay; it has proved justifiable in some U.S. fisheries.

Reusable containers for boxing at sea are usually made of plastic. Careful icing is necessary to minimize the surface area of fish in contact with the box. Plastic boxes provide more heat transfer resistance than aluminum boxes in vessels with uninsulated fish holds and for in-plant storage prior to processing.

All fish boxes must be equipped with drains, preferably directed outside the boxes on the bottom of a stack.

Table 1 Organoleptic Quality Criteria for Fish

Factor	Good Quality	Poor Quality
Eyes	Bright, transparent, often protruding	Cloudy, often pink, sunken
Odor	Sweet, fishy, similar to seaweed	Stale, sour, presence of sulfides, amines
Color	Bright, characteristic of species, sometimes pearlescent at correct light angles	Faded, dull
Texture	Firm, may be in rigor, elastic to finger pressure	Soft, flabby, little resilience, presence of fluid
Belly	Walls intact, vent pink, normal shape	Often ruptured, bloated, vent brown, protruding
Organs (including gills)	Intact, bright, easily recognizable	Soft to liquid, gray homogeneous mass
Muscle tissue	White or characteristic of species and type	White flesh pink to gray, spreading of blood color around backbone

SHORE PLANT PROCEDURE AND MARKETING

Proper use of ice and adherence to good sanitary practices ensure maintenance of iced fish freshness during unloading from the vessel, at the shore plant, during processing, and throughout the distribution chain. Fish landed in good quality will spoil rapidly if these practices are not carried out.

Fish unloaded from the vessel are usually graded by the buyer for species, size, and minimum quality specification. A price is based in part on the quality in relation to market requirements. Fish also may be inspected by local and federal regulatory agencies for wholesomeness and sanitary condition. Organoleptic criteria are most important for evaluating quality; however, there is a growing acceptance, particularly in Canada and some European countries, of objective chemical and physical tests as indexes of quality loss or spoilage. Organoleptic quality criteria vary somewhat among species, but the information in [Table 1](#) can be used as a general guide in judging the quality of whole fish.

In New England and the Canadian Atlantic provinces, groundfish unloaded from the vessel may be placed in boxes and trucked to the shore plant or conveyed directly from the hold or deck to the shore plant. Single- or double-wall insulated boxes are normally used for transporting fish. Wooden boxes are rarely used because they are a source of microbiological contamination. Ice should be applied generously to each box of fish, even if the period prior to processing is only a few hours. Fish in the plant awaiting processing for longer than a few hours should be iced heavily and stored in insulated containers or in single-wall boxes in a chill room refrigerated to 2°C. If refrigerated facilities are not available, the boxes of fish should be kept in a cool section of the plant that is clean and sanitary and has adequate drainage.

Large boxes of resin-coated plywood or reinforced fiberglass that hold up to 450 kg of fish and ice are used by some plants in preference to icing fish overnight on the floor. These **tote boxes** are moved and stacked by forklift, can be used for trucking fish to other plants, and make better use of plant floor space. Generally, fish awaiting processing should not be kept longer than overnight.

Fresh fish are marketed in different forms: fillets, whole fish, dressed-head on, dressed-headed (head removed), and, in some instances, steaks. The method of preparing fish for marketing depends largely on the species of fish and on consumer preference. For example, groundfish such as cod and haddock are usually marketed as fillets or as dressed-headed fish. Freshwater fish such as catfish and bullheads are usually dressed and skinned; lake trout are not skinned, but are merely dressed; and lake herring are marketed in dressed, round, or filleted form.

PACKAGING FRESH FISH

Most fresh fish is packaged in institutional containers of 2 to 16 kg capacity at the point of processing. Polyethylene trays, steel cans, aluminum trays, plastic-coated solid boxes, wax-impregnated corrugated fiberboard boxes, foamed polystyrene boxes, and polyethylene bags are used.

Fresh fish is often packaged while it still contains process heat from wash water. In these cases, it is advantageous to use a packaging material that is a good heat conductor. The fresh fish industry makes little use of controlled prechilling equipment in packaging. As a result, product temperatures may never reach the optimum level subsequent to packaging. Traditionally, institutional fresh fish travels packed in wet ice; in this case, it may cool to the proper level in transit even if process heat is initially present. However, there is a trend toward the use of leaktight shipping containers for fresh fish because modern transportation equipment is not designed to handle wet shipments. Also, some customers want to avoid the cost of transporting ice yet demand a product that is uniformly chilled to 0 to 2°C when it reaches their door. Shippers who use leaktight shipping containers have to upgrade their product temperature control systems to ensure that the fish reaches ice temperature prior to packaging. Rapid prechilling systems that result in crust freezing can be applied to some fresh seafood products, but this practice must be used with discretion since partial freezing harms quality.

Some general requirements for institutional containers that hold products such as fillets, steaks, and shucked shellfish are (1) sufficient rigidity to prevent pressure exerted on the product, even when containers are stacked or heavily covered with ice; and (2) measures to prevent ice-melt water from contaminating the product. Some containers have drains permitting the drip associated with the fish itself to run off. Others are sealed and may be gastight, which increases shelf life. One problem associated with sealed containers is the emission of a strong odor when the package is first opened. Although this odor may be foul, it soon dissipates and has no adverse effect on quality. Dressed or whole fish may be placed in direct contact with ice in a gastight container.

