Fisheries Utilization Research—50 Years in Retrospect, Part II: The Enduring Research Themes

JOHN A. DASSOW

Introduction

The enduring themes of fisheries utilization research are neither surprising nor mysterious, but are simply the basic questions we ask about the components of our food supply. Quality: How good is it to eat? Nutrition: How good is it for us? Safety: How safe is it to eat?

Thus, the quality, nutrition, and safety of fishery products comprise the triad of past and future utilization research. The scientific knowledge base for the triad must be continually updated as fishery resources, the water environment, and man's use of both produce changes in the nature and composition of our fishery foods. Also, we include those fishery commodities, such as industrial fish and fish meal, that are used as animal feed components, since they affect the quality and composition of meat, poultry, and aquaculture-produced fish. Finally, the fishery products used in pet foods are important as they relate to the health of millions of pets.

In past years, I reviewed many reports of the fisheries chemists of the 1930's and 1940's for information on the quality and nutritive values of fish and shellfish, simply because the data from recent publications were often meagre and inconsistent. One problem is the need for adequate species sampling in relation to the fishing areas and the species' commercial size range. On numerous occasions I was impressed with the wide ranging research on quality and nutritive value 40 and 50 years ago. Remember that this was at a time when laboratory analytical methods were labor intensive and required manipulative skills unknown to a modern food chemist. Today much of the food analysis depends on instrumentation and methods with speed and precision that are breathtaking to a chemist of my vintage.

Early in my career in the 1940's, I became familiar with this intensive quantitative methodology for vitamins and mineral analyses only to see it give way in the 1950's to the new and increasingly expensive instrumentation technology. For this reason, I was doubly impressed with the range and validity of the data published by some early researchers. One example is the data on copper and iodine content of edible fish portions by Nilson and Coulson (1939) in comparison with current data. Other examples include the reports of Harrison and others (1935, 1937, 1939) on quality and composition of fish oils and meals. I have referred to these early researchers not just as part of the history, but because, in my view, they achieved a standard of excellence in both their vision and their research on the quality and nutritional value of fishery products.

When we turn to the research on product safety, the docket is heavily weighted toward the period after 1962, the year that "The Silent Spring" by Rachel Carson (1962) was published and alerted the public to the dangers of DDT and other environmental problems. The story of marine biotoxins is possibly the most intriguing since, for once, man is not to blame for natural and historic occurrences of deadly toxins in some species of fish and shellfish. The same cannot be said of botulism and several other unpleasant diseases related to fishery consumption. These are reviewed in the final section.

One common thread in our enduring themes is that the 50 years from 1937 to 1987 produced much new and important knowledge; however, the growth and diversification of the fishing industry and expanding concerns for the quality and safety of our food supply provide greater impetus for the next 50 years of research on both old and new problems. For those who want to know more, see the Literature Cited section.

Quality

Quality of fresh and preserved fish and shellfish is of first importance in our review because an understanding of quality and its maintenance is essential to production and marketing of every fishery product. We can define quality as the "essential character" of a product, but if you think about your favorite fish, in my case salmon, you realize that quality also includes the element of "freshness," the fresh-caught flavor and texture.

In the laboratory we can confirm the identity of a fish and determine its freshness and quality by chemical and microbiological methods. This is not enough, however, to define the really top quality of flavor and texture that makes some specimens of a given species especially desirable. All this is true of most natural foods, including fresh fruit and vegetables as well as fresh fish. Experienced fishermen, both commercial and sport, learn that fish from some areas or at a particular time or season will have that top quality, showing what nature can accomplish when everything is just right. The problem from the consumer's view is how to find and identify the high quality fresh fish in the market. There

John A. Dassow, now retired, was a Supervisory Research Chemist with the Utilization Research Division, Northwest and Alaska Fisheries Research Center, NMFS, NOAA, Seattle, WA 98112. Current address: 4510 86th Ave. S.E., Mercer Island, WA 98040. Views or opinions expressed or implied are those of the author and do not necessarily represent the position of the National Marine Fisheries Service, NOAA.

is no simple laboratory test for this top quality. The old advice "If you don't know fish, know your dealer" is not always practical. In the early 1970's, the NMFS Gloucester Laboratory developed a program with local fish dealers that demonstrated for the first time a quality assurance label for Grade A fresh fish. More on that later. Laboratory quality tests are more useful in the region of fair to borderline edibility of fresh fish, and it is here that we find the real work area for the chemists and microbiologists, who in the past 50 years have greatly advanced the methodology for quality assessment.

Fresh Fish

This was my introduction to utilization research in 1940. My assignment was the chemical determination of freshness in thawed samples of Pacific salmon, *Oncorhynchus* spp., which were prepared and frozen at intervals as the iced fish were allowed to slowly deteriorate into the obviously inedible state of spoilage.

At this point I might as well admit what most chemists realize after working in this area of "freshness" determination in fish—the fact that most methodology measures the degree of spoilage, not degree of freshness. It wasn't until many years later, in our research on preservation of radiation-pasteurized fish, that we and others developed the methodology for measuring the early enzymatic changes in the nucleotides of fish flesh, for example hypoxanthine, a truer index of freshness (Spinelli, 1971). Not that spoilage criteria such as total volatile base, ammonia, trimethylamine, volatile acids, volatile reducing substances, hydrogen sulfide, histamine, lactic acid, indole, pH, and others which I've forgotten aren't useful. It's simply a matter of selecting the substance most likely to appear during the early to late spoilage sequence in the fish or shellfish of concern.

Regulatory agencies, such as the U.S. Food and Drug Administration, find spoilage criteria essential for defining unwholesome products. For fish, I favor total volatile base and total bacteria count as a good starting point. For fresh oysters, both pH and lactic acid are simple and useful. Mechanical fish "freshness" testers, such as the British surface conductivity tester of the 1960's, were developed for dockside inspection and, although useful, didn't prove to be consistent indicators for Pacific species.

Wayne Tretsven, microbiologist, takes samples from fish at a Seattle filleting plant for determination of bacterial counts and quality evaluation (Utilization Research Division photo, Seattle, 1958).

Because of the limitations of these laboratory or objective tests for fish quality, sensory examination (i.e., subjective tests) became increasingly significant in our research on quality. For whole and dressed fish, buyers and inspectors judge appearance, firmness, odor, and visual defects. The problem in judging both raw and cooked fish is to be unbiased and consistent.

In 1974 the NMFS Gloucester Laboratory, in cooperation with several fish producers and processors, initiated a landmark program on quality assurance of fresh fish fillets. Under the U.S. Department of Commerce inspection program, quality assurance tests at dockside, the processing plant, and retail outlets were used to demonstrate the feasibility of providing the consumer with consistently fresh fish. During the two years of the study, the number of retail markets involved grew from 2 to 200 and the sales volume to nearly 1 million pounds/year at an added cost of $0.10/pound for the quality assurance. Several years later in 1981, a study showed that the sales volume of U.S. Grade A quality fish fillets had expanded to 11 million pounds/year in the 15 northeastern states. This certainly demonstrated the feasibility of the program and the consumer demand for high quality fresh fish (Gorga et al., 1982; Ronsivalli, 1982).

At this point I should emphasize the necessity of proper methodology in all this sensory quality assessment. In fact, the methodology becomes a significant part of the research. For judging quality of fresh and cooked fish, scoring procedures for appearance, odor, flavor, texture, and acceptability must be selected carefully and judged with a trained panel. Use of statistics is essential for compiling results.

