Chapter VIII

Marine sciences

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A MAJORITY OF THE WORLD'S POPULATION obtains at least half of its daily protein requirements from seafood and related products. Seafoods contribute less to the animal protein diet of most Americans because of the ready availability of meat, but they are still an important part of the preferred diet of many of our people. The lakes, streams, and rivers of the United States, and the seas adjacent to its coasts, play an important role in the welfare and economy of the country. These waters provide transportation, recreation, and avenues of waste disposal, as well as food. The aquatic environment of the United States, including the continental shelf to a depth of 100 fathoms, occupies about 17 % of the total area (4,271,074 square miles); of this, 15 % is seawater over the shelf and nearly 2 % is freshwater in lakes, streams, and rivers.

Research in aquatic sciences in the United States began seriously in the latter part of the 19th century, and has progressed most rapidly since 1940. Other studies became possible after the war because of the application of newly developed scientific theory and technology. Biological studies of the aquatic resources have contributed to human welfare by increasing the harvest of food from the ocean and freshwaters, by managing the resources and their environment so that food production may be sustained, and by promoting man's health and general welfare.

Primary organic production—the photosynthetic pro-

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duction of organic matter by green, chlorophyll-bearing plants—is the ultimate source of all life on earth. In the sea, the process of organic production is carried out mainly by small, usually microscopic, unicellular algae. These plants provide the basic food, directly or indirectly, for all other marine life, including species important to man as food.

In the early 1950's a technique was developed involving the use of radioactive isotopes as tracers that for the first time permitted the rapid, sensitive, and accurate measurement of the rate of organic productivity in the sea. This technique, which could be employed routinely on oceanographic expeditions, found widespread application to ocean exploration, and is now used extensively. As a result, man has a better knowledge of the total organic productivity of the ocean, as well as its seasonal and geographical variability.

The mechanisms and dynamics by which the photosynthetically produced organic matter is passed through the "food chains" or "food webs" of the sea, ultimately reaching species that are of direct value to man, are becoming better understood. We know enough to permit calculations of the potential food production from the seas. This potential is several times the present harvest. Whether man is able to realize this potential depends on a complex of technical, social, economic, and political problems. But some marine food resources are, or are about to be, overexploited. Basic studies in biological oceanography and marine ecology have pointed up the need for scientific management of the world's fisheries. In addition, it is essential to explore for new fishery resources.

Studies of biological productivity and the related physical and chemical oceanographic processes that limit and control productivity have made it possible to predict when and where to expect major concentrations of fish. Such information, together with knowledge of the magnitude and rate of renewal of the resources, permits their exploitation with maximum efficiency and safety for their preservation. Application of physical oceanography to the problems of fishery prediction is one of the more promising new approaches to the field of marine food resource management.

Knowledge of the chemical and physical mechanisms and processes that limit and control the production of organic matter in the sea make it possible to consider improving the ocean's productivity. Pilot-scale projects are being planned in which limited marine areas will be fertilized by pumping deep, nutrient-rich water to the surface. Hopefully this will increase the rate of photosynthetic production of the unicellular algae.

Of great importance for food production and protection of environmental quality are recent experiments using human wastes as nutrients for stimulating the growth of marine algae under controlled conditions, and feeding the unicellular plants to shellfish or other valuable food species. Wastes thus can be recycled for useful purposes. Such control and enhancement of basic biological productivity, coupled with an expanding ability to cultivate a variety of marine organisms under controlled conditions, give promise of a substantial increase in productivity of sea food.

The algae supply many basic nutrients, and are a rich source of many minerals (e.g., iodine, sodium, chlorine) and vitamins (e.g., thiamin, niacin, riboflavin, folic acid, ascorbic acid, and provitamin D). Some algae have a high protein content. For example, *Chlorella* can be cultured easily to contain 60% protein on a dry weight basis.

The large algae (seaweeds) have been used in cattle feeds (to increase butterfat content in milk), in chicken feeds (to provide for higher iodine content of eggs), and in fertilizer. The best known use of algae is in production of seaweed extractives, which are used extensively in laboratories as a growth medium (agar-agar) for cultivating microorganisms, and in products such as ice cream for consistency stabilization, in chocolate milk to provide body and suspend the cocoa, in eggnog as a stabilizer, and in milk-based cooked puddings as a solidifying agent. Seaweed extractives are also used extensively in dietetic foods to provide the body and texture normally supplied by sugar or starch.

The successful attainment and maintenance of the maximum yield of food from the sea depends in great degree on results of scientific research. Such research has several objectives: *1*) to locate, concentrate, and catch fish more quickly and less expensively; *2*) to improve and maintain the quality of the food product; *3*) to develop new products that will appeal to the consumer; *4*) to prevent overfishing; and *5*) to improve the economic position of the fisheries generally.

Fish and shellfish provide 10–13 % of world's consumption of animal protein. Most of this comes from the sea. Recently, the annual marine fishery harvest has been about 60 million metric tons, a weight nearly equal to that of the world production of meat and poultry. Most marine scientists agree that the ocean could produce more food, but it is not so clear how much more.

