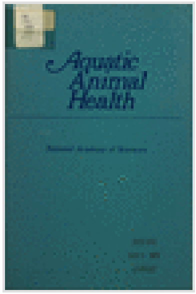

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Aquatic Animal Health

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AGRICULTURAL BOARD
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1973

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Preface

In 1970 the Committee on Animal Health appointed a task force to assess the sources of aquatic animal protein available to meet future nutritional needs of a rapidly expanding human population. These scientists were asked to examine the role of aquatic animals as a renewable food resource, to elucidate the problem of disease in aquatic species that are important to man, to place these disease situations in order of priority and to suggest possible corrective measures, and to identify needs and opportunities in research. The task force prepared a preliminary report dealing with these topics and recommended the appointment of a Subcommittee on Aquatic Animal Health to carry out a more detailed study.

The stated charge of the Subcommittee was, in turn, "to review the status and future potential of proteins of aquatic animal origin, to evaluate the problems encountered in maintaining the health of aquatic animals, and to make recommendations for advances in research and education to improve the nation's capabilities for dealing with these health problems."

The members of the Subcommittee are grateful to the predecessor task force for its contributions and to those persons from private and governmental organizations who assisted in the preparation of this report by providing information and insights.

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Present Utilization of Food of Aquatic Origin

The world commercial fisheries catch increased about 6 percent annually between 1947 and 1968 and reached a total of 64 million metric tons (MT) in 1968 [Food and Agriculture Organization (FAO), 1970]. The catch of marine fish in 1968 was 50 million MT; crustaceans, mollusks, and other invertebrates, 5 million MT; seals and miscellaneous aquatic mammals, 0.01 million MT; miscellaneous aquatic animals and residues, 0.06 million MT; and aquatic plants, 0.89 million MT. The yield of freshwater fisheries in 1968 was 7 million MT. This figure does not include sport fishing and subsistence fishing, which are estimated to be nearly half as large as the recorded commercial catch.

The world commercial catch declined in 1969 to about 63 million MT (Food and Agriculture Organization, 1971). Although some species were in short supply, the decline was largely due to economic factors as distinct from overall availability of fisheries resources. About 7 million MT of the 1969 catch (or nearly 11 percent of world production) came from fresh waters.

The catch rose to a record high of 69 million MT in 1970 (Food and Agriculture Organization, 1971). This total was about 10 percent higher than the total for 1969. Herrings, sardines, anchovies, and related species accounted for about 21 million MT of the 1970 catch, nearly equal to the total world catch in 1948.

The largest increase in catches during 1970 was in marine fish. These catches rose from 48 million MT in 1969 to 54 million MT in 1970. Freshwater catches increased 0.2 million MT during this time. Small increases for crustaceans and mollusks were also recorded.

The Pacific Ocean produced the largest commercial catch in 1970, 35 million MT compared with 30 million MT in 1969. The Atlantic was next with 24 million MT, compared with 23 million MT in 1969. The Indian Ocean, comprising about one fifth of the earth's marine surface, produced 3 million MT, a slight increase over 1969. Recent studies by FAO indicate potentials of 14-20 million MT for the Indian Ocean.

Peru continued to be the leading fishing nation in the world in 1970, catching 13 million MT, compared with 9 million MT in 1969 and 11 million MT in 1968. Most of Peru's catch was anchoveta (*Engraulis ringens*), processed into fish meal for export. The second leading nation was Japan, totaling 9 million MT. The Soviet Union was third, with 7 million MT. The People's Republic of China was next, with an estimated 6 million MT, followed by Norway with nearly 3 million MT, the United States with 2.7 million MT, and India with less than 2 million MT.

Idyll (1970) commented that of the 57.4 million MT of marine commercial products taken in 1968, 36 percent consisted of fish used for such products as meal, oil, bait, and fertilizer. Large quantities of these products are waste (e.g., shells of mollusks and crustaceans). He estimated that not more than 35 percent of the gross weight of the fisheries harvest, or about 21 million MT, was in the form of edible fish flesh. He pointed out that about 19 percent of fish flesh is protein; 5 percent, fat; 3 percent, nitrogen; 1 percent, phosphorus; and the remainder, water.

Idyll also noted that the cost of producing animal protein from the sea is significantly lower than the cost of production on land. He indicated that in gross weight, or in calories consumed, the contribution of the sea to human food is statistically insignificant but that in terms of animal protein, the contribution is important. The Commission on Marine Science, Engineering and Resources (1969) stated, "Fish provide about 3 percent of man's direct protein consumption, but because fish meal is fed to land animals, fish are the basis of about 10 percent of all animal-protein food production."

The use of fish in human diets has risen more rapidly than the rate of human population increase. Georg Borgstrom (personal communication) stated that in the past three decades much of the increase in available fish protein is consumed by developed and centrally planned societies. The inadequacy of protein resources in some parts of the developing world is a serious concern.

Increased Demand for Protein

The predicted increase in world population during the remainder of this century can be expected to act in two ways to increase the consumption of aquatic protein: First, as personal incomes increase, demand for improved diets will also rise; second, as more people suffer from protein deficiency as a result of insufficient income, they will demand a more equitable distribution of animal protein food. For political, as well as humanitarian reasons, nations having sizable numbers of protein-deficient citizens will seek to meet the protein demands.

Chapman (1966) maintained that there was no actual food shortage throughout the world; rather, the shortage was in protein. Idyll (1970) estimated that at least 500 million people consume diets that are deficient in total protein. Whole fish protein contains the balance of amino acids that is needed in human nutrition.

Some unexploited species of fish are not being harvested at all, and others are being harvested in relatively small quantities. W. Chapman has recently noted that about 5 million MT of anchovies could be taken annually from waters adjacent to California and near Patagonia.

Other unexploited species are the thread herring of the Gulf of Mexico and Pacific off Central America; *Sardinella* off Central West Africa, the Arabian and

Oman Seas, and Northwest of Australia; the Arctic capelin*; and substantial quantities of hake off the coast of North America and Latin America; very large but unknown amounts of squid, and very large amounts of small invertebrates or krill in Antarctica . . . capable of a sustained yield on the order of 100 million tons per year.

*The Arctic capelin is no longer underutilized. Norwegian scientists report that current harvests have reached or exceeded levels of maximum sustainable yield.

Potential Food from the Aquatic Environment

Anyone seeking a usable estimate of future fish harvest is confronted by a maze of conflicting predictions. One difficulty lies in the discrepancy between the number of fish available and the number of fish harvested. Even in the most heavily fished waters, not all available fish are harvested. Moreover, many areas are fished lightly or not at all, although we must also recognize that many species are overfished. Furthermore, fluctuations in fish stocks add to the difficulty of making reliable forecasts. The Peruvian fishery for anchoveta (*Engraulis ringens*) is an outstanding example where stock fluctuations have taken place. Scientific studies of the resource have indicated that under average conditions the sustainable yield was around 8-10 million MT. During 1972, however, a severe crisis took place in the anchoveta fishery when there were unusual oceanographic conditions off the coast and an almost complete recruitment failure. Catches in the second half of 1972 were cut to almost nothing. This resulted in a reduction in catch of more than 6 million MT in 1972 compared with 1971. It is hoped that the stock is now rebuilding.

Jackson (1971) aptly states that:

> Nature and man's fate are inseparable, and future fishing cannot be evaluated apart from the world of men or from the environment. We must estimate how many people may exist in the future. It is imperative that we recognize that both the quality of human existence and the quality of the environment in

which fish live will be determined largely by what we humans do to the total environment. We must determine how much food, particularly animal protein, the future population will require, and consider possible new foods. We can make informed guesses about the sizes and kinds of future catches and which sea and freshwater area will produce them. None of us believes any longer, if any of us ever did, that aquatic resources are limitless.

MARINE FISHERIES

The extent to which estimates of fish harvests differ is illustrated in Table 1. The differences are due chiefly to the fact that authorities considered the variables in different ways. For example, those who made the estimate for 1966 included krill and other unutilized species, whereas most of the other authorities omitted them. All such estimates are affected by uncertainty about the harvesting process, uncertainty about aquaculture production, and diminution of fish stocks by disease and pollution.

Menhaden, which traditionally has supported the largest U.S. fishery, is threatened by environmental pollution in its early life stages

TABLE 1 Estimates of Total Ocean Yields of Aquatic Animals

Author	Forecast (million metric tons)	Year	Method[a]
Thompson	21.6	1949	ext.
FAO	55.4	1955	ext.
Finn	50-60	1960	ext.
Graham and Edwards	55 (bony fishes)	1962	ext.
Meseck	55 (by 1970)	1962	ext.
Graham and Edwards	60 (bony fishes)	1962	ext.mf.
Schaefer	66 (by 1970)	1965	ext.
Meseck	70 (by 1980)	1962	ext.
Alverson	80	1965	ext.
Bogdanov	70-80	1965	ext.mf.
Graham and Edwards	115 (bony fishes)	1962	mf.
Schaefer	160	1965	ext.
Schaefer	200	1965	mf.
Pike and Spilhaus	200	1965	mf.
Chapman	1,000	1966	mf.
Pike and Spilhaus	180-1,400	1962	mf.

Source: Sprague and Arnold (1972).

[a]ext., extrapolated from catch trends of existing knowledge of world fish resources; mf., energy flow through food chain.

and heavy fishing pressure later in life; it is another species in need of wise management. Other species showing signs of serious depletion are, for example, yellowtail flounder, herring, American lobster, and haddock from the northwestern Atlantic. There are many other examples in various parts of the world.

Noting the long-term increase in marine harvests since 1938, Shaefer (1965) predicted the trend would continue until at least 1970, "by which time the harvest should have reached 66 million metric tons." (As noted elsewhere, the total world fisheries catch in 1970 was 69 million MT, of which 62 million MT were from salt water.) Schaefer conceded that the various projections of yields were "a rather uncertain set of numbers, based on many assumptions and imprecise estimates." He pointed out that the potential total harvest of the world's fisheries had been consistently underestimated by fisheries experts and concluded that "a potential harvest of 200 million tons a year is probably conservative."

Several estimates of fish production made as late as 1969 emphasized the disparity of opinion on this subject. For example, Chapman (1969) asserted, "I think we can very conservatively say that within ten years from now world fish production will be somewhat above 80 million tons, and that twenty years from now productions will have doubled to about 125 million tons."

Ryther (1969) estimated that some 240 million tons of fish are produced annually in the sea. He doubted that the sustained yield of fish to man could be much more than 100 million tons. Pointing out that total fish landings had increased at a rate of about 9 percent annually over the past quarter century, he expressed doubt that the industry would be able to expand for more than a decade.