Leaktight shipping containers are used with nonrefrigerated transportation systems, such as air freight, and consequently require insulation. Foamed polystyrene is particularly suited to this application. For typical air freight shipments, the most economical thickness of insulation is between 25 and 50 mm. To maintain product temperature in transit, shippers use either dry ice, packaged wet ice, packaged gel refrigerant, or wet ice with absorbent padding in the bottom of the container. Foamed polystyrene containers may be of molded construction or of the composite type, in which foam inserts and a plastic liner are used with a corrugated fiberboard box.

At the retail level, fresh fish may be handled in two ways. Stores with service counters display fish in unpackaged form. However, markets without service counters sometimes package fish prior to displaying for sale. Both types of outlets receive the product in institutional containers. If the fish is prepackaged at the market, high labor and packaging costs may be incurred, and the temperature of the product is likely to rise. Often, relatively warm fish is placed in a foam tray, wrapped, and displayed in a meat case, the temperature of which may be 4°C or more. This drastically reduces the shelf life of the fish. Centralized prepackaging at the point of initial processing appears to have many important advantages over the present system. A number of retail chains have their suppliers prepackage the product under controlled temperature and sanitary conditions.

FRESH FISH STORAGE

The maximum storage life of fish varies with the species. In general, the storage life of East and West Coast fish, properly iced and stored in refrigerated rooms at 2°C, is 10 to 15 days. This depends on the condition of the fish when it is unloaded from the boat. Generally, freshwater fish properly iced in boxes and stored in refrigerated rooms may be held for only 7 days. Both of the above time limitations refer to the period between when the fish is landed and processed to when it is consumed.

Cold storage facilities for fresh fish should be maintained at about 2°C with over 90% relative humidity. Air velocity should be limited to control ice loss. Temperatures less than 0°C retard ice melting and can result in excessive fish temperatures. This is particularly important when storing round fish such as herring, which generate heat from autolytic processes.

Floors should have adequate drainage with ample slopes toward drains. All inside surfaces of a cold storage room should be easy to clean and able to withstand the corrosive effects of frequent washings with antimicrobial compounds.

Irradiation of Fresh Seafood

Ionizing radiation can double or triple the normal shelf life of refrigerated, unfrozen fish and shellfish stored at 1°C (see Table 2). No off-odors, adverse nutritional effects, or other changes are imparted to the product as a result of the radiation treatment. However, irradiation of fish is still not common and is not permitted in some jurisdictions.

Modified Atmosphere Packaging

A product environment with modified levels of nitrogen, CO₂, and oxygen can curtail the growth of bacteria and extend shelf life of fresh fish. For example, whole haddock stored in a 25% CO₂ atmosphere from the time it is caught keeps about twice as long as it would in air. However, a modified atmosphere does not inhibit all microbes, and spoilage bacteria, because of their great number, usually restrict the growth of the few pathogenic bacteria present. Traditionally, the obvious signs of spoilage serve as the safeguard against eating fish that may have dangerous levels of pathogenic bacteria.

Because modified atmosphere packaging can be a safety hazard, it is being introduced slowly in several countries under close monitoring by regulatory agencies. This type of packaging requires complete knowledge of regulations and a good control system that maintains proper temperature and sanitation levels.

Table 2 Optimal Radiation Dose Levels and Shelf Life at 1°C for Some Species of Fish and Shellfish

Species	Optimal Radiation Dose, kGy Air Packed	Shelf Life, Weeks
Oysters—shucked, raw	2.0	3 to 4
Shrimp	1.5	4
Smoked chub	1.0	6
Yellow perch	3.0	4
Petrale sole	2.0	2 to 3 (4 to 5 when vac pac)
Pacific halibut	2.0	2 (4 when vac pac)
King crabmeat	2.0	4 to 6
Dungeness crabmeat	2.0	3 to 6
English sole	2 to 3	4 to 5
Soft-shell clam meat	4.5	4
Haddock	1.5 to 2.5	3 to 4
Pollock	1.5	4
Cod	1.5	4 to 5
Ocean perch	2.5	4
Mackerel	2.5	4 to 5
Lobster meat	1.5	4

FROZEN FISHERY PRODUCTS

The production of frozen fishery products varies with geographical location and includes primarily the production of groundfish fillets, scallops, breaded precooked fish sticks, breaded raw fish portions, fish roe, and bait and animal food in the northeastern states and in Atlantic Canada; round or dressed halibut and salmon, halibut and salmon steaks, groundfish fillets, surimi, herring roe, and bait and animal food in the northwestern states and in British Columbia; halibut, groundfish fillets, crab, salmon, and surimi in Alaska (salmon roe in Alaska is called “ikura”); shrimp, oysters, crabs, and other shellfish and crustacea in the Gulf of Mexico and South Atlantic states; and round or dressed fish in the areas bordering on the Great Lakes.

The fish obtained from these areas differ considerably in both physical and chemical composition. For example, cod or haddock are readily adaptable to freezing and have a comparatively long storage life, but other fatty species, such as mackerel, tend to become rancid during frozen storage and therefore have a relatively short storage life. The differences in composition and marketing requirements of many species of fish necessitate consideration of the specific product with regard to quality maintenance and methods of packaging, freezing, cold storage, and handling.