The potential world catch of fishery products is probably at least twice the present yield and may be considerably higher. The Food and Agriculture Organization of the United Nations suggests that upper limits on ocean fish production are conservatively 100 million metric tons for whales and marine fish; 2 million metric tons for shrimp, lobsters, and crabs; and 3 million metric tons for clams, oysters, mussels, squid, and octopuses. One method of increasing the present harvest is to use some of the many species that are currently not utilized. For example, over 50 % of the United States catch of marine animals consists of fewer than two dozen species. It may be that the natural production of some species of marine animals could be increased substantially by intensive cultivation by man.

RESOURCE ASSESSMENT

Systematic documentation of the marine animal resources inhabiting the continental shelf and slope adjacent to the United States was started in the latter part of the 1940's by the agency which is now the National Marine Fisheries Service of the U. S. Department of Commerce. Information has been collected on the bottomdwelling fish and shellfish communities in the northeast Pacific Ocean from the Bering Sea to Baja California, and on shrimp, scallops, lobsters, clams, and industrial fish species along the Atlantic seaboard and in the Gulf of Mexico. Seasonal distribution and abundance of a number of fish species that are major resources have been documented and subsequently became the objective of commercial fishing activities.

Fisheries which developed as a direct consequence of this explorative research in the northeast Pacific include the king crab fishery of the Bering Sea and the Gulf of Alaska, the large deep-water (pandalid) shrimp fishery of the Gulf of Alaska, the hake fishery in Puget Sound and off the coasts of Oregon and Washington, the ocean perch fishery off Oregon, Washington, California, and British Columbia, the scallop fishery of the Gulf of Alaska, and the deep-water flounder fishery off the coasts of Oregon, Washington, and British Columbia. Along the Atlantic seaboard, assessments conducted by U. S. scientists have expanded the shrimp fishery in the Gulf of Mexico, aided development of shrimp fisheries in Central and South America, led to the development of the calico scallop fishery and the major expansion of the industrial fishery in the Gulf of Mexico, and contributed to the development of the clam fishery and the deep-sea lobster fishery of the continental slope and the swordfish industry in offshore waters.

Some indication of the value of explorative research can be derived from the following figures: the Alaska pandalid shrimp industry in the early 1950's was harvesting from 1 to 2 million pounds annually. In the 12 years subsequent to assessment of activities in the northeast Pacific, this fishery industry expanded rapidly, and is now harvesting in the order of 60–70 million pounds. Its annual value at the fisherman level is approximately $3.5 million. The Alaska king crab fishery started following assessment activities conducted in the Bering Sea and Gulf of Alaska in the latter part of the 1940's. The annual value of this fishery in recent years has exceeded $10 million. Shrimp are now harvested by vessels operating in Central and South America as the result of explorative research started in the early 1950's. In 1969, American flag shrimp vessels fishing out of Trinidad, Barbados, Guyana, Surinam, Nicaragua, and French Guiana harvested shrimp valued at over $32 million. This research has also provided jobs in Latin American countries and assisted economic growth in these countries.

When deep-water explorations were undertaken off the coasts of Oregon, Washington, and British Columbia, commercial trawling activities in these waters were limited to depths shallower than 100 fathoms. With the discovery of large concentrations of Pacific ocean perch and flounders on the continental slope, the commercial fishery rapidly expanded into deeper waters, and ocean perch became the most important species in the trawl fisheries in Oregon and Washington. Similarly, Dover sole, which was not exploited to any extent in the northern waters, has become one of the dominant species in the trawl landings. In addition to these species, major fisheries were also developed for Alaska scallops and sablefish on the continental shelf. The assessment of the hake resources in the mid-1960's resulted in development of a United States-based fishery in Puget Sound, and large-scale Soviet activities off the coasts of Oregon and Washington.

Major contributions have been made to both U.S. fisheries and the growth and development of foreign fisheries by explorations conducted by the United States. Foreign vessels harvest some 3 billion pounds of fish annually in areas surveyed by U.S. scientists. The scientific assessment also has included descriptions of the oceanographic features of the area, such as current patterns and temperature regimens. The studies of the International Pacific Halibut Commission pioneered the field of oceanic hydrographic studies in the North Pacific. A prominent seamount was discovered by fishery scientists for which there are now plans to establish a hydrographic laboratory and weather station.

The resource assessment studies have benefited the commercial fishing industry in other ways. A large midwater trawl developed for hake assessment is now used in the commercial trawl fishery of the West Coast. Similarly, a sorting net developed for shrimp sampling has contributed to conservation in that it releases undersized flounders and other fishes, meanwhile maintaining a high quality of shrimp harvested.

The assessment programs also have made important contributions to underdeveloped lands. The United Nations Food and Agriculture Organization and the USAID activities have used many United States experts to conduct resource assessment work in the Indian Ocean, South America, Africa, and elsewhere.

BEHAVIOR STUDIES

Fishermen have learned that the more knowledge they have of the habits of their prey, the more successful they will be in locating and capturing it. Answers to questions about the behavior of commercially important marine animals in relation to fishing techniques and tactics are being obtained from a combination of research and experience.

