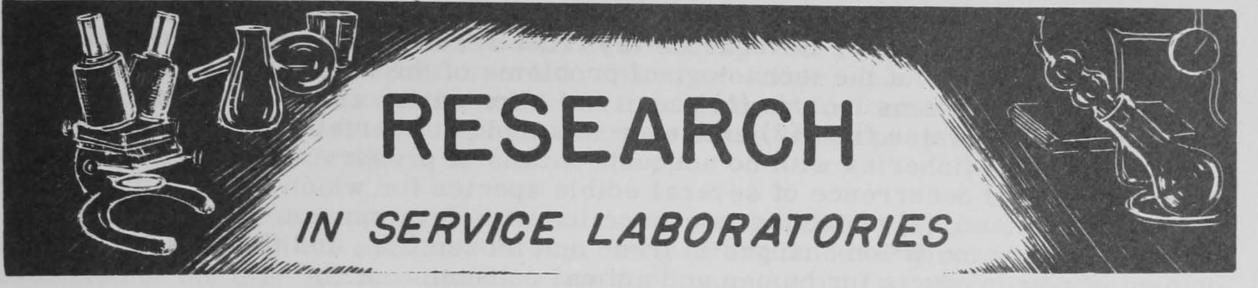

TECHNOLOGICAL RESEARCH ON THE FRESH-WATER FISHERIES OF THE U.S.

This report summarizes briefly the principal technological work carried out on United States fresh-water commercial fisheries and describes in somewhat greater detail the work accomplished in this field since 1950 by the Technological Section of the Branch of Commercial Fisheries, U. S. Fish and Wildlife Service.

WORK BY UNIVERSITIES AND STATE FISHERY DEPARTMENTS

Very limited technological work has been carried out by universities and State Fishery Departments on fresh-water fish. During the early 1940's, Michigan State College carried out work on the vitamin content of some of the Great Lakes species of fish (Ingalls, Klocke, Rafferty, Greensmith, Chang, Tack, and Ohlson 1950; Klocke, Porter, Tack, Leffler, Henry, and Nitchals 1946; Tack, Ingalls, Klocke, Baeder, Cedarquist, Musser, and Ohlson 1947). Some work was also carried out on smoking of carp. Utilization of carp was also the subject of some work carried out by Iowa State College (Olsen 1944). At the University of Wisconsin, the effectiveness of certain antioxidants in retarding rancidity of frozen fresh-water fish was tested (Rice 1952).

EARLY WORK BY THE U. S. BUREAU OF FISHERIES AND FISH AND WILDLIFE SERVICE

Between 1885 and 1900 a number of fresh-water fish were analyzed for proximate composition by Atwater (1892). In most cases the number of fish comprising a sample was so very small (sometimes only a single fish) that the results are almost meaningless.

A limited amount of fresh-water fish work was carried out during the 1920's by the Technological Section of the U. S. Bureau of Fisheries. This work was largely concerned with two fields--utilization of the fresh-water burbot (primarily for preparation of a liver oil of high vitamin-A potency) and investigation of net preservatives for use with fishing gear in Lake Erie. This work has been summarized by Manning (1934). A number of papers descriptive of commercial fresh-water fisheries and touching on their technology (although not based on any original research) were published (Coker 1918; Koelz 1926). During the last war, the Fish and Wildlife Service gave assistance to a Minnesota firm in the development of a process for canning of smoked carp.

WORK OF FISH AND WILDLIFE SERVICE SINCE 1950

Having two technological laboratories each on the Pacific and Atlantic Coasts, the Fish and Wildlife Service has carried out extensive research on marine fishes. With no facilities located near the fresh-water fisheries of the Great Lakes and Mississippi Valley, technological research on these fish was not carried out to any extent up to 1950. Numerous inquiries concerning the composition, processing, and utilization of fresh-water fish were received by the Fish and Wildlife Service. Almost complete lack of such information occurs in the literature. In 1951 it was decided to undertake very limited research in these fields at the Seattle Fishery Technological Laboratory. Several survey trips were first made to familiarize personnel with some of the technological problems of the fresh-water fisheries. Some of these problems include (1) paucity of information as to the chemical composition of fresh-water fish, (2) existence of surplus of certain species during the peak of seasonal fisheries with no adequate means of preserving the fish for human consumption, (3) occurrence of several edible species for which there is limited or no market demand, (4) problems in connection with development of adequate methods of retarding oxidation changes in fresh and frozen fish, and (5) need for development of new products for human and animal consumption.