The Commission on Marine Science, Engineering and Resources (1969) indicated that if man were to utilize species not now being harvested, a total annual production of marine food products of 400-500 million MT (exclusive of aquaculture) would be possible. The Commission noted that beyond that amount expansion costs could become excessive. It conceded, however, that this estimate might be conservative if technological advances in the detection, concentration, and harvesting of marine species were realized. Rounsefell (1971) stated:

> This brave and optimistic statement is hardly in accord with what is and has been occurring. There have indeed been great advances in fishing technology, but all these advances, coupled with much greater fishing effort, and the exploitation of deeper areas, have only resulted in a decreasing catch per unit of

fishing effort. Optimism, therefore, is giving place to genuine concern among fisheries scientists as one species after another falls drastically in abundance under the onslaught of ever increasing numbers of modern fishing vessels with ever increasing sophistication in gear and techniques. . . . Whether the future marine catch rises, remains static, or falls, depends chiefly upon both national and international observance of sound conservation measures. At the present moment there is little reason for optimism.

An international Technical Conference on Fishery Management and Development was held from February 13 to 23, 1973, at Vancouver, British Columbia. It was convened by the Food and Agriculture Organization of the United Nations and was attended by more than 325 participants from 55 nations and 12 international fisheries organizations. This conference was the third worldwide conference dealing with the problem of management and the first to consider in depth the problems of the development of fisheries. Its terms of reference included an examination of population theory, data requirements for management, methods of assessing latent fisheries resources, and techniques of aquaculture. In addition, the conference reviewed the state of the world fisheries resources, the state of their exploitation, the management mechanisms, and perspectives for fisheries development. Political and jurisdictional aspects were not within the purview of the conference, and economic matters were considered only insofar as they related to the problems of making fisheries profitable—not as they related to overall social or political problems.

Among conference participants there was evident a growing consensus that world production of conventional species cannot expand much beyond 100 million MT. The production limit of 100 million MT for conventional species seems entirely realistic and is supported by a variety of independent investigations. The conventional species include some species that are not now much used but that can be caught by conventional methods and processed in conventional ways. The well-known species will produce little, if any, more than at the present. The nonconventional species that could be caught in addition to those now being caught are those that will require new methods of capture, new methods of processing, new products, and new markets. The nonconventional species include krill (species of *Euphausia*, *Munida*, *Pleuroncodes*, *Calanus*, and others), as well as new species of squids and small fish from the middle depths of the open ocean. According to Lyubimova *et al.* (1973) the krill resource "may be between 0.8 and 5 billion tons, yielding a total commercial catch as high as 25 to 50 million metric tons." These same writers report that "Early experimental catches of Antarctic krill by Soviet scientists in the Scotia Sea, and experiments on processing krill to obtain food and fodder yielded promising results and proved the possibility of the commercial utilization of this resource."

FRESHWATER FISHERIES

The yield of freshwater fisheries was approximately 7.6 million MT in 1970, about 11 percent of the total world catch. From this figure are excluded the very large subsistence and sport fisheries, which are estimated to be at least half as large as the recorded commercial catch. With improved management, freshwater fisheries could provide at least three to four times the present catch. In the future, freshwater fisheries will depend largely on improved management, the prevention of further water quality deterioration, and an improvement of those waters that are already polluted.

AQUACULTURE PRODUCTION

Aquaculture (see Bardach *et al.*, 1972), the rearing of fish and shellfish to economic maturity for consumption or for recreational fishing, has been developed more widely in other parts of the world than in the United States. It is practiced intensively in several Asiatic and European nations for the production of human food. Aquaculture produces 6 percent of the fisheries yield in Japan (Gullion, 1968).

Aquaculture, at least in North America, will make its greatest economic impact as a farming industry of such species as trout, salmon, shrimp, and catfish, rather than as a way of producing large quantities of bulk fish. Indeed, the United States imports nearly 75 percent of the fish consumed. As for the widespread notion of producing large quantities of marine plants by culture, the fact is that seaweeds usually thought of as most promising are actually of little nutritional value. However, production of plant material in the oceans is in the range of 150-200 billion MT per year.

Swingle (1970) reported on the commercial production of fish for food from pond culture in the southern part of the United States. With supplemental feeding, the yield of speckled bullheads was as much as 1,000 lb/acre. With intensive feeding, channel catfish produced 2,000-3,400 lb/acre. The National Marine Fisheries Service reported that in 1968, 22 million lb of catfish was produced from 25,000 acres of water.

Pillay states that

> *World production through aquaculture* (excluding bait, sport and ornamental fish and production through stocking of open waters) *is over five million tons*. This has an important role in the food and nutrition of many countires and is particularly significant in integrated rural development. . . . [and] The President's Science Advisory Committee in the United States in a report on the food problem (1967) predicted a projected increase in yield of 15 million tons through pond culture alone, by the year 2000, "if research can provide the management inputs." FAO's Indicative World Plan for Agricultural Development (1969) considered an expansion factor of five by the year 1985 as feasible, and according to this, the world annual production through aquaculture by that year may be around 20-25 million tons. Bardach and Ryther (1968) estimate a higher rate of increase of ten times by the year 2000, which would mean a world production of 40-50 million tons annually.

SPORT AND SUBSISTENCE FISHERIES

The contribution of sport fishing and subsistence fishing to the worldwide production of food is not known. Subsistence fishing takes place throughout the world, whereas recreational angling is largely confined to the developed nations. Stroud (1970) stated that "The magnitude of fish harvests by angling from U.S. waters alone is conservatively estimated by the Sport Fishing Institute to be on the order of 1½ billion pounds of fish annually." He estimated that 60 million anglers fished at least 665 million recreational days during 1969 in the United States; his comparable figures for Canada were 1.8 million anglers fishing 24 million man-days. During January of 1966, 2.3 million Soviet sport fishermen were listed in societies and organizations. There were many more who were not members. In the U.S.S.R., sport fishing is free to all citizens. Unorganized fishermen in the U.S.S.R., in certain cases, are known to nullify the measures taken to protect and increase the stocks. Caspian Fisheries Research Institute scientists blame the stock depletion of Caspian roach, *Rutilus rutilus caspicus*, in the Volga-Caspian region on sport fishing. It seems evident that sport fishing is likely to become a major problem with which Soviet commercial fishermen will have to compete.

Although statistics are not available, we estimate that subsistence and sport fishing contribute an annual world total between 15 and 35 million MT of food.

Fisheries Management

Fisheries management includes all of man's activities that are related to maintenance and enhancement of fisheries resources and their utilization.

In 1973, a marine fisheries committee advisory to the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, stated:

> Good fisheries management is a continuing, experimental process that is concerned with the assessment, protection, and utilization of living aquatic resources in a manner that provides the greatest benefit to society. This involves developing basic policies and assessing the allocation and priorities among user groups. Furthermore, fisheries management includes: the application of results from researches in biologic, economic, legal, institutional, and social aspects of fisheries together with continuing monitoring and evaluation of effects of such applications, development of fisheries technology; improvement of statistical and educational programs; and the development and enforcement of regulations designed to protect and enhance living aquatic resources and to aid in their utilization.

More efficient management of offshore stocks may result in increased, or at least sustained, yield. The lack of effective national or international controls over harvest of most of the world's fisheries could bring about long-term declines in yield. Pressure from both the developing and the developed countries for expansion of fishing may lead to depletion of certain fisheries stocks. Hatchery production, enhanced water quality, and improved fishways have helped sustain the stocks of certain species, such as coho salmon, but the possibility of depletion remains.

Increases in world fisheries resources will require, as a minimum, intensified action in the following areas:

- Improved management at national and international levels to regulate the catch and ultimately to control the fishing effort of many stocks depleted or in danger of depletion.
- Expansion of the international education and training opportunities available to workers in fisheries management and research in the developing countries.
- Development of new food products from aquatic resources that are now unused or underutilized.
- Improved techniques for controlling water quality in lakes, streams, coastal marine waters, and other aquatic systems.
- Improvement in the efficiency of harvesting and processing aquatic animals.
- Extension of aquaculture to suitable fresh, brackish, and salt-water areas and species.
- Development of more effective, more economical, and safer methods of diagnosing and controlling fish diseases.
- Improved economic methods of assessing changes in environmental quality leading to sustained or increased production from the aquatic environment.

Aquatic Animal Health and Disease

EFFECTS OF DETERIORATED AQUATIC ENVIRONMENTS

Disease in wild and cultured populations of aquatic vertebrates and invertebrates may be caused by pathogenic microorganisms, the effects of toxic materials, or general environmental deterioration. Even subtle physical change in aquatic environments may result in stress leading to an impairment of animal health or deterioration of the quality of tissue for human consumption.

The addition of various man-made substances to aquatic ecosystems almost invariably results in deteriorated environments. These include such materials as domestic and industrial sewage; such agricultural residues as pesticides, fertilizers, and silt; petroleum products and mining residues; and such toxic materials as heavy metals, acids, and other industrial wastes. Pollutants, in general, may not be directly lethal to adult animals but may influence reproduction, affect larval or juvenile survival, alter normal patterns of adult or larval behavior, or so weaken the individual organism or populations of organisms that survival is greatly reduced.

In some cases the presence of a particular toxic substance may predispose an organism to invasion by pathogenic organisms, and thus a synergism may obtain between toxic pollutants and debilitating microorganisms or macroscopic parasites. Low-level radioactivity may also affect the health of aquatic organisms. Dubos (1955) said, "There are many situations in which the microbe is a constant and ubiquitous component of the environment but causes disease only when some weakening of the patient by another factor allows infection to proceed unrestrained . . .". More recently, Cockburn (1963) stated, "Infectious disease is composed of three variables, the host, the pathogen, and the environment. It is in a constant state of flux, capable of changing in step with any variation of any one of its components."

Disease in aquatic organisms has been reported by numerous authors and was the principal topic of several recent volumes (Amlacher, 1970; Sindermann, 1970; Snieszko, 1970; Mawdesley-Thomas, 1972). In the section of his paper dealing with diseases of marine fishes, Sindermann (1970) devoted five pages to genetic and environmentally induced abnormalities. The role of stress in the medical sense was explained by Selye (1950). Wedemeyer (1970) discussed the significance of stress for fish, but did not discuss pollutants as stress factors.