During the 1960's sensory research blossomed at our laboratories during our extensive research on gamma radiation pasteurization of fresh fish. Since

the irradiation at low level kills or inactivates the more sensitive spoilage bacteria, such as the pseudomonas, the spoilage of the chilled irradiated fish fillets is delayed substantially but is atypical because other types of spoilage bacteria eventually proliferate. This means that total bacteria counts and some chemical tests, such as total volatile base, may not be useful spoilage indices. Actually, the problem of quality definition in irradiated pasteurized fish was quite difficult. The treated refrigerated fillets declined in acceptability the first week during the initial enzymatic changes in the flesh and then, for a period of 1 or 2 weeks, stayed at a mediocre quality level that, to most observers, was edible but not really good.

I used to call this the lowest common denominator of acceptable quality—okay but without the fresh fish flavor. Incidentally, this same problem of atypical spoilage pattern and mediocre quality during extended storage occurred in the antibiotic (tetracycline) treatment of fresh fish fillets studied by various laboratories (not by Utilization Research as a matter of policy) in the 1950's. The antibiotic treatment of fresh foods to inhibit spoilage bacteria had other health implications, however, and was soon forbidden. The desirability of gamma irradiation for fresh fish pasteurization is still under consideration.

In recent years an old idea, studied at the Gloucester lab in the 1930's, for storing chilled fish in a modified atmosphere rich in carbon dioxide, has reappeared. The result is similar to irradiation in that the treatment inhibits normal spoilage bacteria, but the enzymatic changes and slow growth of other bacteria in the fish yield a product with extended storage life but a mediocre quality. Gamma radiation and modified atmosphere treatments have potential value for extending keeping quality of fresh chilled fish for some markets but not for my taste. I think better methods of icing and chilling fish aboard vessel can help more, such as box icing and refrigerated sea water systems studied at the Seattle and Gloucester laboratories and elsewhere. Today's recognition of proper handling and the rapid shipment of fresh fish from coast to coast, and in fact from around the world, provide a greater selection of quality fresh fish for all tastes than I ever imagined 50 years ago.

Preserved Fish

It's been clear for more years than I've been around that quality of frozen or canned fish can be no better than that of the original fish; therefore, the first approach to quality is to consider the same sensory, chemical, and bacterial factors useful in the fresh fish. These are apt to be most useful in frozen fish since the heat process in canning destroys bacteria and alters the chemical and physical nature of the fish. For the consumer, the real need in frozen fish has long been a visible warranty of quality assurance (Nickerson and Ronsivalli, 1979; Gorga et al., 1982).

In frozen fish, appearance, odor, flavor, and texture changes are the important criteria in the sensory examination of the thawed and cooked fish. Depending on the oil content and susceptibility of the species, oxidation of the fat in the surface layers of the fish is a critical quality factor. Discoloration and dehydration of the surface will be observed in frozen fish and shellfish if they are not protected during frozen storage by ice glazing or moisture-vapor-proof packaging. The texture of frozen fish and shellfish is a good quality indicator of storage time and temperature. Typically, during long storage, frozen fish changes from a moist succulent texture in the cooked product to a dry, tough, or fibrous texture that renders the product unacceptable even if the flavor is good.

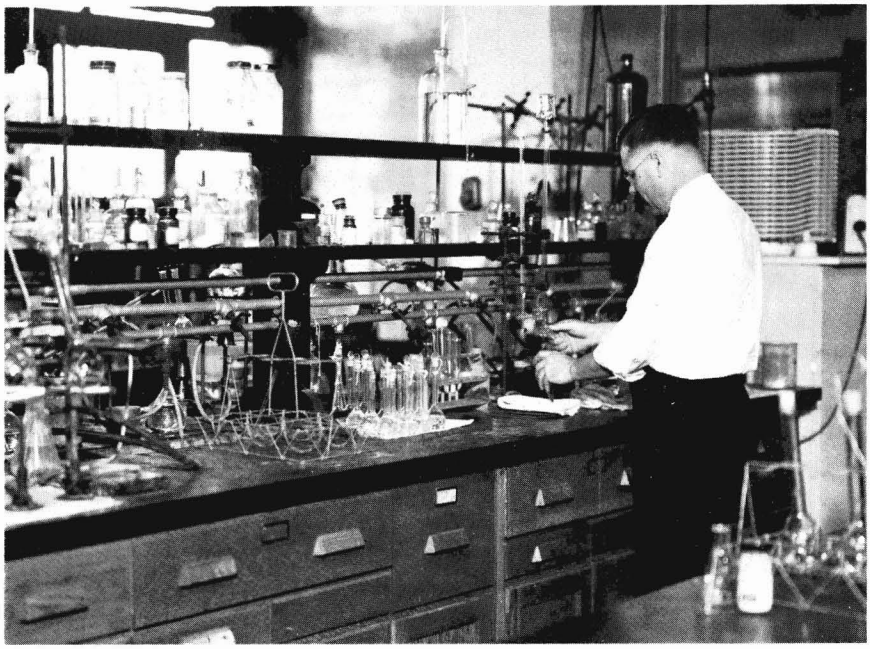
These changes in frozen fish are time and temperature dependent but differ remarkably in various species; therefore, research on frozen fish and shellfish requires a good knowledge of the species characteristics, the quality of fresh fish, and the variables in harvesting and handling prior to freezing. The major studies of freezing and storage of Atlantic and Pacific fishes have been conducted since 1940 at the BCF-NMFS Gloucester and Seattle laboratories where the facilities have been available for preparation, freezing, and storage at various temperatures. The Ketchikan and, since 1971, the Kodiak laboratories have conducted additional research on Alaska species, most recently walleye pollock, *Theragra chalcogramma*. Traditionally, little freezing and storage research was conducted at the College Park Laboratory (relocated to Charleston, S.C., in 1978) since the program emphasis was on mid-Atlantic species in which freezing was of little importance. The exception was freezing and storage of blue crab, *Callinectes sapidus*, meat at College Park, a study of considerable scope in the 1950's and later.

The major engineering and cold storage research was conducted at the Gloucester Laboratory during the 1960's and 1970's and included a long-term study of the time-temperature tolerance of frozen fish of various species. In addition a major engineering study was conducted of the design and construction of a jacketed cold storage, an effort aimed at improving the operating efficiency of frozen storage and minimizing the undesirable temperature fluctuations. A major factor in the freezing and storage research at Gloucester and Seattle during these years was the close collaboration with the refrigerating industry and commercial cold storages and fish processors.

A few comments about the interest of Utilization Research on the quality of canned fish and shellfish are in order. In general, the industry through the National Food Processors Association (formerly National Canners Assocation) Laboratories in Washington, D.C., Berkeley, Calif., and Seattle, Wash., led the way since the 1920's in quality determination and improvement in canned foods, including salmon, tuna, crab, and shrimp. The Seattle laboratory of National Food Processors and the Northwest industry association collaborated with the NMFS Seattle Utilization Research Laboratory in numerous projects of joint interest. To name a few, studies of quality and canning of king crab in the 1940's and 1950's, canning of Pacific pink shrimp in the 1950's when the machine peeler was introduced into the Pacific Northwest and Alaska, and canning of salmon frozen at sea in Alaska for later thawing and canning ashore.