COMPOSITION OF FRESH-WATER FISH

An investigation was initiated at the Seattle Fishery Technological Laboratory in 1951 to obtain information as to the proximate chemical composition of fresh-water fish (Stansby 1954). This project is still under way. Lots of the commercially-important species were procured. In most cases the edible portion of 16 individual fish were analyzed for each batch, and the composition of the composited trimmings was also determined. From this information, the composition of the whole fish was calculated. The length, weight, and fillet yield for each fish was also determined. For most of the species, batches of fish taken at different seasons and in different areas are being analyzed. A complete survey of each species taken in several areas at different seasons would result in such a monumental number of analyses that it could not be attempted. A rather complete study of the variation in chemical composition of one species, sheepshead (*Aplodinotus grunniens*), is being undertaken. This species is one of the most widely distributed fish in North America, occurring in lakes and rivers from Canada to Nicaragua (Barney 1926). It is taken commercially in three different fisheries (Great Lakes, rivers, and in rough-fish removal from small lakes). Analyses are being made to see how composition of this fish varies from year to year (at the same season and taken in the same place), from one season to another (in the same area), and from one area to another (at the same season). Information obtained in this study will be useful in deciding how many batches of other species must be analyzed to obtain adequate information on their composition.

A considerable number of analyses have already been completed. In the case of sheepshead a trend in the oil content of the meat is developing and it appears that those sheepshead taken in the Mississippi River and tributaries have a uniformly high oil content, those taken in Lake Erie have a lower oil content with the oil content varying fairly widely from fish to fish. Sheepshead taken from small lakes vary as to oil content, depending upon the lake from which they are taken. In some lakes the average oil content of sheepshead is between 1 and 2 percent while in other cases the oil content is as high (8 percent or more) as is the case with fish from the Mississippi River.

Sheepshead are sold commercially on the basis of the texture of their meat, being classified as hard-meat sheepshead (for which there is little demand) and soft-meat sheepshead (which are considered to be of high quality and sell at a higher price). Since there may be a correlation between oil content and the texture of the sheepshead, this factor is now being investigated.

Results of analyses of many lots of fresh-water fish have been published in issues of *Commercial Fisheries Review* since December 1951. Some results include the relatively low oil content of lake herring revealed by these analyses and the very low protein content of the Siscowet lake trout.

Simultaneous with the investigation of proximate composition of fresh-water fish, experiments have been carried out to determine the cold-storage life of the various species. The fish have been in most cases filleted, and packaged and stored at 0° F. At suitable intervals organoleptic examination of the stored fish has been carried out to determine the maximum cold-storage life. Tests have not been limited exclusively to commercial species. When available, sports-fish species are also being tested, since such information is in demand for home freezing of such fish. Preliminary results of the cold-storage phase of the program have been reported by Miyauchi (1954).

In these tests several species have shown particularly poor cold-storage life. Lake chub (Leucichthys species) is especially prone to develop rancidity due to oxidation of the oil. An investigation has been carried out to determine means of minimizing this rancidity development. Use of such antioxidants as ascorbic acid, ascorbic and citric acid, and propyl gallate are of little or no value. Covering the fish with a heavy ice glaze and maintaining this glaze throughout the storage period was found to be the most effective treatment. Fish frozen in 5-gallon tin cans after covering the fish with water kept in good condition at 0° F. for 6 months, or longer.

Sheepshead show a marked tendency to darken rapidly due to oxidation of tissue pigments. This oxidation starts even before the fish are frozen and progresses during storage. No effective method has yet been developed to retard this darkening.