Temperature is the most important factor limiting the storage life of frozen fish. At temperatures below freezing, bacterial activity as a cause of spoilage is limited. However, even fish frozen within a few hours of catching and stored at -29°C will deteriorate very slowly until it becomes unattractive and unpleasant to eat.

Fish proteins are permanently altered during freezing and cold storage. This denaturation occurs quickly at temperatures not far below freezing; even at -18°C fish deteriorates rapidly. Badly stored fish is easily recognized: the thawed product is opaque, white, and dull, and juice is easily squeezed from it. Although properly stored product is firm and elastic, poorly stored fish is spongy, and in very bad cases, the flesh breaks up. Instead of the succulent curdiness of cooked fresh fish, cooked denatured samples have a wet and sloppy consistency at first and, on further chewing, become dry and fibrous.

Among other factors that determine how quickly quality deteriorates in cold storage are the initial quality and composition of the fish, the protection of the fish from dehydration, the freezing method, and the environment during storage and transport. These factors are reflected in four principal phases of frozen fish production and handling—packaging, freezing, cold storage, and transportation.

Today, many species are brought from warm and tropical waters where parasites and toxins could infect them. In addition, food dishes that use raw seafood, such as sushi and sashimi, have gained wide popularity, making them a potential health risk. Parasites are not life-threatening but can cause pain and inconvenience. They are easily destroyed by cooking or by deep freezing (-40°C). Marine toxins could be deadly and are not affected by temperature. Susceptible species should not be eaten during periods when toxins could be developed.

PACKAGING

Materials for packaging frozen fish are similar to those for other frozen foods. A package should (1) be attractive and appeal to the consumer, (2) protect the product, (3) allow rapid, efficient freezing and ease of handling, and (4) be cost-effective.

Package Considerations in Freezing

Refrigeration equipment and packaging materials are frequently purchased without considering the effect of the package size on freezing rate and efficiency. For example, a thin consumer package results in a faster rate of product freezing, lower total freezing

costs, higher handling costs, and higher packaging material costs; a thicker institutional-type package results in a slower rate of product freezing, higher freezing costs, lower handling costs, and lower packaging material costs.

Tests indicate that the time required to freeze packaged fish fillets in a plate freezer is directly proportional to the square of the package thickness. Thus, if it takes 3 h to freeze packaged fish fillets 50 mm thick, it takes about 4.7 h to freeze packaged fish fillets 65 mm thick. The insulating effect of the packaging material, the fit of the product in the package, and the total surface area of the package must be considered. A packing material with low moisture-vapor permeability has an insulating effect, which increases freezing time and cost.

The rate of heat transfer through packaging material is inversely proportional to its thickness; therefore, packaging material should be (1) thin enough to produce rapid freezing and an adequate moisture-vapor barrier in frozen storage and (2) thick enough to withstand heavy abuse. Aluminum foil cartons and packages offer an advantage in this regard.

Proper fit of package to product is essential; otherwise, the insulating effect of the air space formed reduces the freezing rate of the product and increases freezing cost. The surface area of the package is also important because of its relation to the size of the freezer shelves or plates. Maximum use of freezer space can be obtained by designing the package so that it fits the freezer properly. Often, however, these factors cannot be changed and still meet customer requirements for a specific package.

Package Considerations for Frozen Storage

Fish products lose considerable moisture and become tough and fibrous during frozen storage unless a package with low moisture-vapor permeability is specified. The package in contact with the product must also be resistant to oils or moisture exuded from the product, or rancidity of the oils and softening of the package material will occur. The package must fit the product tightly to minimize air spaces and thereby reduce moisture migration from the product to the inside surfaces of the package.

Unless temperatures are very low or special packaging is used, the oils in fish will oxidize in frozen storage, producing an off-flavor. One effective type of packaging is to replace the air surrounding the frozen fish with pure nitrogen and to seal the fish in a leak-proof bag made of a material that is a barrier to the passage of oxygen.

Types of Packages

Packaging materials consist of either paperboard cartons coated with various waterproofing materials or cartons laminated with moisture-vapor-resistant films and heat-sealable overwrapping materials with a low moisture-vapor permeability. Paperboard cartons are usually made of a bleached kraft stock, coated with a suitable fortified wax, polyethylene, or other plastic material.

Overwrapping materials should be highly resistant to moisture transmission, inexpensive, heat sealable, adaptable to machinery application, and attractive in appearance. Various types of hot melt coated waxed paper, cellophane, polyethylene, and aluminum foil are available in different forms and laminate combinations to best suit each product.

Consumer Packages. These usually hold less than 500 g and are generally printed, bleached paperboard coated with wax or polyethylene and closed with adhesive. Fish sticks and portions, shrimp, scallops, crabmeat, and precooked dinners and entrees are packaged in this way. In the case of dinners and entrees, rigid plastic, pressboard, or aluminum trays are used inside the printed paperboard package. Rigid plastic or pressboard packages are becoming more common because they are better for microwave cooking. The packaging of these products is normally mechanized.

Materials such as polyethylene combined with cellophane, polyvinylidene chloride, or polyester and combinations of other plastic materials are used with high-speed automatic packaging machines to package shrimp, dressed fish, fish fillets, fish portions, and fish steaks prior to freezing. In some instances, tearing of the wrapping material by fins protruding from the fish has been a problem. Otherwise, this method of packaging is satisfactory and affords the product considerable protection against dehydration and rancidity at a comparatively low cost. This packaging method has also created new markets for merchandising frozen fish products. Boil-in-bag pouches made of polyester-polyethylene and combinations of foil, polyethylene, and paper are used for packaging shrimp, fish fillets, and entrees. These packages are also suitable for microwave cooking.