The information most important in predicting areas of abundance is on the responses of animals to temperature, salinity, and food gradients of the ocean, and the yearly and daily migrations that species make. Once fish are located, choices of gear and tactics are dictated by the animals' social behavior and swimming activity, and their responses to the gear itself.

An important role of behavior research relates to the unknown effects of pollution. Most of the world fishery resources spend a part of their lives in estuaries. To preserve fish and shellfish stocks it is essential to have knowledge of the behavioral and physiological responses of the animals to polluted and dammed water courses.

For example, when alarmed, many fishes can swim rapidly for short periods and can escape a net about to encircle or engulf them. The design and use of towed nets such as trawls depend greatly on the swimming abilities of the fish being sought. The predictive study of swimming speed has its roots in basic science. Accurate equations have been developed that predict "burst" or escape speeds of fish. There are differences in speed due to the shape and size of fish. To illustrate, contrast the requirements of a towed net to capture the large, powerful tuna which have burst speeds faster than 10 mph with gear for small flatfish whose burst speeds are no greater than 0.5 mph. Since towing speeds are usually less than 5 mph, it is apparent that a very large net would be needed to catch tuna. Studies provide computations relating escape speeds to the net diameter and towing speed. Design of gear must also take into account the behavioral consideration of how far the fish can sense and react to the net.

Information on behavior of fishes is required in the design of fishways. Many dams on the rivers of the Pacific Northwest have been provided with fishways to allow migrating salmon to pass upstream to spawning grounds. Early fishways were designed by rule-of-thumb, but the more efficient and economical structures have been designed on the basis of information from behavior studies. The Bonneville Fishery Laboratory, operated by the National Marine Fisheries Service and funded largely by the U.S. Corps of Engineers, has designed successful fishways for upstream migration. They have also designed collecting devices for young salmon migrating downstream, and have developed criteria for operation of turbines to reduce the mortality of the downstream migrants. Without this information the salmon runs in the streams of the Pacific Northwest could not be maintained at their present levels.

In Maine, behavior studies have led to the use of air-bubble curtains to guide herring schools to the point of capture. The reaction of herring to the air curtain appears to be primarily a response to visual stimuli. This technique has allowed the extension of fishing activities beyond the limits of depth and distance from shore imposed by the conventional passive methods of fishing with stop seines or weirs.

The purse-seine fishery for menhaden off the Atlantic and Gulf coasts of the United States has been made more efficient by utilizing the response of the fish to electricity. By fitting the anode of a pulsed direct-current circuit to the nozzle of the pump hose, the fish are attracted to the nozzle, and the efficiency of pumping the catch from the net to the carrier vessel is greatly improved. Partly as a result of this technique it has been possible to reduce the crews from 22 to 10 men per boat, to increase the fishing power, and to reduce the strain on the net. Electrical gear has also been devised to improve the efficiency of shrimp trawls. Some species of shrimp normally burrow in the daytime, and an electrified shrimp trawl has been designed and tested which can catch as many shrimp during the day as at night. It is hoped in this way to extend fishing operations to a 24-hour basis.

These examples—some applied, others awaiting application—are instances of basic research on fish behavior conducted in the past 2 or 3 decades. Far more basic knowledge is required to improve the efficiency of location and capture of marine animals of economic importance.

VALUE OF PREDICTION OF FISHING SUCCESS

Much of the justification used for funding ocean research is based on the premise that knowledge of the sea and its occupants is of practical value to military and commercial interests. It is difficult to place a dollar value on military use of this information, but commercially the forecasting of fishing success has obvious potential.

The United States is the major world market for tuna, shrimp, crab, lobster, salmon, groundfish, and fish reduction products. In the United States the value of all processed fishery products produced from domestic and imported raw material is now about 1.7 billion dollars annually, a very substantial industry. Raw material acquisition has become a world wide task. Segments of the U.S. fishing industry may be found in most of the fishing nations of the world.

Due to the nature of the resources and present methods of harvest, there are wide fluctuations in the abundance, distribution, and availability of fish and shellfish stocks from year to year and even within years. At the other end of the chain, established food products, by nature, have relatively stable markets. A major problem is to smooth out the oscillations so the processors and marketers may effect orderly merchandising.

The shrimp industry provides a practical example. The U.S. market utilizes more than one-third of the total world production of shrimp. Domestic production accounts for 45% of U.S. needs, and a major share of this comes from the grounds in the Gulf of Mexico. These fisheries have been studied extensively during the past 15 years. Excellent statistical information on landings is available on a current basis. A historical study of supply–demand–price relationships in the United States reveals that the year-to-year fluctuations in the supply of shrimp from domestic sources are the key factors in determining trends in price of raw shrimp. Biological data show that: *1*) fishing effort for the three major species—brown, white and pink—in the Gulf of Mexico has reached a level where further increases in fishing effort have a minor effect on total landings; *2*) the major share of the landings are from the initial age group. Total stock mortality (from fishing and natural sources) is extremely high, and the recruits to the fishery are cropped off as they enter the fishery; *3*) fluctuations in year-class strength vary by a factor of two to six and are related largely to nearshore environmental changes. Forecasts of abundance from year to year can be integrated with market demand, price inventory, and import information to provide a sound planning base for fishing and processing operations.