Lake herring (Leucichthys artedi) were reported by the fishing industry to be especially difficult to hold frozen in cold storage without alteration or loss in flavor. Experiments are now under way to investigate this problem. This program, as well as some of the other current work on cold storage of fresh-water fish being carried out at the Service's Seattle Fishery Technological Laboratory, is being sponsored jointly by The Refrigeration Research Foundation and the U. S. Fish and Wildlife Service. Collaboration is also being obtained on the lake herring project from the Frozen Foods Laboratory, University of Minnesota.

PROBLEMS FOR FUTURE INVESTIGATION

Additional information on the chemical composition of both the edible and waste portion of fresh-water fish is needed. Data on vitamin content as well as on proximate composition would be of value. For some species a better knowledge of the thiaminase content (if present) would be helpful in developing markets for use of trimmings or other waste as products for feeding fur-bearing animals.

Research on developing new food products from species for which surpluses exist is especially needed. These fish include lake smelt and lake herring which are caught in such large quantities at certain seasons that much of them have to be sold for animal feed. Development of new products from these species might widen markets so as to boost demand for them as human food.

Other species such as burbot (Lota lota maculosa) are not even landed although probably of good edibility if a suitable marketing form could be developed. Research on utilization of hard-meat sheepshead is also needed. Many millions of pounds of these fish are available each year in Lake Erie but are not landed because the low demand keeps prices to the fishermen below operating costs.

Research on new products from rough fish, such as carp and buffalo, might create better demands for these fish which at present have only limited markets in a few Eastern cities.

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IRON-SULFIDE DISCOLORATION OF TUNA CANS[1/]

BACKGROUND

Within the past few years, tuna canning has become one of the leading fishery industries in the United States. In building the market for tuna, the packers have taken pride in presenting a high-quality product with consumer appeal.

Tuna is canned in three different styles: a solid pack consisting of two or three large pieces of solid meat; a chunk pack consisting of several smaller chunks of meat; and a grated or flake pack consisting of small pieces packed solidly in the can. During recent years, a harmless black deposit of ferrous iron sulfide has sporadically occurred in cans of solid-pack tuna. The deposit is found on the inside surface of the can or lid, almost entirely in the area adjacent to the headspace. If a pack of

1/ This investigation, which was carried out at the Service's Seattle Technological Laboratory, was jointly sponsored by the Continental Can Company and the U. S. Fish and Wildlife Service.

canned tuna, on being sampled, is found to contain this ferrous-sulfide discoloration, the pack is not marketed; for not only are the discolored cans unsightly, but any homemaker opening a discolored can is likely to think that the tuna in it is spoiled. Though the discoloration is harmless, it thus gives rise to a considerable financial loss.

In addition to the ferrous-sulfide discoloration, another type of discoloration may also be found on the inside surface of the can. This second type of discoloration, or staining as it is called, is caused by a formation of tin sulfide, which is quite similar in color to the can enamel and which forms under the surface of the enamel film. Since this tin-sulfide staining is not very noticeable, it does not materially affect the sales appeal of the canned tuna and is therefore not usually considered greatly objectionable. Thus, of the two sulfides that may be found in canned tuna, ferrous sulfide poses by far the more serious problem.

It might be pointed out that this problem is not specific to tuna but is prevalent in many other protein foods. If a means of preventing iron-sulfide deposits in tuna cans is discovered, it is likely that the deposit could be eliminated from these other products.

Previous workers on this problem have concerned themselves primarily with the practical approach of eliminating the discoloration by improving the enamels on the inside surface of the cans. Very limited work has been done in an effort to study the underlying causes of the deposit. It is known that the formation is ferrous iron sulfide and that it appears primarily in the headspace of solid-pack tuna as a result of a reaction between iron in the tin can and sulfide present in the fish. It has also been established that excessive iron exposure (e. g., fracture of the tin coating) is not the direct cause of iron sulfide formation. Other factors that showed no correlation with the degree of discoloration were vacuum, headspace, net weight, moisture content, pH, and drained weight (Kleinschmidt 1953).