Pippy and Hare (1969) reported on a fish epidemic that may have been induced by stress resulting from heavy metal pollution in the Miramichi River, New Brunswick, Canada. Sprague and Ramsay (1965) and Sprague *et al.* (1968) investigated heavy metal poisonings in the same area. Halstead (1970) reviewed the numerous pollutants, including heavy metals, that are known to cause disease or otherwise stress marine organisms. Stress, in the widest sense of this word, is a very important factor in the health of aquatic animals. Therefore, in aquaculture the aim of management should be to reduce stress as much as possible so as to improve the health of cultured animals, to reduce loss of animals from diseases, and to avoid low productivity.

Numerous reports have been made in regard to microorganisms that thrive on organic enrichment and seriously affect aquatic organisms (Collins, 1970). For example, this situation can be brought about directly through the toxins produced, or indirectly by depressing the amount of dissolved oxygen available to aquatic life. Shotts *et al.* (1972) reported a widespread loss of wildlife in Lake Apopka, Florida, that resulted from infection by the bacterium *Aeromonas hydrophila*. The organism apparently thrived because of overabundance of nutrients entering the lake from municipal sewers, citrus farms and processing plants, and organic debris from water hyacinths. The widespread mortality of animal life contributed further to the organic load, thus aggravating the problem. In the New York Bight, fin rot disease has been prevalent in several species of finfish and is apparently caused by three genera of bacteria, *Aeromonas, Pseudomonas,* and *Vibrio* (Mahoney *et al.*, 1973). These bacteria appear to be associated with waters heavily polluted by domestic and industrial wastes; the epidemic has been found to be restricted to grossly polluted waters.

Pollutants in deteriorated environments may adversely affect behavior patterns and thus indirectly affect an aquatic population or predispose individual organisms to predation. Elson *et al.* (1972) discussed the deleterious effects of pollutants on salmon movements in a polluted estuary. Stirling (1970) conducted studies of the effects of copper and phenol, common industrial wastes, on burrowing activities of the bivalve *Tellina tenuis*. He observed that as little as 0.25 ppm of copper inhibited normal burrowing, thus predisposing this species to exposure and predation. Marine sediments in the New York Bight and other heavily industrialized coastal waters contain over 900 ppm of specific metals, including copper, chromium, lead, and zinc (Sandy Hook Laboratory, 1972). Some marine organisms have been reported to become adapted to estuarine sediments containing very high concentrations of heavy metals (Bryan and Hummerstone, 1971). Pearce (1969) found that sublethal increases in water temperature resulted in changes in behavior of the mussel *Mytilus edulis* that greatly increased the possibilities for predation. One of his co-workers (Iwantsch, 1970) also found that sublethal temperatures depressed reproduction in *Mytilus edulis*.

Mileikovsky (1970) reviewed the influence of pollution on pelagic larvae of bottom invertebrates in marine nearshore and estuarine waters. He concluded that pollutants in marine and estuarine waters constitute an important economic problem and that "specific research must be carried out into the problem of how floras and faunas of marine coastal and estuarine waters can survive under environmental conditions made progressively less suitable as a result of seawater pollution caused by human activities."

In reviewing the literature concerned with the effects of pollution or environmental deterioration on marine organisms, one is struck by the fact that in many cases the experimental species used are those that are most tolerant of stress conditions. The common mummichog *Fundulus heteroclitus* is a fish that normally lives in estuarine habitats having wide ranges of temperature, salinity, and general water quality. Although this species would be expected to have a higher tolerance to environmental stress, it is frequently used to assess the impact of a variety of pollutants. Investigators should, on the contrary, use more susceptible organisms in their evaluation of the effects of pollutants or stress factors. These would include adults of the more fragile species, the eggs and larvae of various adult organisms, and species that can be used in aquaculture.

The literature indicates that environmental deterioration is one of the major causes of the decline in standing crops and diversity of finfish and shellfish. In 1916, Nelson predicted the decline of oysters in Raritan Bay as a result of industrial discharges (Federal Water Pollution Control Administration, 1967). Only a decade or two later the shellfish economy of that bay disappeared. Bechtel and Copeland (1970) discussed the relationship of pollution to steady declines in species diversity.

Very subtle changes initiated by man may have adverse effects on environmental quality and, consequently, on aquatic animal health. For instance, Spence and Hynes (1971) found that small dams or impoundments located on freshwater streams resulted in significant changes in the bottom fauna. These changes were the consequences of increased downstream detritus as well as changes in the maximum and minimum water temperatures.

Changes in the physical environment result in immediate changes in species diversity and standing crops of prey organisms in the lower end of the food chain. These changes are reflected in the upper predator level. The conditions brought on by starvation and exposure to certain industrial pollutants are routinely recognized as diseases when they occur in human populations. There is reason to believe that comparable diseases, induced by deteriorated environments, are to be found among the lower organisms that make up the community structure of natural aquatic populations.

If man is to manage natural populations of aquatic organisms effectively in the face of continued human impingement on aquatic ecosystems, he must so modify his activities that stress effects on the ecosystem are reduced. Further, if mariculture is to become a viable endeavor in coastal waters, high-quality waters free from pollution must be maintained. Unfortunately, the net effect of mariculture may indeed be to contribute to pollution of freshwater, estuarine, or marine environments.

Pollution from dumping of wastes has closed 20 percent of the nation's shellfish beds (Ocean Dumping of Waste Material, 1971). Shellfish affected by pollution from these dumpings were found to contain hepatitis and polio viruses and other pathogens hazardous to human health.

Under laboratory conditions, lobsters and crabs exposed to the same pollutants as are poured daily into the New York Bight develop a fouling of their branchial chambers and gills. These test animals perished in 3-4 days. Warnings of high concentrations of a number of toxic elements in the polluted bight waters have been substantiated by a group of scientists from the Smithsonian Institution studying the area. If these elements enter, or have entered, the food chain, a serious hazard to public health may ensue (Ocean Dumping of Waste Material, 1971).

Perhaps of greater significance than the actual initiation of disease in aquatic organisms is the fact that many toxic materials or pollutants reduce the quality of fish and shellfish, rendering them unsuitable for human consumption. Almost a century ago biologists reported that shad and oysters taken from Newark Bay, New Jersey, tasted of kerosine, which affected their reputation and sale (Goode, 1887). The kerosine had its origin in refinery pipes laid along the bottom of Newark Bay before the turn of the century. More recently Blumer *et al.* (1970) reported on the effects of an oil spill off West Falmouth, Massachusetts. They noted that the oil affected surface waters and also spread rapidly along the bottom sediments, with effects that lasted for months. Shellfish were not only killed by the oils but a subsequent year class or crop were as heavily polluted as were those affected by the original spill. The authors stated: "Oysters *transplanted* to unpolluted water for as long as six months retained the oil without a change in composition or concentration."

Contamination of waters from which living resources are harvested, be they wild or cultured, is an international as well as a national problem. Coastal waters account for the vast majority of biological productivity in the world's seas (Ryther, 1969) yet these are the very areas subject to contamination and environmental deterioration. Since many nations and states harvest coastal resources in international seas, often far removed from the fishermen's own shores, the matter of environmental deterioration and concomitant disease and contamination of aquatic organisms may become a major international problem. Nations may eventually become concerned with the health and quality of finfish that are taken in international waters and that had habituated deteriorated coastal environments at some stage of their life history.

TRANSMISSION OF DISEASES FROM FISH AND SHELLFISH TO HUMANS AND DOMESTIC ANIMALS

There are serious diseases that are transmitted from fish and shellfish to humans and domestic animals. Detailed information on such diseases is presented in textbooks by Faust (1955), Borgstrom (1961, 1962), van der Hoeden (1964), and Sindermann (1970) and in a review article by Janssen (1970). These sources include information on sanitary aspects of fish food products and on toxins accumulated from water or food by certain species.

Infectious diseases of aquatic animals are caused by viruses, rickettsiae, bacteria, fungi, and parasitic protozoa and metazoa.

Relatively few viruses are so far known to be pathogenic to fish or to multiply in fish, and there is no evidence that any of these are pathogenic to higher vertebrates. Fish and shellfish exposed to unsanitary conditions can serve as mechanical transmitters of viruses that cause diseases in humans and domestic animals.

One species of parasitic fluke, *Nanophyetus salmincola,* is involved in fish diseases. The adult parasite inhabits the tissues of the intestinal tract of some mammals. When its eggs in host feces reach fresh water, they develop into the miracidium stage, which invades certain species of snails, wherein they change to cercariae. Eventually, the cercariae leave the snails and invade salmonid fish, wherein they change to metacercariae. When mammals eat infested fish, the life cycle of the parasite repeats itself. Sometimes the fluke becomes infected with *Neorickettsia helminthoeca*, which is not pathogenic to fish or fluke, but is pathogenic to some mammals–especially, coyotes, bears, and dogs. The disease is neorickettsiosis; it is sometimes called salmon-poisoning disease. Human cases of nanophyetiasis (a fluke infestation), but not of neorickettsiosis, have been reported (Philip, 1955; Wood and Yasutake, 1956; Farrell *et al.*, 1964; van der Hoeden, 1964).

Some species of bacteria are recognized as typical pathogens for cold-blooded vertebrates and invertebrates and are capable of causing diseases in mammals, including humans (Bullock and McLaughlin, 1970).

Bacteria belonging to the genus *Erysipelothrix* are inhabitants of moist soil. The most widely known disease caused by them is swine erysipelas. They can be found on meat and are saprophytic in sewage; they occur on the surface of many animals and are capable of growing in the mucous covering of fish. Therefore, skin infection caused by *Erysipelothrix* is an occupational disease of fish handlers (Borgstrom, 1962; van der Hoeden, 1964; Janssen, 1970).

Enteric bacteria such as *Salmonella* and *Shigella* do not cause diseases in fish or shellfish but can contaminate fish and survive, even multiply, on the bodies or in the intestines of fish. Consumption of uncooked infected animals may cause disease in man and domestic animals. Recent intensification of the culture of channel catfish (*Ictalurus punctatus*) in the southern United States combined with increased organic matter load of water, resulted in outbreaks of catfish mortalities caused by *Edwardsiella tarda* (Meyer and Bullock, 1973).

Some species of mycobacteria that are common pathogens of cold-blooded vertebrates may cause infection and disease in humans. The first observation of fish mycobacteriosis was made on carp (*Cyprinus carpio*) from a pond contaminated with dejecta from humans suffering from tuberculosis (Bataillon *et al.*, 1897). Inoculation of warm-blooded experimental animals with this mycobacterium did not produce an infection. More recent observations have shown that in certain cases people can be infected with mycobacteria from diseased aquarium fish. *Mycobacterium marinum* found in fish (Adams *et al.*, 1970) and *M. balnei* found in swimming pools (Clark and Shepard, 1963) are capable of causing infections in the extremities of mice, which are cooler than the main body.