In these studies our mutual interest was in identifying the nature of quality

problems and preparation of recomendations for processors based on evaluation of both experimental and commercial packs. Similarly, we collaborated with the tuna industry and the National Canners Association laboratory in California in studies of canned tuna and the effects of the brine freezing and thawing techniques aboard vessel on the quality and the salt content of the final product. Toward this end we established and operated a small laboratory at Terminal Island, Calif., during the late 1950's and 1960's. Later, the Terminal Island facility was closed, but in the 1970's we collaborated with the tuna industry and University of Hawaii researchers in a contract study of the problem of occasional outbreaks of scombroid fish poisoning from consumption of tuna or other scombroid species found in tropical waters. This will be discussed later.



Hugo W. Nilson, assistant pharmacologist, in the pharmocology laboratory at the Fishery Technological Laboratory, U.S. Fish and Wildlife Service, College Park, Md., about 1940. Nilson was active in research on nutritional values of seafoods in the diet. He was later director of the laboratory (Utilization Research Laboratory photo, Charleston, S.C.)

Quality Standards and Inspection

In 1954, the passage of the Saltonstall-Kennedy (S-K) Act provided funds for development and implementation of voluntary grade standards for fishery products. The objectives for seafoods were similar to the established program for agricultural food product standards: To provide uniform grade standards for the form and quality of seafoods, based on industry application, and to provide a voluntary inspection service under contract to processors. Initially, and for some years, the Gloucester and Seattle laboratories and, later, the NMFS Pascagoula Laboratory were active in developing and evaluating grade standards for frozen fish sticks, fish portions, breaded shrimp, fish fillets, salmon and halibut steaks, whole and dressed fish, and several other seafood products.

The most interesting research at Seattle was in developing the standards for frozen halibut steaks and dressed halibut. The study involved studies aboard halibut fishing vessels and collaborative evaluation of halibut with the industry. The research led to a much deeper understanding on our part of not only the chemistry of quality change but the complexity of applying detailed knowledge to a grade standard usable by the industry. The result years later was a general grade standard for whole and dressed fish of any suitable species. Again, as in freshness evaluation, the researcher learns that detailed procedures for grading may be too costly for industry application.

Guidelines based on inspection experience and quick methodology are more useful in quality control. As the voluntary inspection program developed, it was obvious that a laboratory dedicated to the development and application of quality standards and inspection methodology was necessary. The technological laboratory at Pascagoula, Miss., was assigned this responsibility and currently conducts seafood quality research and provides fishery inspection and management services (Garrett, 1988).

Nutritive Value

Studies of nutritive value and chemical composition of fish and shellfish must be ranked as our most enduring theme inasmuch as the importance of reliable nutritional data for fish and shellfish and their products was well established by 1937. In looking back even further, we find that about 1879 Spencer F. Baird, an assistant secretary of the Smithsonian Institution and the first U.S. Commissioner of Fisheries, initiated a landmark study on composition of fish. Baird interested W. O. Atwater of Wesleyan University, Middletown, Conn., in the need for information about the nutritive value and chemical composition of fish.

Atwater first went to Europe and studied the latest methodology of analysis and composition of foods in German laboratories. Then he and his students, especially one student, Charles Woods, obtained and analyzed the available species of fish and shellfish for moisture, oil, protein, and ash contents. The results (Atwater, 1888) were published as a 200-page paper in the Report of the U.S. Commissioner of Fisheries for 1888-1889. The report provided the basic reference on proximate composition of fish and shellfish for the next 50 years and is still of value for comparison of composition ranges in relation to species size and distribution.

Research technologist Charles Butler demonstrates to fishermen the sampler developed by the Seattle laboratory for taking a representative sample of fish livers for vitamin A assay (Utilization Research Division photo, 1948).

This is not to say that by 1937 the subject of analysis and composition was of little further interest to fishery chemists. Quite the contrary. The increasing utilization of various species, the need for composition in relation to size and biological condition, and the interest of nutritionists in detailed data on organic and mineral constituents in food products were major factors in expanding the field of fish analysis and composition.

Some of the questions about composition and nutritive value were quite difficult to answer with the chemical methodology available in the 1930's. Major questions included the amino acid composition of the proteins in fish and shellfish, the biological value of fish proteins, and the determination of the inorganic elements of nutritional significance, such as copper, iron, calcium, sodium, and iodine. The new and growing field of vitamins in human nutrition brought new questions for fishery researchers. First among these was the content of vitamins A and D in fish and fish oils (Harrison et al., 1937); somewhat later was the content of the B vitamins in fish. Speaking of the old methods, in 1937 the vitamin A and D assays were conducted by the biological rat assay and required 28 days minimum. Six years later when I was on the staff at the Ketchikan laboratory, we did vitamin A assays with the new filter spectrophotometers in about an hour per sample. Several years later with the new Beckman slit spectrophotometer it took 10 minutes.

The high content of vitamin A in fish liver oils and the increasing demand for vitamin A supplements by the food and pharmaceutical industries set the stage for expansion of the domestic fish liver oil production (Butler, 1948). Two events

late in the 1930's set it off on the U.S. west coast. First was World War II which cut off most imported fish oils, especially Norwegian cod liver oil. Second was the findings of rich sources of vitamin A oil in livers of several species of Pacific shark—referred to as "liquid gold" by some.

By 1941 a major shark fishery had developed from California north along the coast to Alaska. Processing plants for vitamin oil production from fish and shark livers and viscera followed. By 1943 the value of vitamin A oils, mostly from Pacific coast sharks, was about $15 million. Prices for livers were based on vitamin A content, and the Seattle laboratory had a major program underway in cooperation with industry on vitamin A sources, biological variables, sampling methods for livers, vitamin A assay methodology, and process methods for production of high potency vitamin A oils.

I saw part of the action as a chemist at the Ketchikan laboratory on vitamin A assay, then spent 1 year, in 1945-46, as chemist in a fish liver oil processing plant, also in Ketchikan. The bust came a few years later as synthetic vitamin A and imported fish liver oils took over. By 1950 fish liver landings on the West coast were about 10 percent of the landings 5 years earlier. Today there is still a small domestic production of natural vitamin A oils, but imports are the main source and my spoonful of cod liver oil, taken every morning, comes from Norway.

The composition research was conducted in several temporary laboratories during the early 1930's—Gloucester, Washington, D.C., and Charleston, S.C. When the College Park laboratory opened on the University of Maryland campus in 1935, personnel and equipment were transferred there, and a unified program on nutrition was established. The early work included some excellent studies on mineral content of fishery products, which I found valuable over 40 years later in compiling data for dieticians on minerals and trace elements in fish (Nilson and Coulson, 1939; Nilson, 1941).

At that time I compared the early data with the latest available and found that the early work was not only accurate but quite detailed on the question of variability among samples and species. I recall that the copper and iodine data were particularly helpful. Unfortunately, many of today's researchers overlook much good research of earlier years because they leave the university with the idea that anything more than 5 years old is not worth looking up.

The determination of the amino acid content of fish and the biological value of fish proteins were key elements in the nutritional research area at College Park during the 1940's and later. This research demonstrated that fish proteins are complete proteins for human and animal nutrition and have a high biological value, factors that are just as important today in recommending more fish in the diet.

The growing field of animal nutrition for improved production of meat and poultry and the role of fishery feed materials has been a significant program at College Park and Charleston since the 1940's. Composition data and nutrient availability are the basic requirements for fish meals and other fishery products used as ingredients in animal feeds. The early research reflects these factors as well as the effect of processing methods (Harrison et al., 1935). The timing was excellent because agricultural research showed an increasing interest in scientifically formulated animal diets, especially in relation to protein balance and growth factors. After World War II and in later years, the major developments in the expansion and improved economics of large-scale chicken production simply would not have been achieved without the application of the new science of feed efficiency and growth factors. The contribution of fish meal, fish solubles, and other fish ingredients was shown to be significant for animal nutrition in the early research at the Gloucester Laboratory and, after 1935, in the research at the College Park Laboratory.