For fishing vessel operations, the value of forecasting fish abundance is obvious. However, the present state of the art offers little practical assistance on a day to day basis, although some success has been obtained in special weather forecasts.

It is difficult to evaluate the dollar potential of weather forecasting to the seafood industry. However, a 5% saving would be 85 million dollars annually. Probably less than 5% of this amount is being gained as a result of present very limited forecasting operations.

Fishery scientists readily admit that present skills in predicting resource availability have not reached their full potential due to the lack of: *1*) current synoptic information on the physical properties of the air and ocean; *2*) basic research into the life histories of the animals under consideration; *3*) understanding and interest by fishery scientists in the application of their findings to the forecasting of fish landings; *4*) clear communication of the existing information to industry people in a usable form; and *5*) currency in the data that were transmitted to the fishing industry. Most studies that relate to the prediction of fish supplies utilize historical information and findings are published years later.

During the past 10 years, rapid advances have been made in certain of these areas. The sums spent on ocean research related to fisheries have increased. The results are encouraging. Synoptic data from satellites are now being processed and integrated with information obtained from surface sources to improve ocean and air data coverage on a real time basis. But information on the fish and shellfish stocks themselves is lagging. Worse yet is the lack of fundamental research linking the environment and fishing activities with stock abundance and distribution.

The reduction of ocean research budgets in recent years has accentuated the problem. New technology is being developed, but this is rapidly producing a gap between the hardware capabilities and the synoptic data being gathered and the software development (research) necessary to utilize the information intelligently. Steps must be taken to correct this deficiency or a major share of the projected gains will not be realized.

PRESERVATION OF FISHERY PRODUCTS

Fish are important in feeding the world's population, but this use is reduced because seafood products are extremely perishable. The availability of fish in inland areas requires inexpensive methods of preservation that keep the product wholesome. Historically salting, drying, smoking, and combinations of these methods have been used to retard decomposition. These methods are still in use in much of the world; they lend themselves to small operations, are simple and inexpensive.

In most industrial countries supplies of animal protein are abundant, and fish and shellfish are consumed because they are enjoyable components of balanced diets. In these countries the availability of refrigeration and the existence of highly developed distribution systems make fresh or frozen fishery products generally available. Consumers in these countries prefer their fish in these forms.

Refrigeration is a highly efficient means of controlling the growth of spoilage bacteria, but refrigeration methods still can be improved. Very recently research on spoilage control led to a major advance in the use of refrigerated seawater on board fishing vessels for holding fish at high-quality levels for extended periods of time at temperatures above the freezing point. The advantage of refrigerated seawater in the control of spoilage bacteria is that its freezing point is about 1 C lower than that of freshwater. This permits holding the fish in unfrozen state at a lower temperature than is possible with ice. The technique of saturating the seawater with carbon dioxide before adding fish to this refrigerant, and of keeping the seawater saturated during the entire holding period, permits an approximate doubling of the holding period. At the end of this holding period the quality of the product is significantly higher than that of the same products held for half that period of time in ice or in unmodified refrigerated seawater.

The bactericidal action of ionizing radiation has been known for more than half a century, but only recently has it been shown that meat can be sterilized by high-energy X-rays. In addition, penetrating electrons have been used as an experimental and demonstration tool for sterilizing a variety of raw food, and this led to a new method for preserving food. Ionizing radiation can be used to sterilize food, but the energy required to destroy all the bacteria present is so great as to alter the chemistry of the food product, producing undesirable flavors and odors. Research has shown that at lower radiation doses, preservation of fish and shellfish can be effected at a pasteurizing level (approximately 90% of the spoilage bacteria are destroyed) without altering the flavor or odor of the product. Such a product requires refrigeration at temperatures of about 2–5 C; in this temperature range fish and shellfish can be held for about 3 weeks after irradiation—a time sufficient for shipment throughout the United States by surface transportation, and for sale at the retail level as high-quality "fresh" products.

The control of spoilage in fishery products by radiation pasteurization does not destroy the deadly botulism bacterium, *Clostridium botulinum* Type E. Fresh fishery products sometimes carry small numbers of spores of this pathogen, but they have never been known to cause a case of botulism. As further protection of consumers, recent studies on the mechanism of toxin formation have shown that bacteriophages (viruses that attack bacteria and are found almost universally in the vegetative cells of *C. botulinum*), can be eliminated from the cells by laboratory procedures, thereby causing the cells to lose their ability to produce toxin. When the cells are reinfected with the bacteriophage, the cells become toxin producers again. When bacteriophages from one type of botulinum are added to bacteriophage-free cells of a different type, the host of the "foreign" bacteriophage produces toxin again but now the toxin produced is characteristic of the type of botulinum from which the bacteriophage was originally eliminated. This work has significance for the entire food field, because *C. botulinum* is a ubiquitous pathogen and is always a potential hazard in a nonsterile food product that is stored after the normal bacterial flora have been altered by processing.