Another bacterium that is a common pathogen of freshwater fish is *Aeromonas liquefaciens* (synonyms: *A. punctata* and *A. hydrophila*). This organism has been identified as a true human pathogen (Caselitz, 1966; von Gravenitz and Mensch, 1968)

The marine bacterium *Vibrio parahaemolyticus* was first described in Japan as a human pathogen. Raw seafood containing this bacterium is capable of causing acute and severe intestinal infections in people and is one of the most troublesome enteric pathogens in Japan (Janssen, 1970). Recently, it was discovered in marine environments in North America and Europe and was found to cause diseases of fish and shellfish (Janssen, 1970). Enteritis caused by *Vibrio parahaemolyticus* is common in countries where raw or inadequately cooked seafood is consumed.

Important parasitic diseases can be transmitted from fish and shellfish to humans. Protozoan zoonoses transmitted from aquatic animals are not known in higher terrestrial animals or in humans. Trematodes, on the other hand, do cause disease.

Clonorchiasis and opistorchiasis are common parasitic diseases of fish. Humans and domestic animals are infested with metacercariae of these trematodes as a result of eating raw flesh of infested fishes (Dogiel *et al.*, 1970; Sindermann, 1970).

Heterophyiasis is an intestinal disease of humans common in many countries where raw fish is consumed. About 10 species of the trematode family Heterophyidae are involved.

Paragonimiasis is a disease of lungs, brain, and visceral organs of man and carnivorous animals. It is caused by a trematode parasite, *Paragonimus westermani*, inhabiting crabs and shellfish.

Schistosomiasis is a widespread disease in tropical and subtropical regions. More than 100 million people are affected as a result of contact with water containing the larval form of the parasite. It is basically a human disease, but occurs also in domestic animals. It does not affect any of the economically significant aquatic mollusks serving as food. Therefore, its significance is limited. Cercarial dermatitis, or "swimmers itch," is in the same category. Courtenay and Robins (1973) believe that this parasite and its intermediate host could be transported and established in Florida.

The best known human cestodiasis of fish origin is caused by *Diphyllobothrium latum*, or "fish tapeworm." It has a complicated life cycle. After passing through copepods and fish, it may infect humans and dogs eating insufficiently cooked infested fish. It is common in areas where such fish are consumed. *Ligula intestinalis*, another fish tapeworm, often infests carnivorous mammals but is rare in humans (van der Hoeden, 1964).

Dracontiasis is an Asian disease of humans caused by a nematode, *Füllerbornius (Dracunculus) medinensis*. This nematode may infest humans who drink water containing infested copepods of the genus *Cyclops*.

Trichinellosis is unknown in cold-blooded vertebrates. Occasionally, aquatic animals, such as seals and whales, may contain *Trichinella* and serve as a source of the parasite for humans and domestic carnivorous mammals.

Anisakiasis is an acute allergic disease of humans, often requiring emergency gastrointestinal surgery if the patient's life is to be saved. Its occurrence has increased since 1955, when gutting of iced herring replaced gutting at sea. Danger of human infestation can be eliminated by cooking, deep freezing, and salting (van der Hoeden, 1964; Sindermann, 1970).

In addition to the above-listed pathogens or parasites that may be transmitted to humans or domestic animals, there are other ways in which aquatic animals can be harmful. There are, in marine and estuarine environments, dinoflagellates belonging to the genera *Gymnodynium*, *Gonyaulux*, and *Prymnesium* that may accumulate in shellfish or be present in large quantities in coastal areas. Shellfish, water, and even spray containing these dinoflagellates are highly toxic to fish, terrestrial animals, and humans (Rounsefel and Nelson, 1966; Sarig, 1971). Many tropical marine fish contain in their flesh specific toxins that are harmful to people eating such fish. Still other species contain glands with powerful toxins capable of killing people within minutes after they are stepped on (Russell, 1971). Cases of human beings fatally poisoned by eating flesh of fish that are capable of accumulating mercury and cadmium from water polluted by industrial waste have been described (Kotsuna, 1966).

SIGNIFICANCE OF DISEASES AMONG INTENSIVELY RAISED AND WILD FISH AND SHELLFISH

The cost of disease prevention and control of fish culture operations is difficult to assess. The main reason for the lack of cost data is the virtual absence of mortality records in all fish-raising industries. Araji (1972) canvassed the majority of the commercial trout growers in the State of Idaho and estimated that the 15 percent annual post-hatching mortality reduced the production potential of the industry in Idaho by more than 1.5 million pounds in 1970. G. W. Klontz (1973, unpublished) has estimated that disease reduced the 1972 commercial rainbow trout production potential in Idaho by 3.2 million lb. These figures amount to an estimated 7.5 cents/lb produced, or $750,000 in 1970 and $1.35 million in 1972. This represents 25 percent of the production costs.

Comparable figures for the channel catfish industry in the United States range from 10 to 25 percent of the production costs (Brown *et al.*, 1969; Davis and Hughes, 1970; Foster and Waldrop, 1972). The national channel catfish processed production during January through November 1972 was 10,245,896 lb (Rasor, 1972). At an average production cost of 25 cents/lb (Bureau of Sport Fisheries and Wildlife, 1970; Davis and Hughes, 1970) the cost of disease control and prevention is estimated between $256,000 and $640,000 annually.

The Subcommittee has no knowledge of mortality or disease cost data for the pond fish industry or for the marine fish and shellfish industry.

The Division of Fish Hatcheries, U.S. Bureau of Sport Fisheries and Wildlife, estimates their cost of disease control and prevention at 10–15 percent of the total production costs or $1–2 million (H. N. Larsen, personal communication). Fisheries administrators in several state conservation agencies contacted by the Subcommittee estimate their disease prevention and control costs to be 20-30 percent of production costs.

The best estimate of total fish production costs in the United States that the Subcommittee can derive, based on available information, is between $30 million and $35 million. Assuming that 20 percent of this amount is spent for disease control and prevention, the total being spent annually for labor, chemotherapeutic agents, and loss-of-production potential is between $6 million and $7 million.

SPECIFIC DISEASES

Epidemiologically, diseases of fish and shellfish may be classified as either noninfectious or infectious. The former are caused by chemical and physical agents; the latter by biologic agents.

The primary noninfectious diseases of fish and shellfish originate from alterations of the aquatic environment. The nitrogenous excretions of fish give rise to pathological changes in the respiratory system at concentration above 1 ppm in most freshwater systems. Other environmental alterations having an adverse effect on fish husbandry are due to agricultural contaminants (pesticides, herbicides, and fertilizers), industrial contaminants (heavy metals, thermally enriched discharges, various organic chemicals, various inorganic chemicals), and poor management practices (overcrowding, under- and overfeeding, inadequate records, unsanitary conditions). Unfortunately, the noninfectious diseases of fish and shellfish have been considered of low priority until the past few years. The recent upsurge in environmental awareness has alerted specialists to investigate the often designated "natural mortalities" among both fish and shellfish.

The infectious diseases of fish and shellfish result from bacteria, viruses, fungi, protozoa, and metazoa. Fish-to-fish transmission follows the initial exacerbation, the resultant course lasting a few days to several months, depending on the nature of the pathogen.

Ten of the 17 recognized bacterial diseases of freshwater and marine fish in the United States are considered extremely serious and occur regularly in epidemic proportions. The remaining seven are sporadic in nature and are seldom diagnosed; but knowledge of their existence and loss of production potential is essential. A brief description of each disease follows:

1. Fin rot (fin erosion) is a progressive erosion and disintegration of the fins of hatchery-raised fish. Several species of bacteria have been isolated during outbreaks; but the main contributory causes are thought to be crowding and nutritional imbalances, especially of vitamins. Treatment and control are effected by external antibacterials, sanitation, and management.
2. Bacterial hemorrhagic septicemia is an acute to subacute systemic bacterial disease caused by *Aeromonas liquefaciens.* All species and ages of fish are susceptible and losses are usually significant. It is traditionally a springtime disease and can be effectively controlled by certain systemic antibacterials.
3. Furunculosis is a peracute to chronic systemic bacterial disease caused by *Aeromonas salmonicida.* All species and ages of fish are susceptible, the majority of outbreaks occurring in young-of-the-year fish. Although direct transmission in salt water has not been adequately proven, marine fish have become infected with the organism and subsequently died of the disease from eating clinically ill salmon smolts following seaward migration. The disease can occur at any time, is sometimes stress-mediated, and can be effectively controlled by certain systemic antibacterials.
4. Pseudomonad septicemia is an acute to subacute systemic bacterial disease caused by members of the genus *Pseudomonas.* All species and ages of fish are susceptible during any season of the year. Springtime and stress-mediated outbreaks are frequent, and losses are usually significant. Outbreaks may be effectively controlled by certain systemic antibacterials.
5. Vibriosis is an acute systemic bacterial disease caused by *Vibrio anguillarum.* The disease occurs most frequently in marine fish, but it has become established in certain freshwater fish populations. Losses are especially catastrophic during the spring in juvenile anadromous and marine fish-raising operations. The disease may be effectively controlled by certain systemic antibacterials.
6. Bacterial kidney disease is a normally chronic, but sometimes acute, systemic bacterial disease of salmonids caused by a species of *Corynebacterium.* The disease is widespread and epi-

demics occur usually in the fall when the water temperatures are declining or in the early spring on rising water temperatures. This disease is not effectively controlled by systemic antibacterials.

7. Columnaris disease is an acute systemic and cutaneous disease of freshwater fish caused by *Chondrococcus columnaris*. The disease is widespread and occurs most frequently during the summer in young-of-the-year fish. Losses are usually high. There is frequently a dual infection with *Aeromonas liquefaciens* in warm water fish. The disease may be effectively controlled by certain systemic and external antibacterials.
8. Bacterial gill disease is a peracute respiratory disease of juvenile hatchery-raised fish (primarily salmonids and ictalurids). A complexity of environmental, physiological and bacterial factors are involved in causing an outbreak. The disease occurs most frequently in the springtime when the fish are actively growing and are crowded in water that is low in dissolved oxygen and high in ammonia. The bacteria involved are, for the most part, unspecified myxobacteria and pseudomonads. *Chondrococcus columnaris* has been implicated on several occasions. The disease may be effectively controlled by reducing the population density and administering external antibacterials.
9. Cold water disease (peduncle disease) is a chronic external and systemic bacterial disease of juvenile salmonids caused by *Cytophaga psychrophila.* The disease occurs during the low-water-temperature months. Outbreaks with catastrophic losses have been reported in yolk sac fry. The disease may be controlled by certain external and systemic antibacterials.
10. Saltwater myxobacteriosis is an acute external bacterial disease of juvenile anadromous salmonids in salt water and is caused by members of the genus *Sporocytophaga*. It is sporadic during the early summer. It may be effectively controlled by certain external antibacterials.
11. Pasteurellosis is an acute systemic bacterial disease of marine fish caused by *Pasteurella piscicida*. Severe sporadic outbreaks have occurred in the Chesapeake Bay. It has not been diagnosed in fish culture systems.
12. Ulcer disease is a subacute to chronic systemic bacterial disease of salmonids caused by *Hemophilus piscium*. Until the advent of chemotherapy, outbreaks occurred frequently in trout hatcheries in the eastern United States. Outbreaks are seldom recorded

in recent years. The disease may be effectively controlled by certain systemic antibacterials.