The interest in these findings and the search for the "unknown growth factor(s)" in fish meal and solubles led to extensive contract research coordinated by the Utilization Research Laboratories in the late 1950's and the 1960's. This research as well as much animal research on the nutritive value of fish oils in the diet was conducted after additional funds became available for technological research under the S-K Act of 1954. This legislation, incidentally, still provides allocation of funds from import duties on fishery products for research grants to both universities and industry on problems and developments that can improve fishery products and processes.

Three major studies of the composition of fish and shellfish and their food and industrial products were undertaken from 1955 to 1980. The first, an inhouse study, was established at the Seattle laboratory to provide basic composition and sodium content data on a wide range of Pacific coast species with particular attention to the variables of size, catch area, and biological condition for major species. Analyses generally included the edible portions and waste along with yield data to provide, for the first time in many species, a complete reference for utilization as food or animal feed (Stansby, 1976).

The second study was coordinated by the College Park Laboratory and was the determination of 15 trace elements in 204 species of finfish, molluscs, and crustaceans. The samples were obtained by Utilization Research personnel and analyzed by a private laboratory under contract.

The third study at the College Park/Charleston Laboratory was the compilation of a comprehensive report and a computerized data bank from 1,204 publications covering the chemical and nutritional composition of 1,500 species of finfishes, whales, and shellfish, and their products. The second and third studies were published as separate reports (Hall et al., 1978; Sidwell, 1981).

The study of composition and nutritive value is never finished, no matter how impressive these large compilations are. For one thing new products arrive, such as surimi and surimi analog products. Another factor is the changing need for information, e.g., the need for data on the omega-3 fatty acid content in fish in response to the interest in possible health benefits.

Yet another factor is changing analytical techniques. When I determined cholesterol in fish oil about 40 years ago, I used a colorimetric procedure that was checked against a gravimetric pro-

Home economists Jean Burtis, Rose Kerr, Dorothy Robey, and Polly S. Moore in a test kitchen in the College Park Laboratory, about 1960 (Utilization Research Laboratory photo, Charleston, S.C.).

cedure. The colorimetric procedure measured total sterols and, depending on the amount of sterols other than cholesterol present, your values would be high. Today there is a more specific procedure for cholesterol.

Finally, new species arrive in the market, and composition data are needed for dieticians and nutritionists. An example is monkfish, *Lophius americanus*, a very ugly fish from New England that has fillets of wonderful flavor and texture and is now available in fine fish markets. The 1981 compilation mentioned above, however, does not list monkfish. Presumably, it wasn't marketed that much then.

Dieticians and home economists have long contributed to studies on nutritive value of fish and shellfish and its acceptability. A test kitchen and one or more home economists have usually been a part of the well-equipped fisheries utilization laboratory. The largest test kitchen and home economics staff were at the College Park Laboratory for many years. The staff prepared and published many colorful booklets of fishery recipes, of which some are still available from U.S. Government Printing Office outlets.

Three important species of utilization comprised their responsibility: 1) Providing facilities and methods for sensory panel evaluations, 2) developing and testing recipes for institutional and consumer use, and 3) providing cooked fish dishes for determination of the composition and nutritive value of the final product. In recent years our laboratories have provided data on nutritive value of seafoods for the increasing number of dieticians who are concerned with dietary controls in hospitals and institutions. For their use, the composition of the cooked fishery item is the determining factor, and the basic fish composition data are used in modifying recipes to suit nutritional goals. The new interest in nutrition, the increasing consumption of fish in the U.S. (from 12 pounds per capita in 1982 to 15 pounds in 1987), and the availability of high quality seafoods indicate that developing fish and shellfish recipes with good palatability and nutritive value will continue to be important to all fish consumers.

Product Safety

Of the enduring research themes in fisheries utilization, product safety has undergone the greatest changes in the significant research areas during the 50 years of our review. In 1937 the research emphasized the microbiology and control of the common spoilage and food poisoning organisms in seafoods, with special emphasis on crustaceans and mollusks. Fresh crabs and crab meat, clams, and oysters were recognized as highly vulnerable to spoilage, also to contamination with food poisoning organisms such as staphylococci and salmonella. The research, therefore, emphasized the microbiology of processing and marketing of these species with dual goals of product improvement and consumer safety (Anzulovic and Reedy, 1942; Piskur, 1947; Pottinger and Lemon, 1948).

At the time, the methods for bacterial culture and identification were slow and laborious, and much attention was given to rapid quality control methods, sanitation, and recommendations suitable for industry. Related research included potential use of chemical preservatives, importance of prompt refrigeration for raw and precooked shellfish, and safe process methods for canned products. The dangers of botulism in mishandled seafoods was known but not a subject of major research in utilization laboratories. The major problems of organic poisons and toxic metals in fishery products were still in the future. In some ways it was the "age of innocence" for product safety.

In food poisoning cases, fish and shellfish, if consumed, are suspect because of their perishability and the ease of contamination. For this reason utilization research typically has included microbiological studies of the major species and the effects of contamination and subsequent mishandling. A major part of the work has been development of processing recommendations for industry in cooperation with the health agencies responsible for food regulations.

A good example of this is the early research at College Park in which Anzulovic and Reedy (1942) showed that proper sanitation during processing of blue crab, heat pasteurization of the meat in sealed containers, and refrigerated storage prior to use, improved both the keeping quality and safety of the product. A study of preservation of chilled clam meats at the Ketchikan Laboratory demonstrated simple tech-

niques for improving keeping quality (Piskur and Stansby, 1946). A few years later, in response to complaints about spoiled crab meat and moldy smoked fish produced in Ketchikan, the laboratory microbiologist demonstrated surprising improvement in product quality and safety by use of proper sanitation and chilling procedures during processing of each product. Admittedly, it was not very sophisticated research in these and other studies but it was essential and to the point.

Increasingly in the past 50 years, this problem of food-related illness has been investigated by Federal and state health agencies that are also responsible for the regulations established for consumer safety. Utilization Research has maintained close liason and, in many cases, has conducted cooperative research with agencies investigating seafood-related health problems. Our laboratories in turn became increasingly involved with product safety research requiring extensive knowledge not only of the causative agents in seafoods, both bacterial and chemical, but also of the related marine or fresh water environment.

The research projects that developed into major programs, and of particular interest for our review, are botulism, mercury in fish, toxic organic contaminants in the marine and fresh water environment, and naturally occurring toxins in certain fish and mollusk species. In view of the controversies on aspects of these topics and their complexity, I urge those interested to look up articles listed in the Literature Cited section for more details (i.e., Stansby and Alverson, 1973; Stout and Beezhold, 1981; Stout et al., 1981, and others).

Botulism

This subject is fraught with fear and frequent misinterpretation in the public mind. Botulism is a rare disease that strikes suddenly after consumption of even the smallest amount of a preserved food that has been contaminated by the bacteria *Clostridium botulinum* and mishandled and stored under the conditions permitting the bacteria to grow and develop a deadly toxin. Under these conditions, normal spoilage and the objectionable odors accompanying spoilage are usually absent and there is little indication that the food contains a deadly toxin. The toxin is destroyed if the food is held at boiling temperature (100°C) for 10 minutes or more. This, of course, is the reason for the admonition to always heat any home-canned nonacid food, which includes fish and meat, for 10 minutes before consumption. My mother used to can green beans the old-fashioned way when I was a boy. She did know about the danger of botulism and never let my brother or me even taste the green beans after she opened a jar until the contents had been boiled at least 10 minutes. As I found out years later, this was no small matter, because for many years home-canned string beans were a major cause of death from botulism in the United States.