Institutional Packages. The 2 kg and larger cartons used in the institutional trade are commonly constructed of bleached paperboard that has been waxed or polyethylene coated. Folding cartons with self-locking covers, full-telescoping covers, or glued closures are used. Often the cartons are packaged inside a corrugated master carton or are shrink-wrapped in polyethylene film.

Products such as fish fillets and steaks are individually wrapped in cellophane or another moisture-vapor-resistant film and then packed in the carton. Fish, such as headed and dressed whiting and scallop meats, are packed into the carton and covered with a sheet of cellophane. The cover is then put in place and the package is frozen upside down in the freezer. Raw, unbreaded products, such as shrimp, scallops, fillets, and steaks, are sometimes individually quick frozen (IQF) prior to packaging. IQF products can be glazed to enhance moisture retention. This method is preferred over freezing after packaging because it leads to a product that is more convenient to handle and sometimes obviates the need to thaw the fish before cooking.

For institutional frozen fish, the current trend is toward printed paperboard folding cartons coated with moisture-vapor-resistant materials instead of waxed paper or cellophane overwrap, though “shatter pack” bulk is also common. Some frozen fish products and seafood entrees destined for institutional markets are packaged in aluminum trays or in rigid plastic trays so they may be heated within the package.

FREEZING METHODS

Product characteristics, such as size and shape, freezing method, and rate of freezing, affect the quality, appearance, and cost of production.

Quick freezing of fish offers the following advantages:

- Chills the product rapidly, preventing bacterial spoilage
- Facilitates rapid handling of large quantities of product
- Makes use of conveyors and automatic devices practical, thus materially reducing handling costs
- Promotes maximum use of the space occupied by the freezer
- Produces a packaged product of uniform appearance, with a minimum of voids or bulges

For further information, see [Chapters 8, 9, and 15](#).

Blast Freezing

Blast freezers for fishery products are generally small rooms or tunnels in which cold air is circulated by one or more fans over an evaporator and around the product to be frozen, which is on racks or shelves. A refrigerant such as ammonia, a halocarbon, or brine flowing through a pipe coil evaporator furnishes the necessary refrigeration effect.

Static pressure in these rooms is considerable, and air velocities average between 2.5 and 7.5 m/s, with 6 m/s being common. Air velocities between 2.5 and 5 m/s give the most economical freezing.

Lower air velocities slow down product freezing, and higher velocities increase unit freezing costs considerably.

Some factories have blast freezers in which conveyors move fish continuously through a blast room or tunnel. These freezers are built in several configurations, including (1) a single pass through the tunnel, (2) multiple passes, (3) spiral belts, and (4) moving trays or carpets. The configuration and type of conveyor belt or freezing surface depend on the type and quantity of the product to be frozen, the space available to install the equipment, and the capital and operating costs of the freezer.

Batch-loaded blast freezers are used for freezing the following: shrimp, fish fillets, steaks, scallops, and breaded precooked products in institutional packages; round, dressed, and pan-fried fish; and shrimp, clams, oysters, and salmon roe (ikura) packed in metal cans.

Conveyor blast freezers are widely used to freeze products prior to packaging. These products include all types of breaded, precooked seafoods; IQF fillets, loins, tails, steaks, scallops, and shrimp; and raw, breaded fish portions. In the case of portions, which are sliced or sawed from blocks, the function of the blast freezer is to harden the batter and breading before packaging and lower the temperature of the frozen fish for storage if it has been tempered for slicing.

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 2.5 m/s and the period of exposure to the air is controlled. Consumer packages of fish fillets or fish-fillet blocks requiring close dimensional tolerances undergo bulging and distortion during freezing unless restrained. In blast rooms or tunnels, the product can be frozen on specially designed trucks, enabling distribution of pressure on the surfaces of the package and remedying this condition. It is difficult to control the expansion of the product on conveyor installations.

Freezing times for various sizes of packaged fishery products are shown in [Figure 2](#).

Plate Freezing

In the multiplate freezer, freezing is accomplished by refrigerant flowing through connected passageways in horizontal movable plates stacked vertically within an insulated cabinet or room.

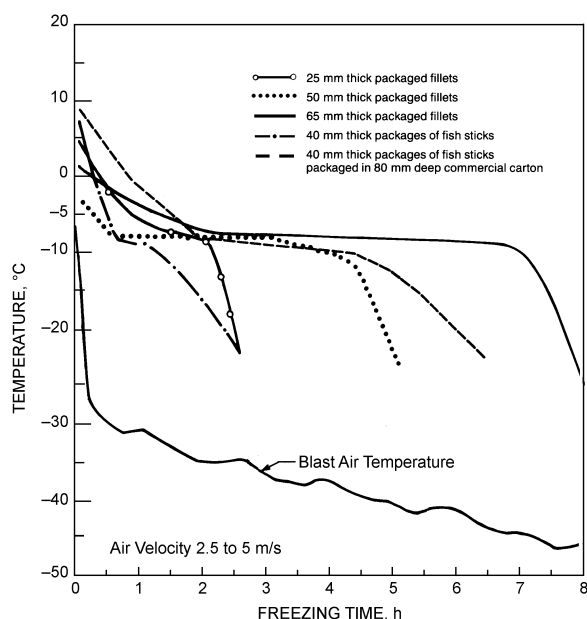


Fig. 2 Freezing Time of Fish Fillets and Fish Sticks in Tunnel Blast Freezer (Air Velocity 2.5 to 5 m/s)

The plate freezer is used extensively in freezing fishery products packaged in consumer cartons and in 2 and 5 kg institutional cartons. Fish to be plate frozen should be properly packaged to minimize air spaces. Spacers should be used between the plates during freezing to prevent crushing or bulging of the package. For most products, the thickness of the spacers should be about 0.8 to 1.5 mm less than that of the package.