FISH PROTEIN CONCENTRATE

Research and development by private industry and government during the past 15 years have resulted in the development of other processes for making fish available where seafood is desired but is infrequently consumed because of its perishability or high cost. One of these techniques is the production of concentrates of fish protein. These are dehydrated and defatted fish, usually reduced in particle size to a powder. Most developed processes are physiochemical in nature, but include some interesting biological processes. Research has shown that the protein content of the final product can be increased by the use of fish oil as a source of energy by microorganisms. As the organisms grow and break down the oil, they produce additional protein in the form of single-cell organisms. Other methods involve the enzymatic breakdown of fish protein to smaller molecules that retain the nutritive value of the original protein but simplify the removal of oil.

All processes are designed to produce a dry product that is highly resistant to bacterial and mold growth, acceptable as an ingredient of other foods, and retentive of the nutritional properties characteristic of animal protein. In the past 3 or 4 years plans for the commercial production of fish protein concentrate have become a reality in Canada and in Europe. The Federal Government has financed the construction of a demonstration fish protein concentrate plant in Aberdeen, Washington, that began operations in the Spring of 1971. The purpose of the plant is to demonstrate to industry and government the feasibility of economically converting little-used fish resources into shelf-stable, palatable, nutritious, concentrated protein and to provide facilities in which pilot-scale processes can be tested and modified to increase the efficiency of converting fish to protein concentrate.

Another interesting new technique for the control of spoilage organisms on freshly caught fish is being investigated currently. The principle involved is the absorption of heat by evaporating water and the liberation of heat by condensing water vapor. Fish are placed in a sealed chamber and subjected to a moderate decrease in pressure; moisture on the surfaces of the fish evaporates and quickly cools the surfaces by absorbing in the form of heat the energy required for evaporation; steam is then introduced into the chamber; the hot water vapor condenses on the surfaces of the cooled fish, giving up the latent heat of evaporation to the surfaces and, of course, to bacteria on the surfaces; after a few seconds a vacuum is applied again, and the fish are quickly cooled to refrigerator temperatures. The heat from the condensing steam is sufficient to destroy about 99% of the vegetative cells on the fish, but the time allowed for heat absorption by the fish is so short as to obviate heat damage to the fish flesh. Taste-panel evaluations have shown that stored fish treated by this method are highly acceptable after conventionally iced fish are rejected.

MANAGEMENT OF RENEWABLE RESOURCES

Success in managing living marine resources and their fisheries depends as much on maintaining the yield of traditional resources as on developing unused resources. The period since 1945 has seen many advances that have contributed to fishery management. Major advances in the last 25 years include: *1*) clear demonstration that even in the ocean selective fishing can disturb the ecological balance, allowing other species to capture the energy released by reducing the abundance of exploited species, and this must be taken into account in research planning and analysis and in management practices; *2*) modern techniques for identifying stocks and races of fish, which permit identification of the origin of migratory species caught on the high seas; *3*) research leading to successful control of predators, especially sea lampreys in the Great Lakes, and boring snails and other predators of oysters and clams; and *4*) improved understanding of the concepts of maximum sustainable biological and economic yields, which are leading to more sophisticated management concepts.

Several decades ago many people thought fishery resources of the oceans were inexhaustible. In recent years, however, the understanding of the potential catches has been considerably modified. Research will need to continue. Three principal needs must be satisfied: to improve our understanding of the distribution and abundance of all marine life in time and space; to elucidate the environmental requirements of the resource; and to eliminate or alleviate the social–political impediments to efficient harvesting.

The methodology for managing stocks of fish, developed in the science of population dynamics of harvested fish populations, has made its greatest advances in the last 20 years. These advances are incorporated in three basic ideas: the yield–per–recruit idea; the equilibrium–yield idea; and the stock–recruitment idea.

The yield–per–recruit approach to management can be thought of in terms of all the fish in a population born in any particular year. At the time an individual fish becomes susceptible to capture, it is called a recruit. The initial number of fish in this group will continually diminish by natural mortality from a variety of causes. During the early life of this group of fish the growth of individuals will be rapid and the total weight of the group will continue to increase even though the numbers of fish are continually decreasing. As time progresses, however, growth will slow down and eventually the total weight of the group will diminish. It is clear that the total weight of the group increases, then decreases, and that the maximum yield from the population could be taken when the population is at its maximum weight. It is not, however, practical to catch all the fish at a single instant of time, and the yield–per–recruit theory tells us how to budget fishing intensity over the life-span of the fish to maximize the yield–per–individual after it enters the fishery.

The equilibrium–yield idea acknowledges that the capacity of a population of fish to reproduce itself depends on its size, and that the maximum reproduction in weight occurs at some level of population size that is intermediate between zero population size and some maximum upper limit of population size. When this maximum reproduction in weight occurs the biomass will tend to increase, but, if the "surplus production" is harvested, the population will remain in equilibrium and the surplus production can be harvested indefinitely.

The third idea, that of stock and recruitment, says that the number of individuals recruited into a fishery will be a function of the size of the spawning stock. Thus, when the spawning stock is zero, the recruitment will obviously be zero. As the spawning stock increases the recruitment from the spawning stock also increases. In some instances it appears that for some levels of spawning stock the recruitment is at a maximum, which is a desirable management criterion.