The organism was isolated in 1896 by Van Ermengen from salted ham that had caused human fatalities. In 1904 it was isolated from canned beans and since then seven strains or serotypes of *C. botulinum* have been identified from a variety of foods and common soil. My first experience with botulinum research was in 1952 when I was chief of the Fishery Products Laboratory, Ketchikan, Alaska.

One of our research objectives in Alaska was to develop process ideas for expanding the utilization of sexually mature fall salmon, mostly canned as a lower quality product. One product was a heat-pasteurized smoked and salted salmon egg spread that would utilize the tons of salmon eggs then discarded by the canneries. The problem with our product was that we couldn't give it a safe heat process without ruining the soft caviar-like texture. The question was whether the pasteurized sealed product would pose a problem of botulism if mishandled or stored at room temperature.

I consulted experts at the National Canners Association Laboratory in Berkeley, Calif., who suggested that we prepare an experimental pack inoculated with a spore suspension of *C. botulism*. (Type A and B strains were used.) The pack would then be shipped to the Berkeley laboratory where storage and toxicity tests of the inoculated samples would be conducted. This was done and the conclusion was that the smoked salmon egg spread with an 8 percent salt content (16% in water phase) presented no hazard of botulism even if stored at room temperature (Carlson, 1955).

Research at the Seattle laboratory in later years on the protective effect of salt levels in smoked fish showed that the high salt levels in our smoked spread had precluded any problem of botulism. The process was used by two specialty salmon processors in Alaska in subsequent years, but in the meantime the Japanese demand for salmon eggs developed. Within a few years lucrative contract arrangements with Alaska salmon processors by Japanese companies took care of the problem of surplus salmon eggs. Our process is not used now to my knowledge.

About 10 years later in the 1963, the potential hazards botulism and the need for research blew wide open after several incidents of botulism poisoning and deaths in the Great Lakes area resulted from mishandling and improper storage of hot-smoked lake chubs and whitefish (*Leucichthys* and *Coregonus* spp.) As a result, the Utilization Laboratory at Ann Arbor, Mich., undertook a substantial study of the technical and microbiological aspects of the processing and marketing of hot-smoked fish. Primary emphasis was placed on the occurrence, survival, and potential hazard of *C. botulinum* in the products. Processing and marketing recommendations to assure safety of hot-smoked fishery products were developed in collaboration with the industry and a national advisory committee of outstanding specialists in food microbiology and botulism (Eklund and Poysky, 1970; Graikoski et al., 1970; Graikoski, 1971; Anonymous, 1979).

During this period in the 1960's, research was initiated at the Gloucester, Ann Arbor, and Seattle laboratories under the support of the Atomic Energy Commission (AEC) on the feasibility of using gamma irradiation to pasteurize fresh fish and shellfish and thereby enhance the keeping quality of the refrigerated packaged product. In view of the concerns about botulism hazards, this became a major focus of the microbiological research at Ann Arbor and Seattle. The initial research was on the potential of botulizm outgrowth and toxin formation in sealed packages of

radiation-pasteurized seafoods that were stored at various temperatures, to simulate under experimental conditions the potential hazards of product mishandling that could occur under actual market conditions. This led to a study at the Seattle laboratory of the physiological properties of various strains of *C. botulinum* and related organisms and the factors determining their toxigenicity.

In the early studies of irradiation pasteurization of fresh fish fillets, it was found that low levels of gamma irradiation (100 and 200 kilorads) inactivated a large percentage of the normal spoilage bacteria. The refrigerated storage life of the treated fillets was increased substantially; however, both the sensory and microbiological studies of these fillets during storage showed that there was now a different pattern of spoilage without the usual odors associated with fresh fish spoilage. The refrigerated treated fillets remained in good edible condition for 1-2 weeks longer than untreated fillets.

At this point the idea of irradiation pasteurization looked promising. The studies of the effect of temperature showed that storage at 38°F provided much greater quality extension than storage at 42°F or higher. The important question of product safety with respect to mishandling and storage at higher then desirable temperatures was tackled next by the microbiologists. Since the causative organisms of botulism are commonly present in soil and the marine environment, fresh fish would likely be contaminated with botulism bacteria. Comparative storage studies with sealed packages of untreated and irradiated fish fillets inoculated with known levels of type E botulinum spores were deemed essential to determine if a botulism hazard existed.

Though I had had some experience with botulinum-inoculated seafood at the Ketchikan Laboratory, I was unprepared for the demanding nature of the larger scale studies by our small research team of two microbiologists. Every aspect of the research involved the most meticulous attention to laboratory procedures, including preparation of the inoculated packs, their storage history, the chemical and microbiological examinations, the sensory studies (by odor only with inoculated packs), the necessity of careful replication, and the essential toxin determination by mouse bioassay.

As the research unfolded the possible hazards of botulism in irradiated pasteurized fillets, I became increasingly impressed with the necessity for such research to determine the limits of safety for future consumers of this new product of the atomic age. The detailed studies with irradiated packaged fillets showed that only low levels of irradiation, 100 kilorads or less, and storage temperatures of 38°F or lower could be employed if the product's safety depended on consumer recognition of eventual spoilage of the marketed product.

It is interesting to reflect that despite much excellent research at the Seattle and Gloucester Utilization Laboratories on the chemical and engineering aspects of low-level irradiation of fresh fish, plus extensive marketing studies by others, the government's decision to postpone approval in the 1960's and later has rested primarily on the product safety research much of which was done at Ann Arbor and Seattle. Currently, the question of the industry feasibility of gamma irradiation of fresh fish is being reevaluated under present conditions.

An enormous bonus of the irradiation research was that our microbiological research team at the Seattle Laboratory was well prepared to participate in further studies dictated by the outbreaks of botulism from hot-smoked fish in the midwest in the 1960's and in the canned salmon industry in 1978 and 1982. The government and industry concern for safe process methods for smoked fish led to extensive research at Seattle in cooperation with the Food and Drug Administration on the characteristics of the toxin development (toxigenesis) of the different strains of botulinum, the effects of salt and chemical additives, including sodium nitrite, other process variables, storage temperatures, and recommendations for industry application. In the Great Lakes area, related research and industry cooperative studies were conducted by the Utilization Laboratory at Ann Arbor, Mich., from 1963 to 1971. The result of the integrated research to assure safe wholesome smoked fish products was a series of cooperative studies at Seattle, supported in part by the industry, which has continued to the present (Eklund, 1982).

Further applications for the hard-won knowledge about botulism appeared in such wide-ranging problems as possible hazards from other processes to increase market storage life of fresh fish, e.g. storage in low oxygen atmospheres, and the etiology of outbreaks of botulism in Pacific coast salmon hatcheries, which has resulted in saving millions of fish every year since (Eklund et al., 1982). In the course of this continuing research, major contributions have been made to the fundamental knowledge of the *C. botulinum* organisms and the mechanism of toxin development.

Mercury in Fish

When I took physics in high school in 1933, we were allowed to use mercury freely in experiments demonstrating its interesting properties. For most of us, the toxic nature of mercury became apparent in the 1950's when we read accounts of the Minimata disease in Japan. The cause of the epidemic of neurological disabilities, we were told, was long-term consumption of fish from the waters of Minimata Bay that had been heavily polluted by industrial dumping of mercury compounds.