13. Streptococcal septicemia is an acute systemic bacterial disease of warm water fish caused by a species of *Streptococcus.* Only a few outbreaks of this disease have been recorded.
14. Flavobacteriosis is an acute to chronic systemic bacterial disease of freshwater and marine fish caused by several members of the genus *Flavobacterium.* It occurs sporadically and treatment is symptomatic.
15. Mycobacteriosis is a chronic systemic bacterial disease of all fish and is caused by *Mycobacterium fortuitum.* Although it was frequently diagnosed in Pacific salmon, the disease is now rarely seen because untreated frozen fish are no longer used in the diet of young salmonids. The disease occurs sporadically in nature and in aquarium fish. There is no known effective treatment.
16. Streptomycosis is a chronic systemic bacterial disease of salmonids and certain other freshwater fish caused by members of the genus *Streptomyces.* It has been diagnosed rarely, and there is no known effective treatment.
17. Nocardiosis is a chronic systemic bacterial disease of all fish caused by *Nocardia asteroides.* It occurs very rarely, and there is no known effective treatment.

Five virus diseases of fish occur in epidemic proportions in hatchery-reared fish. Each constitutes a serious threat to fish culture operations. There is evidence that each disease can occur in wild populations of fish. However, catastrophic losses have not been reported. A brief description of each disease follows:

1. Infectious pancreatic necrosis is a peracute to acute virus disease of juvenile salmonids (particularly, trouts and chars). It is widespread and considered to be egg-transmitted. Losses are generally high in fish less than 2-in. long. The recommended control methods include chemical disinfection of eggs, elimination of carrier females, and depopulation of affected stock.
2. Infectious hematopoietic necrosis is an acute virus disease of juvenile salmonids. This disease has previously been recorded as Oregon sockeye disease, Sacramento River chinook disease, Columbia River sockeye disease, and Leavenworth sockeye disease. The primary fish species affected are chinook salmon, rainbow trout, and sockeye salmon. The disease is endemic in the western United

States, with sporadic outbreaks occurring in other parts of the United States. The virus is considered to be egg-transmitted. Losses are high in less than 2-in. fish in water temperatures below 56°F. Recommended control methods include chemical disinfection of eggs, elimination of carrier females, and depopulation of affected stocks.

3. Viral hemorrhagic septicemia is an acute to chronic virus disease of salmonids, particularly rainbow trout. It occurs in fish of all ages with unpredictable losses. This disease has not been diagnosed in the United States. The major endemic areas are Denmark, France, and Italy. All salmonids—dead or alive—entering the United States must be certified to be free of this virus. Recommended control methods include chemical disinfection of eggs, elimination of carrier females, and depopulation of affected stocks.
4. Catfish virus disease is an acute viral disease of juvenile channel catfish. Recently, a similar disease of blue catfish was detected. Losses in channel catfish fingerlings have been high. A typical outbreak may last for several weeks and be complicated by dual infections with *Aeromonas liquefaciens* and *Chondrococcus columnaris*. Recommended control measures include buying fingerlings from sources free of the disease, maintenance of high dissolved-oxygen levels, and rigid sanitation practices.
5. Lymphocystis is a chronic viral disease of freshwater and marine fish. It seldom causes losses among wild or cultured fishes. Its main effect is to make a potential food fish aesthetically unappealing. There are no known effective control methods.

Comprehensive textbooks on fish diseases describe five mycotic diseases of fish and shellfish. All have been the cause of, or significantly contributed to, serious epidemics in cultured and wild fish and shellfish. A brief description of each follows:

1. Ichthyophonosis is a chronic systemic mycotic disease of freshwater and marine fish caused by *Ichthyophonus hoferi.* All ages and species of fish are affected. There is no treatment. The spread has been controlled by feeding cultured fish only inspected and processed marine fish. Rigid sanitation and disposal methods also have decreased the prevalence of this disease.
2. Branchiomycosis (European gill rot) is a subacute to chronic respiratory mycotic disease of all fishes caused by *Branchiomyces*

sanguinis. Until recently, the disease was thought to occur only in Europe. Several epidemics have been diagnosed in channel catfish in Arkansas. There is no known treatment. The spread can be controlled by strict sanitation and management practices.

3. Dermocystidiosis is an acute to chronic respiratory fungal disease of fish and shellfish caused by members of the genus *Democystidium*. The disease occurs sporadically, and there is no known treatment. The spread has been partially controlled by rigid sanitation and management practices.
4. Saprolegniosis and achylosis are two acute cutaneous mycotic diseases of all fish and fish eggs. The disease generally arises secondarily to pre-existing bacterial infections, nutritional deficiencies, or traumatic wounds. Effective treatment and control methods include external disinfectants and strict sanitation practices.

There are several hundred genera of parasitic protozoa and metazoa that utilize fish and shellfish as intermediate or definitive hosts (see Hoffman, 1967). Fewer than 100 genera have been described as causing primary or secondary disease problems in fish and shellfish. Those protozoa and metazoa causing epidemics in fish and shellfish have been categorized by the portion of the host affected (i.e., gills, body surface, and viscera) (Table 2). The gill parasites and body surface parasites may be effectively controlled by external chemotherapeutics and rigid sanitation practices. The internal parasites may be controlled by disrupting the life cycle. Chemotherapeutics may also be effective in some cases.

Many of the foregoing descriptions of infectious diseases of fish and shellfish pertain to aquaculture systems. These diseases may occur in wild fish and shellfish but with far less devastating effects due to the lack of physical contact between animals.

METHODS OF CONTROLLING DISEASE IN FISH

Seven primary methods are used to control diseases of aquatic animals. Each has varying degrees of use and success, depending on the nature of the disease. These methods are drug therapy, quarantine and restriction of movement, sanitation and disinfection, test and slaughter, destruction or control of a link in the transmission cycle, limitation or control of toxic substance release, and reduction of hazards. Immunization—an eighth method used successfully for control of contagious

TABLE 2 Parasites of Fish and Shellfish

Gill Parasites	External Parasites	Internal Parasites
Protozoa	Protozoa	Protozoa
Trichodina	*Trichodina*	*Schizamoeba*
Chilodon	*Epistylis*	*Bodomonas*
Scyphidia	*Chilodon*	*Eimeria*
Epistylis	*Scyphidia*	*Cryptobia*
Amphileptus	*Costia*	*Trypanosoma*
Trichophrya	*Ichthyophthirius*	*Hexamita*
Oodinium	Trematoda	*Haemogregarina*
Glossatella		*Myxosoma*
Bodomonas	*Gyrodactylus*	*Ceratomyxa*
Tripartiella	*Discocotyle*	*Chloromyxum*
Costia		*Unicapsula*
		Myxidium
Trematoda	Copepoda	*Myxobolus*
		Wardia
Dactylogyrus	*Lernaea*	*Henneguya*
Monocoelium	*Argulus*	*Nosema*
Diplozoon	Nematoda	*Glugea*
Cleidodiscus		*Plistophora*
Urocleidus	*Philometra*	*Dermocystidium*
Clavunculus		*Glaucoma*
Mazocraes		*Vauchomia*
Nanophyetus		*Sarcocystis*
Copepoda		Trematoda
Ergasilus		*Sanguinicola*
Lernaea		*Diplostomum*
Achtheres		*Neascus*
		Clinostomum
		Nanophyetus
		Crepidostomum
		Uvulifer
		Cryptocotyle
		Bucephalus
		Centrovarium
		Phyllodistomum
		Cestoda
		Microphallus
		Corallobothrium
		Proteocephalus
		Triaenophorus
		Eubothrium
		Ligula
		Diphyllobothrium
		Bothriocephalus

TABLE 2 (continued)

Gill Parasites	External Parasites	Internal Parasites
		Nematoda
		Contracaecum
		Anisakis
		Philonema
		Philometra
		Capillaria
		Bulbodacnitis
		Cystidicola
		Metabronema
		Dioctophyme
		Eustrongylides
		Acanthocephala
		Neoechinorhynchus
		Echinorhynchus
		Acanthocephalus
		Tanaorhamphus
		Pomphorhynchus

diseases in humans, poultry, livestock, and domestic pets–has not been a practical method of controlling infectious diseases of fish. Oral immunization, now being investigated, seems to have promise.

Drug Therapy

There are three ways of administering therapeutic compounds to fish: the addition of therapeutic agents to the water, addition to the food, and parenteral injection. The chief limitation is that up to 1973 only four chemotherapeutic or antibiotic agents had been cleared by the Food and Drug Administration for use with fish. Restrictions on the use of many other therapeutic compounds point up the need for use clearance. The Division of Fishery Research and the Division of Fish Hatcheries of the Bureau of Sport Fisheries and Wildlife might well coordinate the research requirements necessary for use clearance of other potentially effective drugs. Use clearance of proprietary drug products has been impeded because of the expense of use-clearance procedures and the limited market potential.

Quarantine and Restriction of Movement

Quarantine and restriction of movement has proved to be one of the most successful methods for controlling various infectious diseases. Pathogens can be contained by careful detection of the pathogens and restriction of their movement. Disease prevention is far better than therapy. Several legislative proposals are or have been considered as means to enhance the effectiveness of this approach.

Sanitation and Disinfection

The use of sanitizing agents to eliminate infectious organisms from the aquatic animal and its environment is useful. Many satisfactory sanitizing agents are available. Combining sanitation and disinfection with quarantine and restriction of movement offers the greatest hope for control of infectious diseases among fish populations.