The three ideas can be used to give advice on the "optimal" amount of fishing intensity to apply to a stock. In the first the intensity of fishing is regulated to maximize the yield-per-recruit, in the second it is regulated to keep the population at a level at which the maximum equilibrium yield can be taken, and in the third it is regulated to maintain a reproductive stock which will maximize recruitment.

The importance of these population dynamics theories to human welfare lies in the fact that, while the fishery resources of the ocean are large, they are also exhaustible and it is therefore necessary to manage them. The present catches of fish amount to about 60 million tons/year. It might be that proper management of these resources, through the application of the principles of population dynamics, would yield this catch with perhaps 25% reduction in fishing effort, thus allowing a reallocation of effort to new stocks, and thus increase man's use of the sea.

The constraints against the full application of population dynamics theory to the management of fisheries are severalfold. Better population dynamics models are needed. Exchange of research results and discussion of their application are needed by all countries fishing international waters. The knowledge provided by fishery science must be applied by international agreement.

DISEASES AND PARASITES

Man is not alone in his consumption of aquatic animals. As with other forms of life, fish and shellfish are susceptible to predation and disease. Research concerned with diseases, parasites, and genetics of aquatic animals is not extensive. Much of the research in these fields has resulted from medical and public health needs. Yet significant contributions to human welfare can be identified.

In the United States and elsewhere in the world there are extensive systems of public and private trout and salmon hatcheries. Prophylaxis and treatment of diseases has been an important part of the technology developed for such systems.

The developing knowledge about certain virus and protozoan diseases of fish in Europe and Asia has led to steps preventing the importation and dissemination of the pathogens in the United States, and has helped to exclude diseases which could devastate hatchery and wild populations of salmon and trout. Knowledge developed during the past decade about the ecological requirements of protozoan and fungal pathogens of oysters has enabled the shellfish industry to modify its operations, and thus prosper even in the presence of the pathogens.

Certain parasites of aquatic animals have received attention because they are potentially infective to humans. Outstanding are the schistosome worms that invade the blood stream. They are transmitted by freshwater snails. Schistosomiasis research has resulted in eradication of the snail vectors from many areas and in the development of prophylactic ointments and drugs to treat human cases. These measures, plus an extensive education program, have resulted in drastic reductions in prevalence and impact of the disease on human populations.

A number of intestinal flukes and tapeworms that parasitize man use aquatic animals as intermediate hosts. Research has identified intermediate hosts and the geographic foci of infection, has developed measures to prevent reinfection of fish hosts, and has led to educational programs to prevent human infection by proper processing of fish.

Certain larval nematode parasites of fish may cause human disease. Although the extent of the problem has only been recognized in the past several years, research has already resulted in recommendations for processing of fish that would completely eliminate the danger of human infection.

One of the outstanding examples of how genetics research with aquatic animals can contribute to human welfare is the remarkable improvement of a race of Pacific salmon by severe artificial selection. A race of fast-growing, large-sized, and rapidly maturing fish has been developed at the University of Washington, and this work serves as a model for similar artificial modifications in other species of aquatic animals.

The matter of disease resistance in aquatic animals has been studied in both fish and invertebrates, and some artificial selection for resistance to particular pathogens has been done. With oysters, evidence has been acquired that early exposure of seed oysters to pathogens may confer a form of acquired resistance. This information is important to the management practices and operations of the shellfish industry.

MAN AND HIS ENVIRONMENT

Research on pollution problems in the marine and brackish water environment is directed toward the amelioration of man's existence. The importance or immediacy of some research programs is sometimes obscured by their indirect approach to problems, but most marine pollution research is associated with the preservation of significant sectors of *1*) man's environment, *2*) his health, and *3*) his food supply.

Gross pollution of the marine environment is caused mostly by the intentional use of the sea as a waste receptacle. The vastness of the ocean has given a false sense of its capacity for assimilating wastes. The obvious degradation of water quality in some estuaries indicates that changes could eventually take place in coastal waters further from shore. In addition to deliberate dumping, enormous amounts of waste material are contributed by run-off from drainage basins, and wastes received through atmospheric fallout constitute an unknown but probably important contribution.

Standard methods have been established for the evaluation of pollution levels at which plants and animals can live. This has resulted in the definition of criteria for water quality and determination of minimum standards of acceptability.

Bioassay techniques have been developed to monitor environmental changes. Analyses of shellfish reveal the presence of persistent chemicals and heavy metals in the surrounding water. Development of automated sensing devices make possible the continuous monitoring of factors important to the health of the marine environment.

Less clearly identified with the investigation of pollution problems, but nonetheless essential, are programs which establish the norms of existing aquatic ecosystems. Such studies identify changes in the numbers and kinds of animals and plants that may occur in succeeding years as a result of pollution.

Medical research has demonstrated the relationships between contaminated seafood and human disease. The role of shellfish as carriers of organisms causing viral and bacterial diseases is well known. Oysters and clams concentrate pathogenic microorganisms from their marine habitat. Consumption of infectious shellfish accounts for about 200 cases of infectious hepatitis in the United States each year. This is not a large number from the standpoint of public health, but it causes loss of revenue from condemned shellfish beds. Shellfish concentrate infectious agents such as polio and other disease-producing viruses as much as 1,000 times over the concentration found in surrounding waters. Some of these viruses may survive in salt water for as long as 2 months, and it has recently been demonstrated that cooking methods such as frying, boiling, and stewing do not render some viruses in oysters noninfectious.