Where very close package tolerances are required, as in the manufacture of fish fillet blocks, a metal frame or tray is used to hold the packages of fish during freezing. The frame or tray is generally the same width as the package and the length of one or two blocks. It must be rigid enough to prevent bulging and to hold the fish block's dimensions. This is sometimes accomplished with rigid spacers that limit the mass and cost of the tray.

Fish blocks are available in two common sizes: 7.5 kg (480 by 250 by 60 mm) and 8.4 kg (480 by 290 by 60 mm). Other blocks are sized for special applications. The fish can be packed in the block with the long dimension of the fillets along the length of the frame (long-pack) or along the width of the frame (cross-pack). The orientation depends on the eventual cutting pattern and type of cutting used to convert the block into a finished product.

A tray is not necessary for other packaged seafoods such as shrimp, fillets, fish sticks, or scallops, where close package tolerances are not as essential. Therefore, an automatic continuous plate freezer with properly sized spacers is satisfactory for these products.

The plate freezer provides rapid and efficient freezing of packaged fish products. The freezing time and energy required for freezing packaged fish sticks is greater than that for fish fillets because heat transfer is slowed by the air space within the package. Energy required to freeze a unit mass of product increases with thickness. The freezing times of consumer and institutional size packages of fish fillets and fish sticks are shown in [Figure 3](#).

Immersion Freezing

Immersion in low-temperature brine was one of the first methods used for quick-freezing fishery products. A number of direct immer-

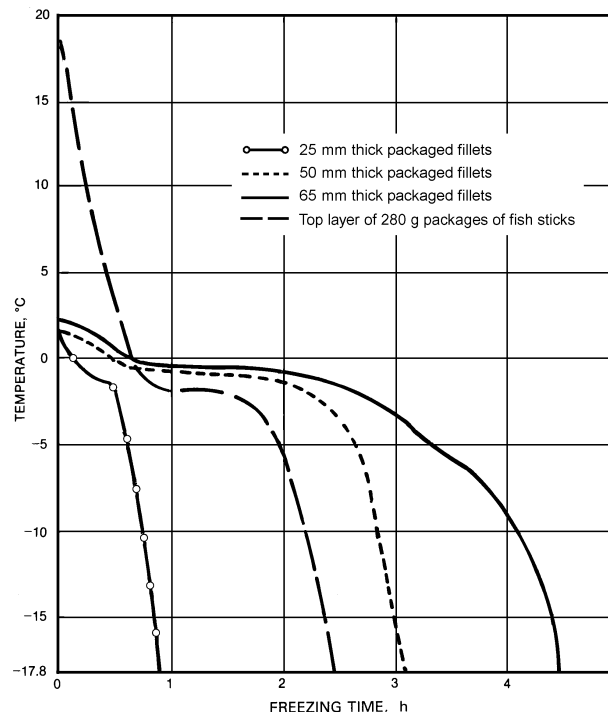


Fig. 3 Freezing Time of Fish Fillets and Fish Sticks in Plate Freezer

sion freezing machines were developed for whole or panned fish. These machines were generally unsuitable for packaged fish products, which make up the bulk of frozen fish production, and have been replaced by methods employing air cooling, contact with refrigerated plates or shelves, and combinations of these methods.

Immersion freezing is used primarily for the freezing of tuna at sea and, to a lesser extent, for freezing shrimp, salmon, and Dungeness crab, as well as king crab and Alaska snow crab (*C. opelio*). Extensive research has been conducted on brine freezing of groundfish aboard vessels, but this method is not in commercial use.

An important consideration in immersion freezing of fish is selection of a suitable freezing medium. The medium should be nontoxic, acceptable to public health regulatory agencies, easy to renew, and inexpensive; it should also have a low freezing temperature and viscosity. It is difficult to obtain a freezing medium that meets all these requirements. Sodium chloride brine and a mixture of glucose and salt in water are acceptable media. The glucose reduces salt penetration into the fish and provides a protective glaze.

Liquid nitrogen spray and CO₂ are coming into wider use for IQF seafood products such as shrimp. Although the cost per unit mass is high, fish frozen by these methods is of good quality, there is virtually no mass loss from dehydration, and there are space and equipment savings. The fish should not be directly immersed in the liquid nitrogen since this will cause the flesh to shatter and rupture.

Immersion Freezing of Tuna. Most tuna harvested by the United States fleet is brine-frozen aboard the fishing vessel. Freezing at sea enables the vessel to make extended voyages and return to port with a full payload of high-quality fish.