Test and Slaughter

Testing for presence of a pathogen within or on the fish, followed by slaughter and deep burial or burning of the carcasses, is used in specific instances of disease. This method of control is used when no therapeutic drugs are known and whenever there is grave danger of spreading the infective agent into susceptible fish populations. It is the least desirable method, but often the most successful. It is the one procedure that can be used to control infectious disease in certain wild stocks.

Destruction or Control of a Link in the Transmission Cycle

Transmission of disease involves movement of the pathogenic agent from host to host or from the environment to the host. The transmission cycle usually includes one or more steps. Many times, intermediate or transfer hosts are involved. Control of the intermediate or transfer host in turn controls or reduces the disease in the primary host. This approach has been found useful, in certain instances, for the control of both infectious and noninfectious diseases of aquatic animals.

Control of Toxic Substance Release

Contamination of water resources will alter or contaminate aquatic animals living within the polluted water. Toxic diseases are becoming a greater threat to existence of some aquatic animal species than are infectious and contagious diseases. Concerted efforts are being made in many parts of the world to reduce or control the release of toxic substances into bodies of water containing populations of aquatic organisms. When used diligently, this method of disease control has generally met with success.

Reduction of Hazards

All living organisms are subject to trauma or physical injury. Natural hazards and man's alteration of the water environments have increased obstacles and physical hazards to aquatic animals. Water flowing through turbines, water falling into plunge pools from high dams, heat released from industry into estuaries, and many similar hazards are increasing. Design engineers have tried in the past to reduce these hazards, but more concerted efforts are needed.

Laws and Regulations for Control of Fish Diseases

Various laws and regulations restrict interstate shipment of diseased aquatic animals at the state level. In many states, regulations require that fish with gross lesions or macroscopically visible parasites be withheld from sale for human consumption; this is done, however, mostly for aesthetic reasons. Thus far, only California and Michigan have effectively enforced these laws. The operation of the California law was described by Wolf (1970). On one occasion, Michigan took legal action against a trout hatchery affected by whirling disease, caused by *Myxosoma cerebralis*, as a result of which the hatchery was closed and disinfected.

Other states have fish disease laws and regulations, but they are seldom enforced (Herman, 1970).

Periodic reports of fish disease committees of the American Fisheries Society, since 1955, have advocated legislation for control of diseases of fish and shellfish at the international, national, and interstate levels (American Fisheries Society, 1955, 1957a,b, 1966a,b, 1967, 1968, 1969, 1970, 1971).

As a result of excellent cooperation between the American Fisheries Society, the Fish and Wildlife Service of the U.S. Department of the Interior, the state conservation agencies, and the government of Canada, several actions were taken to improve the state of fish health in the United States and Canada (Canadian Committee on Fish Disease, 1972). A significant achievement was the modification of Title 50–Wildlife and Fisheries (Bureau of Sport Fisheries and Wildlife, 1968). Under this law, as modified again by the Bureau of Sport Fisheries and Wildlife (1970), all fish and all fish products must be certified free of whirling disease and viral hemorrhagic septicemia prior to interstate shipment. A similar law was enacted in Canada (Fisheries Act, 1969).

The Fish and Wildlife Service established several fish disease diagnostic service laboratories between 1963 and 1966 and plans to establish a fish disease reporting and information center.

The spread of fish diseases as a result of stocking diseased hatchery fish and contamination of water supplies by effluent from fish hatcheries and fish farms is of considerable concern. The Bureau of Sport Fisheries and Wildlife has been the most active agency in efforts to solve these problems. The Salmon Cultural Laboratory, Bureau of Sport Fisheries and Wildlife, at Longview, Washington, was the first to develop procedures for recycling, filtration, and disinfection of the water supply (Burrows and Combs, 1968). More recently, in Nevada, the entire stock of valuable Lahontan strain of cutthroat trout was destroyed, whereupon the hatchery was closed for 2 years, all water supplies were disinfected and are now carefully checked in order to eliminate whirling disease in Nevada. This was done at a cost of over $1 million.

Another action in official recognition of the importance of fish diseases was the "Determination of Whirling Disease as a Resource Disaster" by the Secretary of the Interior in 1969 (Federal Register, 1969).

In the United States, responsibility for control of fish and shellfish is divided between the states and several federal agencies. The Department of the Interior, through its Bureau of Sport Fisheries and Wildlife, is responsible for research on freshwater and anadromous fisheries and for construction and operation of fish hatcheries. The Department of Commerce through its National Marine Fisheries Service is primarily responsible for administration of federal programs dealing with marine fisheries, shellfisheries, and inland commercial fisheries, and for related research. Fish farmers of the southern states look to the Department of Agriculture for assistance in commercial fish culture, which is essentially a farming operation. The Department of the Interior in recent years has had the major facilities and research experience necessary for control of fish diseases (Workshop on Inspection and Certification of Fish Diseases, 1970). A cooperative program between federal and state government agencies would be mot beneficial and would attract widespread support.

The subject of international regulation of fish diseases has been reviewed by Thompson (1972) for the European Inland Fisheries Advisory Council of Food and Agriculture Organization, United Nations. This review "gives details of a survey of legislative and administrative measures enforced in 48 countries to ensure the sanitary control of traffic in live fish and fish eggs."

Another international organization interested in control of diseases of aquatic animals, fish in particular, is the International Office of Epizootics (IOE). IOE organized three symposia, held in 1963, 1966, 1968. Another symposium organized by FAO and IOE was held in Amsterdam in April 1972. The Amsterdam conference was concerned with the control of diseases. The following diseases were discussed and general recommendations for control made: viral hemorrhagic septicemia, infectious pancreatic necrosis, ulcerative dermal necrosis, furunculosis, whirling disease, and infectious dropsy.

In Europe, state veterinarians are responsible for sanitary inspection of all food products of animal origin (Ghittino and Vittoz, 1963).

Considerable concern has been created during recent years by indiscriminate worldwide shipment of aquarium fish and other similar fish and the threat of introduction of undesirable species and exotic fish diseases into native waters (Hoffman, 1970; Lachner *et al.*, 1970). This concern has led to administrative regulations and requests for additional legislative action to deal with these problems.

Manpower and Facilities

Aquatic animal disease specialists address their professional capabilities to the prevention and control of infectious and noninfectious diseases of fish and shellfish. The total number of persons engaged in some aspect of fish health management is unknown because of the diversity of the fisheries industries and the wide variation in degree to which personnel are involved. There are many who devote only a small portion of their total effort to work with fish diseases.

The American Fisheries Society Fish Disease Committee has estimated that there are nearly 100 full-time fish disease specialists in the United States. This figure includes those occupied with diagnosis, research, or teaching. The rate of attrition among these individuals is uncertain. If the rate is comparable with other professions, a figure of 5 percent annually is realistic. If the profession grows at an annual rate of 10 percent and the 5 percent attrition rate is accepted as valid, 15 new positions should open up annually, a figure that teaching institutions might well consider.

The majority of fish health specialist positions today are filled by individuals who received no formal training in fish diseases during their academic career. Practical experience, participation in professional meetings, and continuing education courses have been the source of their training.

Colorado State University is the only university in the United States as of 1973 that offers a Fish Disease option to undergraduates in fisheries science and microbiology. There are other universities that offer a single undergraduate lecture-laboratory course in fish diseases. Other universities and colleges have graduate-level programs that pertain in part to fish health (Martin, 1969).

Training people for the fish health specialties requires that appropriate courses be available at both vocational and academic institutions. The extent of the education required by a given individual will limit the degree of specialization possible. The highest degree of specialization is likely to be obtained at academic institutions having curricula in both veterinary medicine and fisheries sciences. Many of the courses at veterinary medical schools provide the required background for the study of fish and shellfish diseases. A fisheries curriculum, on campus, affords the student an opportunity to apply knowledge acquired in courses in human biology or domestic animal sciences to similar problems in fish.

There is a very limited number of universities in the United States that have both a veterinary medical school and a school (or department) of fisheries. This restricts the potential for producing highly trained graduate fish health specialists. However, an adequate undergraduate background in the life sciences can be supplemented by advanced degrees at institutions offering a fisheries major. Most of the present fish disease specialists were stimulated to work with fish at institutions having general fisheries courses, as well as special courses on disease processes and etiological agents.

The number of new graduates with baccalaureate degrees in fish health-related sciences is unknown. However, the present number is inadequate, if judged by the fact that virtually the same degree of annual mortality in propagated fish and shellfish persists. Fish hatchery managers, aquarium enthusiasts, fish culturists, and fisheries management biologists have not been properly informed of the magnitude of the annual mortality rate in fish and shellfish under their control. It has been estimated that between 20 and 40 percent of cultured fish do not survive to market size. By contrast, the U.S. poultry industry has recorded a more than 75 percent reduction in annual loss of animals to diseases over the past decade (C. F. Hall, personal communication). This low poultry mortality is the result of training poultry disease specialists and of offering continuing education on poultry management procedures. Fish health managers would do well to look at the success of disease prevention, control, research, and training in the poultry industry as a guideline to approaching problems in the fisheries industry. Training fish health specialists and continuing education in the form of short courses, seminars, and workshops for these specialists as well as for managers of the fisheries industry should become a necessary part of fish health management.

Training fish disease specialists must be initiated by those who are working with fish diseases at present and are thus aware of the problems involved. Development of a fish health specialty must be supported by administrators in federal, state, and private agencies who are charged with production or procurement of fishes or shellfishes for both recreational and food needs. They must be made aware of the contributions fish health specialists can make to their operations. Filling of such positions with competent people will provide the impetus for more universities, colleges, and vocational training schools to set up curricula that will train qualified fish health specialists. There is also a potential for private enterprise in fish disease prevention, diagnosis, and control. Some of the efforts to produce fish disease specialists should be expended toward demonstrating the needs for fish disease specialists in private practice to both the student and to the fisheries industry.

There is a need to certify the abilities of fish health specialists. The creation of a national registry of fish health specialists, as suggested by the Fish Health Section of the American Fisheries Society, would provide professional status for these individuals.

Fish health diagnostic and research facilities are now sponsored by federal and state fish and game agencies, associated with universities, and operated by commercial fish farms and by commercial laboratories. The Bureau of Sport Fisheries and Wildlife has nine fish disease research and diagnostic laboratories strategically located to assist the Division of Fish Hatcheries with a given species of fish within the general administrative and geographical region. Federal assistance to state agencies and private fish producers is being curtailed more each year. Diagnosis of disease in the federal fish cultural system requires more and more use of these facilities, whereas funding of these laboratories has remained static or has been reduced during the past few years.