Much effort has gone into studies of shellfish biology and the water quality requirements essential for the production of clams and oysters of acceptable quality. The seeming inevitability of further pollution of shellfish-growing areas has also prompted research on depuration, the process in which contaminated shellfish cleanse themselves when they are maintained for a few days in flowing sterilized seawater. Another approach to protecting man from contaminated seafood is to insure that such products are not harvested. Extensive monitoring is conducted of fish and shellfish, as well as of estuarine water and sediments, for the presence of harmful residues of persistent organic chemicals, heavy metals, and bacterial pollution. The dependence of a majority of commercial fisheries on the estuarine zone gives special importance to pollution abatement in this area.

The success of pesticides in assisting man in his efforts to produce food on land is offset by their hazard to nontarget animals, including aquatic food resources. Some of the more significant research contributions in the field of pollution biology are the studies on the kinetics of persistent synthetic chemicals in aquatic food chains, and of the accumulation of residues that are toxic to important species in man's food supply.

To ensure the continuation of man's harvest from the sea and the maintenance of an esthetically pleasing environment, research in the field of pollution biology must be greatly expanded. Man must abandon the concept of the ocean as a limitless repository for all wastes. Research must be intensified to develop methods for recycling wastes and to insure that only innocuous residues are returned to the environment.

HEALTH AND MEDICAL RESEARCH

Prior to the last 25 years, a few scholars worked on marine microbiological problems of individual interest, but during and after World War II concepts and methodology advanced, integrating the work of marine microbiologists into the whole of marine science. This new activity has permitted marine microbiology to make significant contributions through studies on *1*) properties of microorganisms that enhance our understanding of the origin and processes of life, *2*) microorganisms as they relate to properties of water masses, *3*) effects of microorganisms on productivity of the sea, *4*) stimulatory or inhibitory effects of microorganisms on other forms of life, and *5*) transmission or causation of disease to other forms of life by waterborne microorganisms.

The preponderance of evidence about the origin of life suggests that some process occurred in the primeval seas where nucleic acids or genetic materials were first synthesized. The simplest form of nucleic acids in nature occurs in the virus, and these nucleic acids are surrounded by a protein coat. However, there is evidence that strands of nucleic acid without protein coats may also exist. Further genetic investigations of microbial forms of the sea may fill the many gaps in our knowledge of primitive genetic material organization. Less than 10 viruses of marine animals have thus far been isolated, compared to more than 200 viruses of terrestrial life forms.

Many marine algae and invertebrate animals produce chemical substances that are essential to their growth and development, but are toxic or injurious to other forms of life. Man has exploited the microorganisms of the soil and produced a vast array of lifesaving antibiotics; he has only begun his search for therapeutic drugs from the sea, but already several substances of medical importance have been identified and characterized.

Carrageenan, a sulfur-containing polysaccharide extracted from seaweed, has proved useful in ulcer therapy. Oral doses afford protection from and aids in healing both gastric and duodenal ulcers. Carrageenan also acts as an anticoagulant, and seaweed hydrocolloids have been used as antilipemic agents. Kainic acid extracted from a red seaweed has been used successfully in Japan against a parasitic round worm, a whip worm, and the tape worm.

Extracts from a variety of sponges show broad-spectrum antibiotic effects, especially against human pathogens such as staphylococci, pseudomonas, acid-fast bacteria, and certain pathogenic yeasts. The exact chemical nature of most of these compounds has not yet been determined.

The D-arabinosyl nucleotides, spongothymidine, and spongouridine, were isolated from the West Indian sponge, *Cryptotethya crypta*. These compounds served as models for the synthesis of D-arabinosyl cytosine, a synthetic antiviral agent. "Paolins" extracted from abalone, oyster, clam, queen conch, and sea snail have been reported to be both antibacterial and antiviral. Paolin I inhibits the growth of several viruses in tissue culture and has protected mice infected with poliomyelitis, influenza, or polyoma virus.

Eledoisin, a polypeptide obtained from the posterior salivary glands of the octopus, is 50 times more potent than acetylcholine, histamine, or bradykinin in producing experimental hypotension. Its usefulness in treating high blood pressure in man is currently under investigation. Holothurin, a steroid saponin extracted from the Bahamian sea cucumber, suppressed the growth of certain tumors in some strains of mice.

Vast numbers of algae and other marine organisms contain substances that may contribute to control of human diseases, but the majority of these have yet to be studied in detail.

Living organisms of all kinds maintain a unique internal ionic composition that differs characteristically from the composition of the environment. In most animals this is reflected in higher intracellular concentrations of potassium and lower concentrations of sodium. Many functional activities such as muscle contraction, transmission of nerve impulses, secretion by some glands, activity of the kidney tubules, and absorption of digested food products depend on this concentration difference across cell membranes. The study of these basic cellular phenomena has been particularly advanced by the use of marine organisms.