Discoloration, which is found primarily in solid-pack tuna, appears spasmodically. A packer may have no trouble with the deposit for a year or more and then an entire lot or code may become discolored. Under normal conditions of storage, sulfide discoloration reaches a maximum (usually within 24 hours after processing) by the time the lot or code is inspected. No instances of objectionable discoloration have been reported on grated- or flake-style packs.

Some canners believe that imported Japanese tuna, particularly albacore, give more trouble with discoloration than do fish caught locally. Others claim, however, that the Japanese tuna is superior in quality to American-caught tuna, owing to the universal Japanese practice of bleeding the fish while they are still alive.

The objective of this series of investigations was to study the reaction mechanism whereby iron sulfide is formed during the canning of some batches of tuna. This work will be reported in a series of subsequent articles as follows:

No. 1 - Theory of Iron-Sulfide Formation in Cans

No. 2 - Analytical Methods

No. 3 - Effect of Condition of Raw Fish

No. 4.- Effect of Temperature during Processing and Cooling

No. 5 - Effect of Salt, Oil, and Miscellaneous Packing Additives

No. 6 - Experiments to Elucidate Mechanism of Reactions

No. 1 - Theory of Iron-Sulfide Formation in Cans

INTRODUCTION: During recent years, black deposits of iron sulfide have sporadically occurred in canned tuna. In some packs, the deposit, which is found primarily in the can area adjacent to the headspace, builds up to the extent that it flakes off onto the surface of the meat. This paper is the first in a series of six papers presenting the results of an investigation of the iron-sulfide reaction in tuna cans.

The objective of this paper No. 1 is to discuss the various methods whereby sulfur and iron can become available to react and form iron sulfide in the cans of some tuna packs.

LITERATURE SURVEY: Sulfur has been a main source of corrosion troubles to the food canners since the introduction of the tin can as a packaging medium. A reaction between sulfur and iron or tin in the can may cause a black iron-sulfide discoloration or a green tin-sulfide staining in cans of many sulfur-bearing food products (Johnson and Frost 1951). The sulfur-bearing proteins give rise to sulfide sulfur in proteinaceous foods. This is particularly the case in seafood products (Gortner, R. A.; Gortner, R. A., Jr.; and Gortner, W. A. 1949).

In some instances, the sulfide found in canned foods may be introduced from outside the product. A good example is the corrosive effect of gooseberries that have been sprayed in the field with a lime-sulfur spray (Clough, Shostrom, and Clark 1930).

Trace metals may play an important role in sulfide production. Copper-bearing metals, such as brass or bronze, should be avoided in processing plants, as copper apparently catalyzes the formation of iron sulfide (Johnson and Frost 1951).

In work done with herring, it was found that the hydrogen-sulfide content increases appreciably as spoilage proceeds (Stansby and Lemon 1941; Sigurdson 1947). The sulfide formed in meat due to spoilage comes from the proteins containing the sulfur-bearing amino acids, cystine and methionine (Gortner et al 1949).

There are several factors that have been shown to have a bearing on sulfide discoloration. Crab meat having a high pH increases sulfide discoloration in canned crab meat (Oshima 1932). The rate of dissolution of metals from tin cans containing fish is greatly affected by certain organic compounds peculiar to fish. Trimethylamine oxide appreciably increases the dissolution of tin in canned herring (Jakobsen 1945).

Several investigators have reported the production of hydrogen sulfide in canned foods during retorting. In the heat processing of chicken, hydrogen sulfide is formed by a chemical reaction that is nonbacterial in nature (Sadikov, Shoshin, Starukhina, and Livshitz 1934). Hydrogen sulfide has been found in fish after canning, although the raw material contained none (Tilik 1935).

CAUSES OF SULFIDE PRODUCTION: General: Sulfur occurs in the meat of fresh fish in a form other than as sulfide. It is present largely in the amino acids, cystine and methionine, which make up a portion of the fish proteins. Hence, sulfide sulfur must either come from bacterial or chemical (enzymatic) degradation of the proteins or be introduced during the handling and processing of the fish.