Tuna are frozen in brine wells, which are lined with galvanized pipe coils on the inside. Direct expansion of ammonia into the evaporator coils provides the necessary refrigeration effect. The wells are designed so that tuna can be precooled and washed with refrigerated seawater and then frozen in an added sodium chloride brine. After the fish are frozen, the brine is pumped overboard, and the tuna are kept in -12°C dry storage. Before unloading, the fish are thawed in -1°C brine. In some cases, the fish are thawed in tanks at the cannery. If the fish are thawed ashore, thawing on the vessel is not required beyond the stage needed to separate those fused together in the vessel's wells.

Sometimes tuna are held in the wells for a long period prior to freezing or are frozen at a very slow rate because of high well temperatures caused by overloading, insufficient refrigeration capacity, or inadequate brine circulation. These practices have a detrimental effect on product quality, especially for smaller fish, which are more subject to salt penetration and quality changes. Tuna that are not promptly and properly frozen may undergo excessive changes, absorb excessive quantities of salt, and possibly be bacteriologically spoiled when landed. Some freezing times for tuna of various sizes are shown in [Figure 4](#).

Specialized Contact Freezers. Fish frozen by this method are placed on a slowly moving, solid stainless steel belt. This belt conveys the fish fillets through a tunnel, where they are frozen not only by an air blast but also by direct contact between the conveyor belt and a thin layer of glycol pumped through the plates that support the belt. A refrigerant, such as ammonia or a halocarbon, also flows through separate channels in the plates. This provides the refrigeration effect with minimal temperature difference between the evaporating refrigerant and the product.

Freezing Fish at Sea

Freezing fish at sea has found increasing commercial application in leading fishery nations such as Japan, Russia, the United Kingdom, Norway, Spain, Portugal, Poland, Iceland, and the United States. Including freezer trawlers, factory ships, and refrigerated transports in fisheries, hundreds of large freezer vessels are operating throughout the world. U.S. factory freezer trawlers, factory surimi trawlers, and floating factory ships supplied by catcher vessels

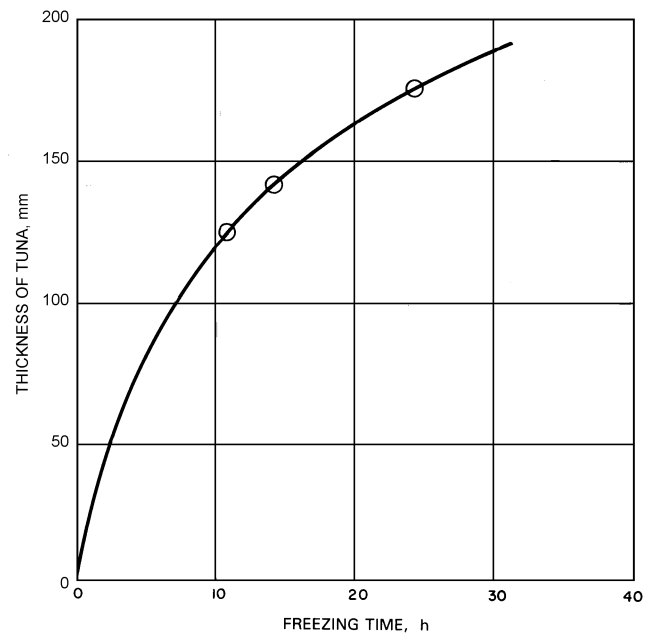


Fig. 4 Freezing Time for Tuna Immersed in Brine

operate off Alaska. These vessels process mainly Alaskan pollock, cod, and flounder, although they do process other species.

Freezing groundfish at sea is uncommon in the northeastern United States largely because fresh fish commands a better price than frozen fish. For the same reason, East Coast U.S. producers avoid putting their product into frozen packs if they can sell it fresh. Hence, much of the frozen fish used in the United States, with the exception of Alaskan fish, is imported from other countries.

Where used, the factory vessel is equipped to catch, process, and freeze the fish at sea and to use the waste material in the manufacture of fish meal and oil. A large European factory vessel measures 85 m in length, displaces 3400 t, and is equipped to stay at sea for about 80 days without being refueled. About 65 to 100 people are required to operate the vessel and to process and handle the fish. On most vessels of this type, contact-plate freezers are used. The freezers can freeze about 27 t of fish per day, and the total capacity of the frozen fish hold may be as high as 680 t.

Because the factory trawler stays at sea for long periods, it can fully use its space for storing fish. However, due to limited available labor, frozen packs are generally of the less labor-intensive types.

The freezer trawler was designed to resolve the disadvantages associated with factory freezer vessels. It is smaller and equipped to freeze fish in bulk for later thawing and processing ashore. Freezer trawlers use vertical plate freezers to freeze dressed fish in blocks of about 50 kg.

Some countries use freezer trawlers to supply raw material to shore-based processing plants producing frozen fish products. This allows the trawlers to fill their holds in distant waters and transport the fish to home base, where it becomes frozen raw material that is held in storage until required for processing. In some cases, trawlers have been designed as dual fisheries, fishing and freezing groundfish blocks during part of the year and catching, processing, and freezing Northern shrimp for the rest of the year.

STORAGE OF FROZEN FISH

Fishery products may undergo undesirable changes in flavor, odor, appearance, and texture during frozen storage. These changes are attributable to dehydration (moisture loss) of the fish, oxidation of the oils or pigments, and enzyme activity in the flesh.

The rate at which these changes occur depends on (1) the composition of the species of fish, (2) the level and constancy of storage room temperature and humidity, and (3) the protection afforded the product through the use of suitable packaging materials and glazing compounds.