The concept of sodium exclusion (sodium is kept out of the cell by a differentially permeable cell membrane) was first established in studies of the marine alga *Valonia*. Subsequent studies of the enormous nerve cells located in the stellate ganglion of the squid and some of its relatives showed that some sodium exclusion also characterized cells of the nervous system. Studies conducted on the giant nerve fibers of squid have provided almost all that is known about the mechanisms of conduction in the nerve fiber. The axons in the squid mantle nerves are nearly a millimeter in diameter, with a cross-sectional area 100 to 1,000 times larger than that of a single human nerve fiber. The size alone of these giant axons permits manipulations that would be impossible in other nerve fibers. Experiments have shown that the transmission of the nerve impulse results from a wave of changing permeability to sodium and potassium that sweeps over the nerve fiber, causing changes in electrical potential.

No single animal has been more important to the development of our understanding of renal function than the angler fish *Lophius piscatorius*, whose small body contains a kidney that lacks glomeruli (the filtering apparatus). One of the major contributions to renal physiology was the demonstration that urine can be produced without an initial filtration process. The discovery of the unique attributes of the angler fish focused attention on the requirements for determining glomerular filtration rates and thus directly contributed to the development of the methods now most widely used by human clinicians to determine kidney function.

Studies have clearly described the mechanics and thermodynamics of muscle contraction, using marine and terrestrial animals. The giant barnacle, *Balanus nubilis*, contains single muscle fibers up to 10 cm long. It has been shown that in this giant fiber the electrical potential of the contracting muscle is due only to calcium flux. This observation on this marine organism has sparked a series of researches in higher animals, establishing the importance of the calcium ion in the contraction of both skeletal and cardiac muscle.

The visceral organs of many fishes of the puffer group contain a virulent poison, tetrodotoxin, that is responsible for much human distress and some fatalities each year. Pharmacologists have identified the mode of action of this material, and chemists have determined its molecular structure. Tetrodotoxin owes most of its effectiveness to its ability to inhibit the ionic active transport processes on which nerve conduction, muscle contraction, and kidney tubule function depend.

The ready availability in nearly limitless numbers of ova and spermatozoa of marine animals has made possible tremendous progress in the understanding of the biochemistry of development. Gametes from marine organisms have provided raw materials for the extraction, purification, and characterization of DNA, the fundamental substance of heredity. The concept that the amount of DNA in the nucleus is directly proportional to the number of chromosomes was developed in a marine organism and provided the start for many studies of the role of the nucleus in cellular synthesis and growth and thus provided useful tools for the development of modern biochemical genetics.

The gametes of marine organisms have also provided raw materials for the definitive studies of the mechanics of the division process, by which cells multiply and by which cellular ingredients are partitioned among daughter cells. These processes are fundamental to an understanding of the orderly development of higher animals.

Fishes supply excellent clinical subjects for the study of activities helpful to man's well being. There are at least 30,000 species of fishes, as compared to 5,000 species of mammals. Fishes live under a wide range of ecological conditions such as temperature, salinity, pressure, and acidity. Like many mammals, they make excellent animals for biomedical research. Fish show behavior patterns of high order. Their body plan, tissue architecture, and physiological functions are essentially the same as in mammals. Some fish are vegetarians, while others are meat eaters. They all require proteins, carbohydrates, and fats for nourishment, and they need essential amino acids, vitamins, hormones, and minerals for proper growth. They are also subject to stresses not unlike some of those that affect man. They are susceptible to diseases, many of which are counterparts of human ailments, such as viral and rickettsial diseases, tuberculosis and various fungus diseases, trypanosomiasis and schistosomiasis, tumors and other cancers, and to environmental stress and pollution. In addition, fishes develop vitamin-deficiency diseases such as polyneuritis and anemia, degenerative diseases such as cirrhosis and fatty degeneration of the liver, and many metabolic disorders, including cataracts, gall and urinary stones, and diabetes. Even the inflammatory responses are similar in many respects to those seen in mammals. Fishes also get old, and if not eaten by predators, die from natural causes.

Fishes are good assay and test animals for pollution and for such biologics as toxin, hormones, vitamins, antimetabolites, and antibiotics. The aggressiveness of Siamese fighting fish and the pigmentary complex of most fish are built-in systems for analyzing cholinergic and adrenergic drugs. There are hundreds of publications on fishes dealing with evolution and genetics, physiology and pharmacology, histochemistry and cytochemistry, parasitology and pathology, reproductive and behavioral studies, and even in aerodynamics!

Of even more direct medical importance is the study of the mechanisms by which organisms are made aware of changes in their environment. Receptor physiology has been investigated in a variety of marine animals, and the results of these studies have been applicable, almost without modification, to man. For example, investigations of the biophysics and biochemistry of vision in the horseshoe crab *Limulus* have done much to clarify the fundamental problem of photoreception and the relationship between incident energy and the generation of the nerve impulse in the optic nerve. These results have direct application to the visual processes in man.

Such basic studies conducted on marine organisms have all contributed significantly to our understanding of normal human function. They add to the long list of contributions of aquatic biology to the welfare of man.

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