Sulfide may be liberated from the proteins by a breakdown of the sulfur-bearing amino acids that are split off from the large protein aggregates, or it might be formed directly from the protein aggregates. Since the pH of canned tuna is slightly acidic (pH 6.1), it is most likely that the liberated sulfide will be found in the form of hydrogen sulfide.

Causes of Sulfide Production Prior to Canning: If fish are allowed to lie on the deck of the fishing vessel for an extended period of time before being iced or frozen, spoilage will produce sulfur compounds such as hydrogen sulfide within the fish. This situation may arise when fishing is good and the catch is piling up faster than it can be handled properly. Even when the fish do not lie on the deck for any protracted period of time but are placed in the brine wells promptly, considerable spoilage sometimes takes place. This may occur when the wells are filled with more tuna than the refrigeration capacity is designed to accommodate. This overloading results in such a slow rate of freezing that the center of the fish may not freeze for several days. Under such conditions, considerable spoilage results. Other potentialities for spoilage occur during lags in the canning process, especially at the stages prior to that of the precook.

It is conceivable that sulfide caused by fish spoilage would be carried through the canning process and into the canned product where it is available to react with some form of metal during heat processing.

Causes of Sulfide Production During Canning: Analysis of the canning process indicates that the following steps include possible causes of sulfide production:

STORAGE--Most tuna are stored in a frozen state from shortly after the time that they are caught until they are thawed for canning. Chemical changes during frozen storage are generally limited to oxidation of oils and pigments and to mild denaturation of the proteins. The latter change might have some effect on the state of sulfur in the protein, but the nature of such an effect is uncertain.

BUTCHERING--Some of the parts of the tuna removed during the butchering operation are more subject to decomposition, with accompanying hydrogen-sulfide formation, than is the meat itself. Incomplete butchering of the fish, whereby some of waste parts remained with the cleaned fish, might result in an increased sulfide content of the final product.

PRECOOKING--The precook removed both moisture and tuna oil from the fish and makes it easier to pack and clean. During this heating, some of the volatile constituents, including sulfides, would also be driven off. The time and temperature of precooking for a given size or species varies considerably from one plant to another. There is a current trend in the industry to cut the precook time to as short a period as possible. Any such diminishing of precook time would result in carrying over more of the volatile sulfur compounds into the canned product.

COOLING, CLEANING, PACKING, AND SEAMING--Failure to handle the fish promptly at this (or other) stages of processing would tend to increase the chance of spoilage, with accompanying increase in volatile-sulfide content of the tuna meat. The fish might also at this stage pick up traces of metal, such as copper from the cleaning table (if present). Such trace metals might be harmful, acting as catalysts in promoting iron-sulfide formation at a later stage.

THERMAL PROCESSING OF CANS--Subjecting proteins to high temperatures, such as occur during retorting, results in some chemical breakdown of the protein, and this reaction may liberate sulfides. The changes occurring at this stage will be of a purely chemical type, since all microorganisms as well as enzymes will be destroyed or inactivated by the heat.

SOURCE OF IRON: General: The so-called "tin can," which is primarily iron, gets its name from the extremely thin coating of tin deposited over the surface to protect the iron from corrosion. Tin protects iron by two mechanisms. The first is the purely mechanical protection afforded by the exclusion of corroding substances. The second is the electrochemical protection that tin gives iron in some instances. In the atmosphere prevailing in cans of many food products, tin is anodic to iron. Thus, tin goes into solution in preference to iron (Jakobsen, Ronald, and Stokke 1945; Jakobsen and Mathieson 1946).

The dependence of this country on foreign sources for tin has continually forced the plating industry into decreasing the amount of tin in tinplate. Present day tinplates vary from 0.000015 to 0.000100 inches in thickness, depending on the grade. Even with the finest tinplating technics, microscopic pores that expose iron are present. Thus, synthetic enamels have been developed to give further protection. Oleoresinous can linings include such materials as phenolic or maleic-modified rosin esters, unmodified phenolics, petroleum resins, and epoxy-type resins.