There are 20 state conservation agencies with fish disease diagnostic and research capabilities at the time of this writing. In most states, one or two individuals are expected to give diagnostic services to an entire state fish cultural system and to the commercial fish and shellfish industries within the state. Many state agencies rely wholly or in part on federal fish disease diagnostic laboratories and personnel.

State and federal fisheries agencies are not set up administratively to cope with the many problems of private fish producers. University agricultural extension service administrative functions should be capable of handling fish health problems. Yet only six state universities have this service as a part of their agriculture extension service activities as of 1973.

The practicing veterinarian has certain laboratory facilities available for diagnosis of diseases of fish and shellfish. Addition of special facilities to which he might refer would enhance the veterinarian's service capabilities. Fish health specialists in private practice would also supply much needed facilities. One answer to the laboratory facility needs of a practicing veterinarian or a practicing fish health diagnostics specialist would be commercially operated area laboratories with capabilities for fish disease diagnostic procedures. There are no such commercially operated laboratories in the United States as of 1973.

Summary and Recommendations

The need for increased food and feed derived from the aquatic environment is an issue that should be faced squarely. The fish and shellfish resources of marine and fresh waters are limited. The most important man-made stresses limiting these resources are environmental degradation and overexploitation. Diseases and kills in aquatic animals, as a consequence of these imbalances, impose still further losses.

Concern about diseases of aquatic species is important not only as they contribute to depletion or extinction of species but also as a hazard to the health and nutritional well-being of man. We are aware of no clearly defined institutional mechanism whereby focus can be placed on programs in aquatic animal health, other than for marine mammals. We have identified the relationships between environmental quality and aquatic animal health that are central to the issue of continued supplies of aquatic animals for use by man. We recommend that:

1. Steps be taken to minimize deleterious alterations of the environment, particularly those alterations having an undesirable effect on the health of aquatic animals.
2. Research on health of aquatic animals consider not only existing problems and disease but anticipate future problems, particularly diseases that result from changing or deteriorating environments. Existing programs concerned with basic and applied research must be augmented

with personnel, funds, and facilities. A favorable climate for such research must be fostered and proper communication maintained if redundancy is to be avoided and available research funds wisely spent.

3. Coordination of state and federal regulations for movement and transfer of animals as they relate to control of disease be established and maintained.

4. Greater effort be devoted to securing international agreements for effective disease control.

5. A program be developed for interaction of appropriate committees of the National Academy of Sciences that relate to the aquatic environment. Special attention should be given to proper communication of problems and to continual re-evaluation of priorities. The NAS should maintain a continuing interest in health of fish and shellfish through committees involving environmental scientists, resources scientists, fish disease specialists, and animal health scientists.

6. Adequate education and training programs be established to produce personnel competent to prevent, diagnose, control, and conduct research on diseases of aquatic animals.

7. Grants-in-aid be provided by state, federal, and private agencies to assist the training of qualified people and for construction of training and research facilities.

8. A technical manual be developed to provide uniform and effective nomenclature and procedures for identification and diagnosis of diseases of aquatic animals.

9. A national fish and shellfish disease recording and reporting center be established, augmented by private and public diagnostic services.

10. An advisory council be formed within the federal government to delineate needs and priorities and to see that appropriate programs are implemented.

References

Adams, R. M., J. S. Remington; J. Steinberg, and J. Seibert. 1970. Tropical fish aquariums: A source of *Mycobacterium marinum* infections resembling sporotrichosis. J. Am. Med. Assoc. 211:457-461.

American Fisheries Society. 1955. Report of the Committee on the Importation of Fish and Fish Eggs. Trans. Am. Fish. Soc. 84:376-377.

American Fisheries Society. 1957a. Report of the Committee on Importation of Salmonid Eggs and Ports of Entry. Trans. Am. Fish. Soc. 85:308-309.

American Fisheries Society. 1957b. Report of the Committee on Importation of Fish and Fish Eggs. Trans. Am. Fish. Soc. 85:309-312.

American Fisheries Society. 1966a. Report of the Committee on Trout Diseases. Trans. Am. Fish. Soc. 95:129-130.

American Fisheries Society. 1966b. Resolutions of the Committee on Trout Diseases. Trans. Am. Fish. Soc. 95:140-141.

American Fisheries Society. 1967. Report of the Committee on Fish Diseases. Trans. Am. Fish. Soc. 96:91.

American Fisheries Society. 1968. Report of the Committee on Fish Diseases. Trans. Am. Fish. Soc. 97:104-105.

American Fisheries Society. 1969. Report of the Fish Disease Committee. Trans. Am. Fish. Soc. 98:183-185.

American Fisheries Society. 1970. Report of the Fish Disease Committee. Trans. Am. Fish. Soc. 99:282-283.

American Fisheries Society. 1971. Report of the Fish Disease Committee. Trans. Am. Fish. Soc. 100:185-187.

Amlacher, E. 1970. Textbook of fish diseases. (Translated by D. A. Conroy and R. L. Herman.) T. F. H. Publications, Neptune City, N.J. 302 p.

Araji, A. A. 1972. An economic analysis of the Idaho rainbow trout industry. AE Series 118, University of Idaho, College of Agriculture and College of Forestry, Wildlife and Range Sciences Experiment Stations, Mosco.

Bardach, J. E., and J. A. Ryther. 1968. The status and potential of aquaculture. Vol. 1, pt. 1. American Institute of Biological Sciences, Washington, D.C.

Bardach, J. E., J. H. Ryther, and O. McLarney. 1972. Aquaculture. Wiley-Interscience, New York. 868 p.

Bataillon, E., R. Dubard, and L. Terre. 1897. Un nouveau type de tuberculose. C.R. Soc. Biol. 49:446–449.

Bechtel, T. J., and B. J. Copeland. 1970. Effects of pollution on fish species diversity in Galveston Bay, Texas. *In* Proceedings, FAO technical conference on marine pollution, Rome, December 1970.

Blumer, M., J. Sass, G. Souza, H. Sanders, F. Grassle, and G. Hampson. 1970. The West Falmouth oil spill: Persistence of the pollution eight months after the accident. Woods Hole Oceanogr. Inst. Tech. Rep. Ref. No. 70–44. 32 p.

Borgstrom, G. [ed.]. 1961. Fish as food, Vol. 1. Academic Press, New York and London. 745 p.

Borgstrom, G. [ed.]. 1962. Fish as food, Vol. 2. Academic Press, New York and London. 777 p.

Brown, E. E., M. G. LaPlante, and L. H. Covey. 1969. A synopsis of catfish farming. Bull. 69, Univ. Ga. College Agric. Exp. Stn.

Bryan, G. W., and L. G. Hummerstone. 1971. Adaptation of the polychaete *Nereis diversicolor* to estuarine sediments containing high concentrations of heavy metals. I. General observations and adaptations to copper. J. Mar. Biol. Assoc. U.K. 51:865–890.

Bullock, G. L., and J. J. A. McLaughlin. 1970. Advances in knowledge concerning bacteria pathogenic to fishes, p. 231–242. *In* S. F. Snieszko [ed.] A symposium on disease of fishes and shellfishes. Spec. Publ. No. 5. American Fisheries Society, Washington, D.C.

Bureau of Sport Fisheries and Wildlife. 1968. Title 50–Wildlife and fisheries. Chapter–Bureau of Sport Fisheries and Wildlife, Fish and Wildlife Service, Department of the Interior. Subchapter B–Hunting and possession of wildlife. Part 13–Importation of wildlife or eggs thereof. 9 p.

Bureau of Sport Fisheries and Wildlife. 1970 Report to the fish farmers. Resour. Publ. 83.

Burrows, R. E., and B. D. Combs. 1968. Controlled environments for salmon propagation. Prog. Fish Cult. 30:123–136.

Canadian Committee on Fish Diseases. 1972. Considerations and recommendations for the control of fish diseases in Canada. Misc. Special Publ. No. 16. Fisheries Research Board of Canada, Ottawa. 52 p.

Caselitz, F. H. 1966. *Pseudomonas-Aeromonas* und ihre humanmedizinische Bedeutung. VEB Gustav Fischer Verlag, Jena. 243 p.

Chapman, W. M. 1966. Oceans fisheries–Status and outlook, p. 15–27. *In* R. C. Steere [Chmn.] Exploiting the ocean, supplement. Marine Technology Society, Washington, D.C.

Chapman, W. M. 1969. Fishing in the future. CERES FAO Rev. 2(3):22.

Clark, F. H., and C. Shepard. 1963. Effect of environmental temperatures on infection with *Mycobacterium marinum* (*balnei*) of mice and a number of poikilothermic species. J. Bacteriol. 86:1057–1069.

Cockburn, A. 1963. The evolution and eradication of infectious diseases. The Johns Hopkins Press, Baltimore. 255 p.

Collins, V. G. 1970. Recent studies of bacterial pathogens of freshwater fish. Water Treat. Exam. (Br.) 19:3–31.

Commission on Marine Science, Engineering and Resources. 1969. Our nation and the sea: A plan for national action, Vol. I, Chap. 4. U.S. Government Printing Office, Washington, D.C.

Courtenay, W. R., and C. R. Robins. 1973. Exotic aquatic organisms in Florida with emphasis on fishes: A review and recommendations. Trans. Am. Fish. Soc. 102:1–12.

Davis, J. T., and J. S. Hughes. 1970. Channel catfish farming in Louisiana. Wildl. Educ. Bull. No. 98, La. Wild Life Fish. Comm.

Dogiel, V. A., G. K. Petrushevski, and Yu. I. Polyanski [ed.]. 1970. Parasitology of fishes. T. F. H. Publications, Ltd., Reigate, Surrey, England. (Distributed in the United States by T. F. H. Publications, Neptune City, N.J.) 384 p.

Dubos, R. 1955. Second thought on the germ theory. Sci. Am. 192:31-35.

Elson, P. F., L. M. Lauzier, and V. Zitko. 1972. A preliminary study of salmon movements in a polluted estuary. Paper FIR:MP/70/E-81. *In* Proceedings FAO technical conference on marine pollution and its effects on living resources and fishing, Rome, December 1970.

Farrell, R. K., M. A. Lloyd, and B. Earp. 1964. Persistence of *Neorickettsiae helminthoeca* in an endoparasite of the Pacific salmon. Science 145:162-163.

Faust, E. C. 1955. Animal agents as vectors of human disease. Lea & Febiger, Philadelphia. 660 p.

Federal Register. 1969. Fishery failure. Determination of whirling disease as resource disaster. F.R. Document 69-1174. 1 p.

Federal Water Pollution Control Administration. 1967. Proceedings, Conference on pollution of Raritan Bay and adjacent interstate waters, Third Session, New York, Vol. 2 659 p. Water Quality Laboratory, EPA, Edison, New Jersey.