Medical and toxicology studies found that the deadly agent in the fish was methylmercury, a toxic organic form converted from the discarded inorganic mercury compounds in the marine environment. In Sweden investigations of industrial mercury pollution in freshwater fishing areas led to closure of fishing areas and the establishment of a legal limit of 1.0 ppm mercury in the flesh of fish for human consumption.

In the 1960's, the BCF Ann Arbor Laboratory began mercury testing in fish of the Great Lakes. After investigating fish from contaminated areas of the Great Lakes, the U.S. Food and Drug Administration established an "in-house" guideline of 0.5 ppm mercury maximum limit in fish for food in May 1969. Marine species in the U.S. market were tested and showed higher than desirable mercury levels in numerous samples of shark, swordfish, tuna, and halibut. Clearly, research was needed on the occurrences of mercury in the ma-

rine environment, in various areas, in various species, and in fish of various ages and sizes. In 1970, these and related studies were initiated by the Seattle and College Park Utilization Laboratories. Much effort by our laboratories and other state and Federal agencies followed until the patterns and sources of the mercury contamination were established for fish areas and commercial fish species.

During the first years after the mercury guidelines were established, the fishing industry was greatly upset by marketing delays and expenses of testing to assure compliance with the law; however, there was no question of the need to safeguard the product safety. Research on freshwater species in the United States and similar work by the Canadians showed that the culprit was industrial pollution by mercury compounds that were converted to methylmercury by bacteria in the water environment. To eliminate such misuse of our water environment, pollution restrictions under Federal and state laws have been enacted or reinforced since the 1970's.

In the research in our laboratories, marine fish samples were obtained both inshore and offshore, and the age and size of fish were correlated with mercury content. Other investigations included analyses of museum speciments of fish to show whether the problem was of recent origin. From the mass of data it appeared that the source in the ocean is the natural occurrence of mercury, augmented by geological and volcanic processes in some areas. The mercury shows up in the food chain, and fish that live 30 or 40 years or more, like swordfish and halibut, may accumulate natural levels of mercury that exceed the 0.5 or 1.0 ppm guidelines. For that reason, the Food and Drug Administration still monitors fish shipments for compliance with mercury guidelines.

One result of all this mercury scare and research was not unexpected. The next question was "What else do we have out there that we ought to know about?". Questions on lead, arsenic, cadmium, and you-name-it levels in fish were on the agenda. The obvious next step was undertaken by the College Park Utilization Laboratory with the assistance of other BCF laboratories and state agencies: Collect representative samples of all commercial fish and shellfish and determine the trace element levels in each and every sample. The result of this substantial program was a published report of over 300 pages with tables and graphs showing the levels of 15 trace elements in 204 species of finfish, mollusca, and crustacea (Hall, Zook, and Meaburn 1978). In case you want to know, here are the 15 trace elements determined: antimony, arsenic, cadmium, chromium, copper, lead, manganese, mercury, molybdenum, nickel, selenium, silver, tin, vanadium, and zinc.

Chemist Alice Hall is determining mercury in fish samples, using an atomic absorption spectrophotometer (Utilization Research Division photo, Seattle, 1967).

Environmental Contaminants

Looking back, it seems that the national concern for the problem of environmental contaminants and the detrimental effects on fish and wildlife first started after "The Silent Spring" was published (Carson, 1962). The literature sources, however, show that the evidence had been building for over 10 years, and Carson's spirited and readable review was most timely. The Bureau of Commercial Fisheries already had biological pesticide research under way on the U.S. east coast and had data showing the accumulation of DDT in oysters and clams and the toxicity of dieldrin to the larvae of oysters, clams, and shrimp in the nursery areas inshore.

In 1963, the Seattle Technological Laboratory initiated a study of the occurrence and distribution of DDT and residual products in the marine and estuarine fish species of Washington. The results over a period of several years showed low DDT residues and no significant buildup in fish off the State of Washington. In contrast, studies of fish of the Great Lakes by the Bureau of Fisheries laboratory at Ann Arbor, Mich., showed by the late 1960's an alarming concentration of DDT and metabolites in several species. A national ban was placed on DDT use in 1972, but the pesticide research continued on other and, in some cases, more deadly pesticides such as dieldrin.

The continuing studies at the Seattle laboratory in the 1970's included extensive analyses for DDT residues, dieldrin, and the toxic and highly stable polychlorinated biphenyls (PCB's) in both Pacific and Atlantic coast fish species. The major Atlantic species studied was menhaden, *Brevoortia* spp., because of its industrial importance and wide range along the coast (Stout et al., 1981). These and related studies by other BCF laboratories provided the essential data for monitoring the fate of these toxic con-

The library at the BCF College Park Laboratory in suburban Maryland hosted many conservation meetings owing to its proximity to Washington, D.C., and its position on the University of Maryland campus. This meeting on fisheries matters on 21 April 1955 was attended by a wide range of representatives from government agencies and private organizations. From left to right are: Carl Shumacher, International Association of Game, Fish, and Conservation Commissioners; Hugo Nilson, BCF College Park Technological Laboratory; John L. Farley, Director, Fish and Wildlife Service; O. Lloyd Meehean, Assistant to the FWS Director; Jack C. Culbreath, Assistant Information Chief, FWS; A. W. Anderson, Chief FWS Branch of Commercial Fisheries; Milo W. Williams, National Geographic Society; Frank C. Daniel, Secretary, National Rifle Association of America; Alastair MacBain, Information Chief, FWS; Albert M. Day, Assistant to the FWS Director; David H. Wallace, Director, Oyster Institute of North America; Joseph Flackne, Arctic Institute; George E. Steele, Jr., National Canners' Association; George B. Fell, Nature Conservancy; Fred E. Hornaday, American Forestry Association; Richard W. Westwood, American Nature Association; Lewis Radcliffe, ANA Vice President; Harry Donahue, Special Assistant to Assistant Secretary of the Interior; and Charles H. Callison, Conservation Director, National Wildlife Institute. FWS photograph by Rex Gary Schmidt, courtesy of the NMFS Charleston Laboratory.

taminants in the fishery environment. The data pinpointed the problems of organic contaminants, such as PCB's, and the need for use restrictions to protect both the fisheries and the environment.

To protect the consumer, the FDA and related state agencies placed maximum levels allowed in fish and shellfish of these and other poisonous compounds that may contaminate the fresh or salt water environment. As a result of the growing significance of the field of environmental contaminants in relation to fisheries, a separate research program, the Environmental Conservation Division, was established in the Seattle laboratory to study the effects of environmental contaminants on marine organisms of the estuarine and nearshore environment of the Pacific coast (Stansby and Alverson, 1973).

Marine Biotoxins, Fish Poisoning, and Parasites

This sounds like an unwholesome collection of undesirables for utilization research, but the significance of these topics to product safety and proper resource utilization is undeniable. As in other studies with health implications, our research was conducted in liason with the appropriate public health agencies that have the responsibility for consumer information and food regulations.

Paralytic shellfish poison (PSP), the biotoxin frequently associated with "red tides" and outbreaks of clam and mussel poisoning, will be our major topic because I am most familiar with the past research, and it is a problem that plagues Pacific, Atlantic, and Gulf fisheries. It's also a problem that is still with us and needs continuing research. Research on PSP was conducted at the College Park, Seattle, and Ketchikan Laboratories in the 1940's and 1950's, with major field studies based on the clams of southeastern Alaska. From then until the present, the research and liason were spasmodic with flurries of activity when an outbreak occurred or when a new potential for utilizing clams developed, as in the geoducks of southeastern Alaska in the 1960's and the surf clams of the Bering Sea in the 1970's.