Composition

The composition of a particular species of fish affects its frozen storage life considerably. Fish with high oil content, such as some species of salmon, tuna, mackerel, and herring, have a comparatively short frozen storage life because of the development of rancidity as a result of the oxidation of the oils and pigments in the flesh. Certain fish, such as sablefish, are quite resistant to oxidative deterioration in frozen storage, despite their high oil content. The development of rancidity is less pronounced in fish with a low oil content. Therefore, lean fish such as haddock and cod, if handled properly, can be kept in frozen storage for many months without serious loss of quality. The relative susceptibility of various species of fish to oxidative changes during frozen storage is shown in [Table 3](#).

Temperature

The quality loss of frozen fish in storage depends primarily on temperature and duration of storage. Fish stored at -29°C has a shelf life of more than a year. In Canada, the Department of Fisheries recommends a storage temperature of -26°C or lower. Storage above -23°C , even for a short period, results in rapid loss of quality. Time-temperature tolerance studies show that frozen seafoods have memory; that is, each time they are subjected to high temperatures or poor handling practices, the loss in quality is recorded. When the product is finally thawed, the total effect of each exposure to mistreatment is reflected in the quality of the product at the consumer level. Continuous storage at temperatures lower than -26°C reduces oxidation, dehydration, and enzymatic changes, resulting in longer product shelf life. From the time they are frozen until they reach the consumer, frozen seafoods should be kept at temperatures as close to -26°C as possible. The shelf life of frozen fish products stored at different temperatures is given in [Table 4](#). Note the increase in shelf life at the lowest temperatures.

For many years, it was thought too costly to operate refrigerated warehouses at temperatures lower than -23°C . However, improvements in the design and operation of refrigeration equipment have made such temperatures economically possible. The production of surimi by West Coast-based factory ships has resulted in the construction of ultracold rooms for its storage. Japanese standards call for this product to be kept at -30°C .

Humidity

A high relative humidity in the cold storage room tends to reduce the evaporation of moisture from the product. The relative humidity of air in the refrigerated room is directly affected by the temperature

difference between room cooling coils and room temperature. A large temperature difference results in decreased relative humidity and an accelerated rate of moisture withdrawal from the frozen product. A small temperature difference between the air and evaporator cooling coils results in high relative humidity and reduced moisture loss from the product.

The relative humidity in commercial cold storages is 10 to 20% higher than that of an empty cold storage because of constant evaporation of moisture from the product. In a cold storage operating at -20°C , with a 70% rh and pipe coil temperature of -25°C , the moisture-vapor pressure of the air within the package (in direct contact with the frozen fish) would be 109 Pa. The air in the cold storage would have a vapor pressure of 91 Pa, and the moisture-vapor pressure at the coils would be 64 Pa. These differences in moisture-vapor pressure will result in considerable moisture loss from the product unless it is adequately protected by suitable packaging materials or glazing compounds. The evaporator coils in the freezer should be sized properly so that the desired high relative humidities can be obtained. However, because of material costs and space limitations, a temperature difference of 5 K between evaporator coils and room air is the most practical.

Packaging and Glazing

Adequate packaging of fishery products is important in preventing product dehydration and consequent quality loss. The packaging, which, in most instances, occurs before freezing, has been described. Individual fish, whether frozen in the round or dressed, cannot usually be suitably packaged; therefore, they must be protected by a glazing compound.

A glaze acts as a protective coating against the two main causes of deterioration during storage: dehydration and oxidation. It protects against dehydration by preventing moisture from leaving the product and against oxidation by mechanically preventing air

Table 4 Effect of Storage Temperature on Shelf Life of Frozen Fishery Products

Product	Temperature, $^{\circ}\text{C}$	Shelf Life, Months
Packaged haddock fillets	-12	4 to 5
	-18	11 to 12
	-29	Longer than 12
Packaged cod fillets	-12	5
	-18	6
	-23	10 to 11
Packaged pollock fillets*	-7	1
	-12	2
	-18	8
	-23	11
	-29	24
Packaged ocean perch fillets	-9	1.5 to 2
	-12	3.5 to 4
	-18	6 to 8
	-23	9 to 10
Packaged striped bass fillets	-9	4
	-18	9
Glazed whole halibut	-12	3
	-18	6
	-23	9
	-29	12
Whole blue fin tuna	-12	4
	-18 to -20	8
	-29	12
Glazed whole herring	-18	6
	-27	9
Packaged mackerel fillets	-9	2
	-18	3
	-23	3 to 5

*Prepared from 1-day-old iced fish.

Table 3 Relative Susceptibility of Representative Species of Fish to Oxidative Changes in Frozen Storage

Severe	Moderate	Minor	Very Slight
Pink salmon	Chum salmon	Cod	Yellow pike
Rockfish	Coho salmon	Haddock	Yellow perch
Lake chub	King salmon	Flounder	Crab
Whiting	Halibut	Sole	Lobster
	Ocean perch	Sablefish	
	Herring	Oysters	
	Mackerel		
	Tuna		
	Lake herring		
	Sheepshead		
	Lake trout		

contact with the product. It may also minimize these changes chemically with an antioxidant.