Fisheries Act–Salmonidae Import Regulations. 1969. The Canadian Gazette, Part II; 13 (15). August. Queen's Printer for Canada, Ottawa.

Food and Agriculture Organization. 1970. Yearbook of fishery statistics, catches and landings, Vol. 28. Food and Agriculture Organization of the United Nations, Rome.

Food and Agriculture Organization. 1971. Yearbook of fishery statistics, Vol. 30. Food and Agriculture Organization of the United Nations, Rome.

Foster, T. H., and J. E. Waldrop. 1972. Cost-size relationships in the production of pond-raised catfish for food. Bull. 792, Miss. St. Univ. Agric. Forest. Exp. Stn.

Ghittino, P., and R. Vittoz [ed.]. 1963. Proc. European symposium on diseases of fish and inspection of marine and freshwater products. Bull. Int. Off. Epizootiol. 59:1-310.

Goode, G. B. 1887. The fisheries and fishery industries of the U.S. Sect. II. A geographical review of the fisheries industries and fishery communities for the year 1880. U.S. Government Printing Office, Washington, D.C. p. 384.

Gullion, E. A. 1968. Ocean science and marine resources: Uses of the sea. Prentice-Hall, Englewood Cliffs, N.J. 202 p.

Halstead, B. W. 1970. Toxicity of marine organisms caused by pollutants. Paper FIR:MP/70/R-6. *In* Proceedings FAO technical conference on marine pollution and its effects on living resources and fishing, Rome, December 1970.

Herman, R. L. 1970. Prevention and control of fish diseases in hatcheries, p. 3-15. *In* S. F. Snieszko [ed.] A symposium on diseases of fish and shellfishes. Spec. Publ. No. 5. American Fisheries Society, Washington, D.C.

Hoffman, G. L. 1967. Parasites of North American fishes. University of California Press, Berkeley. 486 p.

Hoffman, G. L. 1970. Intercontinental and transcontinental dissemination and transfaunation of fish parasites with emphasis on whirling disease, p. 69-81. *In* S. F. Snieszko [ed.] A symposium on diseases of fishes and shellfishes. Spec. Publ. No. 5. American Fisheries Society, Washington, D.C.

Idyll, C. P. 1970. The sea against hunger: Harvesting the oceans to feed a hungry world. Thomas Y. Crowell Co., New York. 221 p.

Iwantsch, G. F. 1970. The effect of high temperature on the gonadal area of representative cross-sections of *Mytilus edulis*, L. M.S. thesis. University of Delaware, Newark. 66 p.

Jackson, R. I. 1971. Famine and the world fisheries. Trans. Am. Fish. Soc. 100:151-158.

Janssen, W. A. 1970. Fish as potential vectors of human bacterial diseases, p. 284-290. *In* S. F. Snieszko [ed.] A symposium on diseases of fishes and shellfishes. Spec. Publ. No. 5. American Fisheries Society, Washington, D.C.

Kotsuna, S. [ed.]. 1966. Minimata diseases. Studies on the toxications due to organic mercury compounds. [In Japanese.] The Research Group of Minimata Disease, Faculty of Medicine, Kumamoto University, 447 p.

Lachner, E. A., C. R. Robins, and W. R. Courtenay. 1970. Exotic fishes and other aquatic organisms introduced into North America. Smithson. Contrib. Zool. 59:1-29.

Lyubimova, T. G., A. G. Naumov, and L. L. Lagunov. 1973. Prospects of the utilization of krill and other nonconventional resources of the world oceans. Paper presented at FAO Technical Conference on Fishery Management and Development, Vancouver, Canada, 13-23 February 1973.

Mahoney, J. B., F. H. Midlige, and D. G. Devel. 1973. A fin-rot disease of marine and euryhaline fishes in the New York Bight. Trans. Am. Fish. Soc. 102(3):596-605.

Marine Fisheries Advisory Committee, U.S. Department of Commerce. 1973. Records of action, Febr. 6-8, MAFAC VI. National Oceanic and Atmospheric Sciences, Washington, D.C.

Martin, R. G. 1969. Fishery science and related courses in North American colleges and universities. Sport Fishing Institute, Washington, D.C. 32 p.

Mawdesley-Thomas, L. E. [ed.]. 1972. Diseases of fish. Academic Press, London. 380 p.

Meyer, F. P., and G. L. Bullock. 1973. *Edwardsiella tarda* , a new pathogen of channel catfish (*Ictalurus punctatus*). Appl. Microbiol. 25:155-156.

Mileikovsky, S. A. 1970. The influence of pollution on pelagic larvae of bottom invertebrates in marine nearshore and estuarine waters. Mar. Biol. 6:350-356.

Ocean Dumping of Waste Material. 1971. Hearings before the Committee on Merchant Marine and Fisheries, House of Representatives. U.S. Government Printing Office, Washington, D.C.

Pearce, J. B. 1969. Thermal addition and the benthos, Cape Cod Canal. Chesapeake Sci. 10:227-233.

Philip, C. B. 1955. There's always something new under the "parasitological" sun. J. Parasitol. 41:125-148.

Pillay, T. V. R. 1973. The role of aquaculture in fishery development and management. Paper presented at FAO Technical Conference on Fishery Management and Development, Vancouver, Canada, 13-23 February 1973.

Pippy, J. H. C., and G. M. Hare. 1969. Relationship of river pollution to bacterial infection in salmon (*Salmo salar*) and suckers (*Catostomus commersoni*). Trans. Am. Fish. Soc. 98:685-690.

Rasor, C. R. 1972. Market report: Processed catfish production increases. Catfish Farmer New Leader 3(2):2.

Rounsefell, G. A. 1971. Potential food from the sea. J. Mar. Sci. 1(3);1-82.

Rounsefell, G. A., and W. R. Nelson. 1966. Red-tide research summarized to 1964, including an annotated bibliography. U.S. Fish and Wildlife Service Special Scientific Report–Fisheries No. 535. 85 p.

Russell, F. E. 1971. Marine toxins and venomous and poisonous marine animals. T.F.H. Publications, Neptune City, N.J. 176 p.

Ryther, J. H. 1969. Photosynthesis and fish production in the sea. Science 166:72-76.

Sandy Hook Laboratory, 1972. The effects of waste disposal in the New York Bight: Summary final report. Informal report No. 2, Sandy Hook Laboratory, Middle Atlantic Coastal Fisheries Center, National Marine Fisheries Service, Highlands, N.J. 70 p.

Sarig, S. 1971. Diseases of fishes. Book No. 3. The prevention and treatment of diseases of warmwater fishes under subtropical conditions, with special emphasis on intensive fish farming. T.F.H. Publications, Neptune City, N.J. 127 p.

Shotts, E. B., J. L. Gaines, L. Martin, and A. K. Prestwood. 1972. *Aeromonas*-induced deaths among fish and reptiles in an eutrophic inland lake. J. Am. Vet. Med. Assoc. 161:603-607.

Schaefer, M. B. 1965. The potential harvest of the sea. Trans. Am. Fish. Soc. 94(2):123-128.

Selye, H. 1950. Stress and the general adaptation syndrome. Br. Med. J. 1:1383-1392.

Sindermann, C. J. 1970. Principal diseases of marine fish and shellfish. Academic Press, New York and London. 369 p.

Snieszko, S. F. [ed.]. 1970. A symposium on fishes and shellfishes. Spec. Publ. No. 5. American Fisheries Society, Washington, D.C. 526 p.

Spence, J. A., and H. B. N. Hynes. 1971. Differences in benthos upstream and downstream of an impoundment. J. Fish. Res. Board Can. 28:35–43.

Sprague, J. B., and B. A. Ramsay. 1965. Lethal levels of mixed copper-zinc solutions for juvenile salmon. J. Fish. Res. Board Can. 22:425–432.

Sprague, J. B., W. V. Carson, and E. J. Schofield. 1968. Zinc–copper pollution in Miramichi River, summer 1967. Chemical autopsy on dead fish and interpretation of associated field data. Fisheries Research Board of Canada, Ottawa.

Sprague, L. M., and J. H. Arnold. 1972. Trends in use and prospects for the future harvest of world fisheries resources. J. Am. Oil Chemists' Soc. 49:345A–350A.

Stirling, E. A. 1970. Some observations on the response of the benthic bivalve *Tellina tenuis* to pollutants. Proc. International Coun. Explor. Sea, 1970. International Council for the Exploration of the Sea, Charlottenlund, Denmark.

Stroud, R. H. 1970. Future of fisheries management in North America, p. 291–308. *In* N. G. Benson [ed.] A century of fisheries in North America. Spec. Publ. No. 7. American Fisheries Society, Washington, D.C.

Swingle, H. S. 1970. History of warmwater pond culture in the United States, p. 95–103. *In* A century of fisheries in North America. Spec. Publ. No. 7. American Fisheries Society, Washington, D.C.

Thompson, P. E. 1972. The major communicable fish diseases of Europe and North America: A review of attempts at their control. FAO symposium on the major communicable fish diseases in Europe and their control. FI:EIFAC 72/SC II-Symp. 10. Mimeo. FAO, Rome. 35 p.

van der Hoedon, J. 1964. Zoonoses. Elsevier Publishing Co. Amsterdam, London, and New York. 774 p.

von Gravenitz, A., and A. H. Mensch. 1968. The genus *Aeromonas* in human bacteriology. New Engl. J. Med. 278:245–249.

Wagner, E. D., and C. Perkins. 1952. *Pseudomonas hydrophila*, the cause of "red mouth" disease in rainbow trout. Prog. Fish. Cult. 14(3):127–128.

Wedemeyer, G. 1970. The role of stress in the disease and resistance of fishes, p. 30–35. *In* S. F. Snieszko [ed.] A Symposium on diseases of fishes and shellfishes. Spec. Publ. No. 5. American Fisheries Society, Washington, D.C.

Wolf, H. 1970. Problems associated with the operation of fish inspection programs in California, p. 36–40. *In* S. F. Snieszko [ed.] A symposium on diseases of fish and shellfishes. Spec. Publ. No. 5. American Fisheries Society, Washington, D.C.

Wood, E. M., and W. T. Yasutake. 1956. Histopathology of fish. II. The salmon-poisoning fluke. Prog. Fish-Cult. 18:22–25.

Workshop on Inspection and Certification of Fish Diseases. 1970. Division of Fish Hatcheries, Bureau of Sport Fisheries and Wildlife, U.S. Department of the Interior, Denver, Colo. Workshop held March 3–5.