The PSP problem in clams and mussels is an ancient one. According to Alaskan natives at Angoon and Wrangell and old-timers at Petersburg, clams and mussels were not eaten during the summer by tribal custom, and there were clam beaches like the Pt. Roberts outer beach (a highly toxic area in our sur-

veys) near Petersburg that were traditionally taboo areas for harvest.

The Russian administrator, Baranof, reported in 1800 that mussel poisoning caused deaths in 1793 from mussels in what is now called Poison Cove in Peril Strait. The early coastal explorer, George Vancouver, reported that four members of his expedition were poisoned and one died after eating mussels from a beach in British Columbia. Cases of mussel poisoning in California and shellfish poisoning in New England and European countries appeared in reports from the early 1900's. Little was known about the cause.

It wasn't until 1937 that California researchers proved that PSP in local mussels originated in the toxic dinoflagellate *Gonyaulax catenella*. In the same year Sommer and Meyer, of the research group at the Hooper Medical Foundation, University of California, established the procedure for assay of PSP by intraperitoneal injection of shellfish extracts into mice. In 1943, following a conference on the PSP problem in Washington, D.C., the FDA established a tolerance level of 400 mouse units (MU) per 100 g of edible shellfish meats. In later years after the toxin had been isolated and identified, a conversion ratio of 1 μg of PSP to 5 MU was established, and the tolerance level, which is still effective, was set at 80 μg or 400 MU of PSP per 100 g of edible shellfish meats.

In Alaska, PSP research began in 1946 at the Ketchikan Laboratory, following seizure by the Food and Drug Administration of a shipment of frozen butter clams, *Saxidomus giganteus*, from Petersburg for presence of PSP. Laboratory and field investigations continued from 1946 to 1952 and included comprehensive surveys throughout the year of the occurrence of PSP in clams from the major beaches of southeastern Alaska. The conclusion of these surveys was that clams from many areas were sufficiently toxic to be a health hazard and that generally in such areas the clams remained toxic all year.

We conducted several surveys, using the 50-foot laboratory boat *Researcher*, to correlate the occurrence of the toxic dinoflagellates in various areas to the clam toxicity in adjacent beaches. The conclusion was that it wasn't that simple. Transplanting studies showed that if you planted nontoxic butter clams to a beach with toxic clams, the transplanted clames became toxic in less than 1 year. When we did the reverse, the toxic clams transplanted in a nontoxic area did not decline in toxicity appreciably in 1 year, indicating that the toxin was firmly bound in the tissue.

Detoxification was not simple either, although later work on the Atlantic coast indicated potential for ozone detoxification (Blogoslawski and Stewart, 1978). Turning to processing as a way out, tests showed that 60 percent of the toxin was in the siphons of butter clams and that the black tips were the most toxic. Extensive heat processing studies showed that by removing the siphons and mincing the clams, then giving a long heat process, almost all harvested clams could be canned safely. The problem was that given the occurrence in some areas of highly toxic clams, one couldn't be sure of a safe product without laboratory tests for PSP, a fairly expensive procedure for a small industry.

In the meantime, the Chemical Corps of the U.S. Army had, by the late 1940's, become interested in isolating and identifying the toxin from California mussels. They needed a major source of toxic shellfish and since the toxin in the Alaska clams appeared identical, they provided funds for harvesting a large quantity of butter clams from the most toxic areas we had found in our surveys of southeastern Alaska. The highly toxic clam siphons were separated, preserved raw in acidified solution, and shipped to the Chemical Corps laboratory, then at Fort Detrick, Md. The extensive laboratory research there and contract research elsewhere solved the problems of isolating and determining the characteristics and structural formula of the toxin (Schantz, 1960; Schantz and Magnusson, 1964). The poison was found to be a neurotoxin and among the most potent known to man. In the end we and the Chemical Corps clarified the toxin problem, but in the meantime, the small clam industry of southeastern Alaska had died in 1946. The research did not restore the industry because the techniques to insure that a safe clam product is harvested and marketed are too costly—at least so far. Since then, the monitoring for PSP in the shellfish harvest areas continues on the Atlantic coast and from California to Alaska, including Puget Sound which, on occasion, has had PSP occurrences (Shimizu et al., 1978). We still haven't answered the question of why and how we have such a toxic little plankton on the Pacific coast and a sister plankton, just as toxic, in the Atlantic, but that's the way it is.

The other items in our collection of undesirables can be mentioned briefly. The fish biotoxin known as ciguatera poison occurs as a result of a food chain mechanism in many reef-associated fish in tropical areas, the Caribbean, and Pacific Islands. Our laboratories have participated in government efforts and research studies to pinpoint the nature and source of this heat-stable toxin and, again, to recommend ways and means of safely harvesting and marketing the fish from problem areas. To date the problem has not had a practical solution because there is no simple method of testing for ciguatera poison, and the nature of these tropical island fisheries requires such a solution. Traditionally, the ciguatera problem has been primarily of concern to the local population; however, the broader use of tropical fish species has created greater concern to fishery and public health agencies, particularly because of the virulence and the heat stability of the toxin.

Another problem of the tropical areas is scombroid fish poisoning, which is caused by formation of the toxic substance(s) during mishandling of the fish prior to processing and not by a naturally occurring toxin as in ciguatera poisoning. The need for research developed in the 1970's as a result of problems in the tuna industry and was conducted under contract to the Department of Food Science, University of Hawaii, with the Seattle laboratory handling the liason and review of the subsequent research. After 3 years of study, their work demonstrated that the origin of scombroid poisoning was enzymatic and bacterial spoilage of the fish. The cause of the illness was traced to the formation of a combination of histamine and other toxic substances in a scombroid fish species, for example tuna, that was not refrigerated properly during handling

or shipment. Since the scombrotoxin is thermostable, it will persist in the canned product and has caused some alarming outbreaks of scombroid fish poisoning, such as in 1973 when it occurred in 232 persons from two lots of commercially canned tuna. Patients became ill less than an hour after eating the fish, and symptoms lasted about 8 hours. All recovered and no hospitalizations were reported. The solution is obvious and lies in proper refrigeration and quality control of all scombroid fish prior to processing.

Our final topic is parasites in fish, meaning visible worms in most cases, and it is a subject many people would rather not discuss. Nevertheless, it's one of continuing concern to the industry and regulatory agencies. During my tenure, consumer complaints and industry requests for information on parasites in fish and the possible health and esthetic complications seemed to flow endlessly into the laboratory. Our field and laboratory studies were quite limited and mostly on identification and incidence of the visible parasites.

In the 1950's and 1960's, during the development and testing of quality standards for fresh and frozen fish, the problem was one of simply defining an acceptable standard for parasites. Zero is preferred but unfortunately unrealistic. Of course, as long as the fish is cooked before consumption, the problem is entirely esthetic, a point not always appreciated by an unhappy consumer finding a worm on an otherwise fine piece of fish ready to be cooked. The only hope is one of consumer education on the biological reality of an occasional parasite despite the diligence of the industry. Fillets are inspected rigorously over strong light by all quality-conscious processors, but human error occurs occasionally and therein lies the problem.

In recent years, the consumption of raw fish, such as the popular sashimi, has created a special problem—the possible medical effect of ingesting a live parasite in a piece of raw fish. The solution is simple (other than not eating it in the first place). If planning to serve or eat raw fish, be sure that the fish have been frozen and stored at least several days at −20°C (−4°F) or below prior to consumption. The problem then is back to the issue of esthetics, not a small issue to many consumers in my experience.