Maximum storage life of fishery products can be obtained by employing the following procedures:

- Select only high-quality fish for freezing.
- Use moisture-vapor-resistant packaging materials and fit package tightly around product, or use a modified atmosphere and oxygen-barrier package.
- Freeze fish immediately after processing or packaging.
- Glaze frozen fish prior to packaging.
- Glaze round, unpackaged fish prior to cold storage.
- Put fish in frozen storage immediately after freezing and glazing, if required.
- Store frozen fish at -26°C or lower.
- Renew glaze on round, unpackaged fish as required during frozen storage.

The recommended protection and expected storage life for various species of fish at -18°C are shown in [Table 5](#).

Space Requirements

Packaged products such as fillets and steaks are usually packed in cardboard master cartons for storage and shipment. These master cartons are stacked on pallets and transferred to various areas of the cold storage room by forklift. The master cartons are strong enough to support one or two pallet loads placed on the shelf of each rack in the cold storage. In cold storages without racks, cartons should be stacked to a height that does not cause crushing of the bottom cartons. Cartons for products in packages that contain a lot of air, such as IQF fillets, must be stronger than those for solid packages of fish in order to resist crushing during storage.

Whole or dressed fish frozen in blocks in metal pans, such as mackerel, chub, or whiting, are removed from the pans after freezing, glazed, and then packaged in wooden boxes lined with wax-impregnated paper or in cardboard cartons.

Round fish stored in wooden boxes can be easily reglazed at periodic intervals during frozen storage. The space requirements for the storage of fishery products are shown in [Table 6](#).

Thawing Frozen Fish. Frozen fishery products can be thawed by circulating air or water. In thawing, the fish should not be allowed to rise above refrigerated temperatures; otherwise, rapid deterioration may occur. Thawing is a slower and more difficult process than freezing when done to ensure that quality is maintained. Each application should be carefully designed.

TRANSPORTATION AND MARKETING

Conditions of temperature and humidity recommended for frozen storage should also be applied during transportation and marketing to minimize product quality loss. Shipment in nonrefrigerated or improperly refrigerated carriers, exposure to high ambient temperatures during transfer from one environment to another, improper loading of common carriers or display cases, equipment failure, and other poor practices lead to increased product temperature and, consequently, to quality loss.

Frozen fish is transported under mechanical refrigeration in trucks, railroad cars, or ships. Most of these vehicles are capable of maintaining temperatures of -18°C or lower. Additional information on equipment used in the transportation and marketing of frozen fish and other foods is given in [Chapters 10, 12, 13, 29, 30, 31, and 47](#) of this volume and in Chapter 28 of the 1994 *ASHRAE Handbook—Refrigeration*.

To minimize quality loss during transportation and marketing, the following procedures should be adhered to:

1. Transport frozen fish in refrigerated carriers (mechanical or dry ice systems) with ample capacity to maintain a temperature of -18°C over long distances.
2. Precool refrigerated carriers to at least -12°C before loading.
3. Remove frozen products from the warehouse only when the carrier is ready to be loaded. Load directly into the refrigerated carrier; do not allow the product to sit on the dock.
4. Check the frozen fish temperature with a thermometer before loading.
5. Do not stack frozen fish directly against floors or walls of the carrier. Provide floor and wall racks or strips to permit air circulation around the entire load.
6. Continuously record the temperature of the refrigerated carrier during transit. Use an alarm to warn of equipment failure.
7. Measure the temperature of the product when it is removed from the common carrier at its destination.
8. If products are shipped in an insulated container, apply sufficient dry ice to maintain temperatures of -18°C or lower for the duration of the trip.
9. Maintain food delivery or breakup rooms at -18 to -12°C . Do not hold products in breakup rooms any longer than necessary.
10. When received at the retail store, place the product in a -18°C storage room immediately.
11. Hold display cases in retail stores at -18°C or lower.
12. Do not overload display cases, especially above the frost line.
13. Record the temperature of the display cases. Provide an alarm to warn of an excessive rise in temperature.

Table 5 Storage Conditions and Storage Life of Frozen Fish

Fish	Recommended Protection*	Storage Life (-18°C), Months
Chub, pink salmon	Ice glazing and packaging	4-6
Mackerel, sea herring, pollock, chub, smelts	Ice glazing and packaging	5-9
Pacific sardines, tuna	Packaging	4-6
Buffalofish, flounder, halibut, ocean perch, rockfish, sablefish, red, sockeye, silver or coho salmon, whiting, shrimp	Packaging	7-12
Haddock, blue pike, cod, hake, lingcod	Packaging	Over 12

*All packaging should be with moisture-resistant films.

Table 6 Space Requirements for Frozen Fishery Products

Commodity	Product Package	Container for Storage	Space Required, kg/m^3
Fish sticks, breaded shrimp, breaded scallops	225 or 280 g	Corrugated master containers	400 to 480
Fish fillets, fish steaks, small dressed fish	0.5, 2.25, or 4.5 kg	Corrugated master containers	800 to 960
Shrimp	1.0 and 2.25 kg	Corrugated master containers	560
Panned, frozen fish (mackerel, herring, chub)	None	Wooden or fiberboard boxes	560
Round halibut	None	Wooden box	480 to 560
		Stacked loose	610
Round groundfish (cod, etc.)	None	Stacked loose	510
Round salmon	None	Stacked loose	530 to 560

14. Because of the accelerated deterioration of frozen fish products in the distribution and retail chain, hold products in these areas for as short a period as possible.

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