Formerly, a single-enamel phenolic resin was used on standard tuna cans. Severe outbreaks of iron sulfide discoloration that accompanied the decrease in tin coating forced the industry into using a double-enameled can to give further protection. The outer enamel usually contains about 15-percent fine-particle zinc oxide added for its chemical reactivity. During heat processing of the canned tuna, sulfide released from the fish reacts with the zinc oxide to form a white compound of zinc sulfide that is not noticeable (Flugge 1951). Recently, new enamels have been developed that allow the use of single-enameled cans in many instances.

Form of Iron: Sulfide will not react directly with elemental iron under the conditions found in a tin can. By some means, iron which is exposed through fractures or imperfections in the can enamel or tinplate is changed into an active form. Since the can discoloration is caused by ferrous sulfide, it seems most likely that the iron in a can must be converted into an ionic (ferrous) state by either purely chemical or electrochemical reaction.

An example of a purely chemical reaction would be the oxidation of exposed iron by moist air or by acids present in the oil or fish.

An electrochemical reaction would be caused by the formation of a galvanic couple between two metals of different potential. If the couple is in contact with a solution of electrolyte, such as a salt solution, a current will flow which results in solution of one of the metals. Since iron is above tin in the electromotive series, it will normally go into solution and be anodic to tin. As was previously pointed out, however, under the conditions that exist in many canned foods, there is a reverse in the nobility between tin and iron, and tin goes into solution as the anode. Hence, if the electrolytic production of ferrous ions is the source of iron in ferrous sulfide, certain batches of tuna appear to have the ability to cause iron to become anodic to tin. Such a reaction would be

$$Fe \longrightarrow Fe^{++} + 2 \text{ electrons} \quad \text{Anode (oxidation)}$$

$$2 \text{ electrons} + 2H^{+} \longrightarrow 2(H) \quad \text{Cathode (reduction)}$$

$$\text{then } 2(H) + X \longrightarrow H_2X$$

$$\text{or } 2(H) \longrightarrow H_2 \uparrow$$

Since discolored cans are not ordinarily hydrogen "swells," a substance X, acting as a cathodic depolarizer, might be present in certain batches of tuna.

FORMATION OF IRON SULFIDE DEPOSIT: It seems most likely that ferrous sulfide is formed in the can area adjacent to the headspace by a reaction between iron from the can, which is in the ferrous form, and sulfur from the fish, which is in the sulfide form. A preliminary analysis of the source of the reacting substances indicates that sulfur is liberated from fish proteins as hydrogen sulfide and that exposed iron in the can is converted to the ferrous form.

Hydrogen sulfide is probably produced by a breakdown of fish tissue. This reaction is due either to spoilage (bacterial or enzymatic action) or to thermal processing of the fish, or to both. Besides supplying sulfide for the reaction, certain batches of tuna also influence the conversion of exposed iron in the can to the ferrous state.

DISCUSSION: From the theoretical analysis of how ferrous sulfide may be formed in certain batches of canned tuna, it was decided to investigate the following variables and their effect on the reaction:

1. The condition of the raw fish.
2. Temperatures during processing and cooling.
3. Salt, oil, and other additives.
4. Commercial packaging and handling technics.

The results of these experiments will be given in subsequent papers of this series.

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OYSTER TECHNOLOGICAL RESEARCH CONTINUES DURING THE SUMMER

Even during the R-less months of the summer, active research work has continued at about full scale in the laboratories of the three contractors concerned with finding greater markets for Southern oysters under the U.S. Fish and Wildlife Service contracts. The studies at Florida State University, Tallahassee, Fla., have included recipe development for oyster stews and soups, and the irradiation of oysters with the radioactive isotope colbalt 60 to evaluate the suitability of this possible method of commercial sterilization.

Samples of oysters have been collected each month at different places in the Gulf to determine what effect the weather, bed location, and local feeding conditions have on the fatness of the oysters. These studies at the Louisiana State University, Baton Rouge, La., also include the examination at regular intervals of oysters frozen under different rates of freezing and held at several different cold-storage temperatures.