In the final article of this 50-year review of fisheries utilization research, Part III, Processing and Engineering Research, I focus on four major areas in which the engineering research was a major part. These are: Radiation pasteurization of fresh fish, freezing fish at sea and ashore, fish protein concentrate, and the surimi process.

Literature Cited

Anonymous. 1979. part 122—smoked and smoke-flavored fish. Code of Federal Regulations, Title 21, Chapter 1, Food and Drugs, parts 100 to 199, p. 136-139.

Anzulovic, J. V., and R. J. Reedy. 1942. Pasteurization of crabmeat. Fish. Market News. Part I, 4(1):3-6. Part II, 4(2):9-10.

Atwater, W. O. 1888. The chemical composition and nutritive value of food-fishes and aquatic invertebrates. U.S. Fish. Comm., Rep. 1888, p. 679-868.

Barnett, H. J., R. W. Nelson, P. J. Hunter, and H. Groninger. 1978. Use of carbon dioxide dissolved in refrigerated brine for the preservation of pink shrimp (*Pandalus* spp.). Mar. Fish. Rev. 40(9):24-28.

Blogoslawski, W. J., and M. E. Stewart. 1978. Paralytic shellfish poison in *Spisula solidissima*: anatomical location and ozone detoxification. Mar. Biol. 45:261-264.

Butler, C. 1948. The fish liver oil industry. U.S. Fish Wildl. Serv. Fish. Leafl. 233, 98 p.

Carlson, C. J. 1955. Preparation of a smoked salmon caviar spread. Commer. Fish. Rev. 17(1):13-15.

Carson, R. 1962. The Silent Spring. Houghton Mifflin, Bost., 368 p.

Dassow, J. A., R. W. Nelson, and W. T. Tretsven. 1971. Developing quality standards for fresh dressed Pacific halibut. *In* Fish inspection and quality control, p. 34-40. Fish. News (Books) Ltd., Lond.

Eklund, M. W. 1982. Significance of *Clostridium botulinum* in fishery products preserved short of sterilization. Food. Technol. 36(12):107-112.

_____, M. E. Peterson, F. T. Poysky, L. W. Peck, and J. F. Conrad. 1982. Botulism in juvenile coho salmon (*Oncorhynchus kisutch*) in the United States. Aquaculture 27:1-11).

_____ and F. T. Poysky. 1970. Distribution of *Clostridium botulinum* on the Pacific coast of the United States. *In* Proceedings of the First U.S.-Japan Conference on Toxic Micro-organisms. U.S. Dep. Inter., Wash., D.C., p. 304-308.

Garrett, E. S., III. 1988. Microbiological standards, guidelines and specifications, and inspection of seafood products. Food Technol. 42(3): 90-98.

Gorga, C., B. L. Tinker, D. Dyer, and J. M. Mendelsohn. 1982. Frozen seafoods: The economic feasibility of quality assurance to the consumer. Mar. Fish. Rev. 44(11):1-10.

Graikowski, J. T. 1971. Seafoods and botulism. *In* Fish inspection and quality control, p. 249-255. Fish. News (Books), Ltd., Lond.

_____, E. W. Bowman, R. A. Robohm, and R. A. Koch. 1970. Distribution of *Clostridium botulinum* in the ecosystem of the Great Lakes. *In* Proceedings of the First U.S.-Japan Conference on Toxic Micro-organisms. U.S. Dep. Inter., Wash., D.C., p. 249-255.

Hall, R. A., E. G. Zook, and G. M. Meaburn. 1978. National Marine Fisheries Service survey of trace elements in the fishery resource. U.S. Dep. Commer., NOAA Tech. Rep. NMFS SSRF-721, 313 p.

Harrison, R. W., A. W. Anderson, and S. R. Pottinger. 1935. Effect of manufacture on the quality of nonoily fish meal. U.S. Bur. Fish., Invest. Rep. 30, 30 p.

_____, _____, A. D. Holmes, and M. D. Pigott. 1937. Vitamin content of oils from cannery trimmings of salmon from the Columbia River and Puget Sound regions. U.S. Bur. Fish. Invest. Rep. 36, 8 p.

_____, _____, S. R. Pottinger, and C. F. Lee. 1939. Pacific salmon oils. U.S. Bur. Fish. Invest. Rep. 40, 21 p.

Lee, C. F., and H. W. Nilson. 1939. Study of the metabolism of naturally occurring fluorine in canned salmon and mackerel. U.S. Bur. Fish. Invest. Rep. 44, 15 p.

Nickerson, J. T., and L. J. Ronsivalli. 1979. High quality frozen seafoods: The need and the potential in the United States. Mar. Fish. Rev. 42(4):1-4.

Nilson, H. W. 1941. Food values in fish and seafoods. Fish Market News 3(11):7-10.

_____, and E. J. Coulson. 1939. The mineral content of the edible portions of some American fishery products. U.S. Bur. Fish. Invest. Rep. 41, 7 p.

Piskur, F. T. 1947. Preliminary study of correlation of pH and quality of shucked Pacific oysters. Commer. Fish. Rev. 9(6):22-24.

_____, and M. E. Stansby. 1946. Preservation of shucked Alaska clams. Commer. Fish. Rev. 8(4):5-12.

Pottinger, S. R., and J. M. Lemon. 1948. Sanitary control practices for the oyster industry. Commer. Fish. Rev. 10(9):7-11.

Ronsivalli, L. J. 1982. A recommended procedure for assuring the quality of fish fillets at point of consumption. Mar. Fish. Rev. 44(1):8-15.

Schantz, E. J. 1960. Biochemical studies on paralytic shellfish poisons. Ann. N.Y. Acad. Sci. 90:843-855.

_____, and H. W. Magnusson. 1964. Observations on the origin of the paralytic poison in Alaska butter clams. J. Protozool. 11(2):239-242.

Shimizu, Y., W. E. Fallon, J. C. Wekell, D. Gerber, Jr., and E. J. Gauglitz, Jr. 1978. Analysis of toxic mussels (*Mytilus* sp.) from the Alaska Inside Passage. Agric. Food. Chem. 26:878-881.

Sidwell, V. D. 1981. Chemical and nutritional composition of finfishes, whales, crustaceans, mollusks, and their products. U.S. Dep. Commer., NOAA Tech. Memo. NMFS F/SEC-11, 432 p.

Spinelli, J. 1971. Biochemical basis of fish freshness. Process Biochem. 6(5):36-38.

Stansby, M. E. 1976. Chemical characteristics of fish caught in the northeast Pacific ocean. Mar. Fish. Rev. 38(9):1-11.

_____, and J. M. Lemon. 1941. Studies on the handling of fresh mackerel (*Scomber scombrus*). U.S. Fish Wildl. Serv., Res. Rep. 1, 46 p.

_____, and D. L. Alverson. 1973. Northwest Fishery Center research on effects of environmental contaminants on marine organisms. Mar. Fish. Rev. 35(5-6):8-14.

Stout, V. F., and F. L. Beezhold. 1981. Chlorinated hydrocarbon levels in fishes and shellfishes of the northeastern Pacific ocean, including the Hawaiian Islands. Mar. Fish. Rev. 43(1):1-12.

_____, C. R. Houle, and F. L. Beezhold. 1981. A survey of the chlorinated hydrocarbon residues in menhaden fishery products. Mar. Fish. Rev. 43(3):1-13.