The physiologist at Tulane University, New Orleans, La., is experimenting with live oysters in sea-water tanks to determine conditions that increase or decrease the amount of liquids lost when the oysters are shucked. The Southern oysters for some reason lose much more liquid than Northern oysters.

JELLIED SALMON

Procedures for preparing a specialty product, jellied salmon, have been developed at the Service's Seattle Fishery Technological Laboratory. Jellied salmon is a canned fish specialty which is prepared by adding a clear hot liquid gelatin and agar jelly to precooked and flaked salmon in the can. Jellied salmon can be served as is, on lettuce as a salad, or in almost any salad that calls for flaked fish.

To prepare jellied salmon the fish are precooked to remove the excess moisture in much the same way that tuna are precooked. Unless this excess water is removed by precooking, an undesirably soft canned product entirely unlike fish flakes is obtained. If the salmon are precooked in steam as in the canning of tuna, a considerable amount of undesirable oxidation of the oil with impairment of flavor occurs. To avoid this oxidized oil flavor, the dressed salmon are precooked or simmered in a very light salt brine just long enough to be cooked through to the bone and in condition for flaking. All of the skin, fat, and bone is then removed. The remaining fish is flaked, packed into cans, covered with the hot jelly, sealed, processed, cooled, and labeled for market.

Jellied tuna is prepared by adding the same type of jelly to the light-meat tuna flakes or grated tuna that remain after packing the solid-pack and chunk-style tuna.

NEW FEDERAL SPECIFICATIONS FOR CERTAIN FISHERY PRODUCTS

FEDERAL SPECIFICATION FOR CHILLED AND FROZEN SHRIMP ISSUED: Federal specification for "Shrimp, raw and cooked; chilled and frozen" (PP-S-316a) was issued June 20, 1955, by the General Services Administration. This supersedes Interim Specification PP-S-00316a, November 18, 1954, and Federal Specification PP-S-316, January 3, 1954. This specification is for the use of all Federal agencies.

NEW SPECIFICATION PROJECTS ASSIGNED TO THE SERVICE: In view of military and Federal agency interest, the development of a new Federal specification for frozen breaded shrimp and the conversion of the military specification for scallops into a Federal Specification are indicated. Both of these projects have been assigned to the U. S. Fish and Wildlife Service. Basic development work on the specification will be carried out at the Fishery Technological Laboratory in East Boston, Mass.

COMMERCIAL FISHING PROSPECTS IN ARCTIC WATERS

Good fishing is obtained in the Atlantic Ocean, in favorable depths, inside the Arctic Circle. For example, the Bear Island grounds at approximately 75° N. latitude are among the most productive in the world.

The Arctic fishing grounds have not been fully explored because: (1) the rigorous climate discourages exploration; (2) floating icebergs are a hazard to navigation; (3) fishing grounds tend to be littered with boulders transported by the ice and trawling operations are hampered; (4) damage to gear restricts the amount of exploratory fishing which can be carried out and borne by private fishing companies; (5) so long as fishing continues to be good on the known grounds in the north Atlantic the incentive to explore further north is lacking.

Few government research vessels carry out extensive exploratory investigations in this Arctic area. Due to poorer catches being made on the closer European grounds as a result of heavy fishing pressure since 1945, several European countries have focused their attention on the Arctic. They are steadily building a fleet of larger trawlers for Arctic work. Until recently, these vessels operated mainly at Iceland and Bear Island, but during the last few years, successful trips have been made to grounds off the southeast coast of Greenland. On these trips the expenses for fuel and gear were high and the working conditions for the crew rather unpleasant.

Cod, halibut, Greenland halibut, and ocean perch (redfish), appear to be plentiful on many grounds in the northeastern and northwestern Atlantic. On some of the banks, and in deeper water, fishing with long lines may be the most productive method of fishing. For many years, long-lining for cod has been done by Porttuguese fishermen on banks between Labrador and Greenland and for halibut by Scottish fishermen at Iceland and Greenland. It seems fairly certain that the exploration of the north Atlantic fishing grounds will be continued, probably to the limits of the ice front.

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