AQUATIC ANIMAL PROTEIN FOOD RESOURCES --

ACTUAL AND POTENTIAL

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SUMMARY

World production of food from aquatic sources reached a plateau during the 1970's. Total yields of fishery products approximated 70 million tons, including about 10 million from fresh water. Aquaculture production accounted for almost 10 percent of the total. United States production from commercial fisheries is currently only about 3 million tons.

Capacity for future expansion of production from aquatic sources exists, but fisheries on natural populations will be dependent on well-managed but limited stocks of "traditional" species, and on increased utilization of "non-traditional" species. Greatest expansion potential is in aquaculture, particularly in estuarine/coastal waters, but to some extent in fresh water as well. The next two decades should see the parallel development of culture of herbivores and omnivores yielding low-cost animal protein, and high technology intensive culture yielding high unit value products.

Effective environmental management will be a key to continued or increased production of protein food from aquatic sources. Coastal/estuarine pollution is a critical present problem, especially near high densities of human population. It is a problem amenable to solution, if national and world priorities for food production so dictate.

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INTRODUCTION

Whenever the interrelated subjects of world population and world protein production are discussed, the conversation ultimately gets around to the role that aquatic animals can, and undoubtedly will, play in meeting future human nutritional needs. It seems important, therefore to assess as objectively and candidly as possible, the present and potential contributions from the aquatic environment to the protein food supply -- to sort out the myths from the realities. The sorting process can be a sobering experience, particularly for those who feel that somehow, if famine stalks the land, the seas will provide.

Since over 70% of the earth's surface is covered by water, and since an enormous amount of plant and animal production goes on in the world's oceans and fresh water, it should be reasonable to expect a greater food yield than we have had so far. The amount of increase that is possible is a subject of much discussion and extensive misunderstanding. It seems evident, though, that any increased yield from the oceans will not be food of plant origin, since the predominant plant production there is in the form of microscopic algae not easily harvested or utilized by humans. The importance of the ocean now and in the foreseeable future is and will be as a source of animal protein (at present about 13% of the world's animal protein is derived from aquatic sources).

Realistic appraisals of the productive potential of the oceans have been made recently. It has become clear that in the sea, just as on land, there are great areas of very low productivity. Most of the really productive areas huddle close to shore, over the continental shelves and in the estuaries, or follow the great current systems of the oceans. Ninety percent of the world's catch of fish is taken on the continental shelves, but less than 10 percent of the ocean surface is over the shelves. Furthermore, we still do not "harvest" most species in the real sense, because we have no control over planting or survival, nor do we fully understand the extent of the standing crop or the dynamics of its production. The marine fisheries still exist largely at a hunting economy level (or at best a primitive range management level), except for slow inroads being made by legally constituted national and international fisheries management bodies, and by the halting emergence of aquaculture as a significant factor in aquatic food production.

There is a large amount of current activity in the United States and elsewhere concerned with management of natural populations of fish and shellfish, as well as aquaculture development. With the enactment of the Fisheries Conservation and Management Act of 1976, the United States assumed fisheries jurisdiction on its continental shelves, and is now in the early and painful throes of attempting rational conservative management of fish stocks, some of which had been heavily exploited and depleted by efficient foreign distant-water fleets since the early 1960's. Other nations have extended their fisheries jurisdictions, and there are numerous efforts -- national and international -- to manage fish stocks to ensure sustained yields of "traditional" species. There are also continuing efforts to expand fisheries to underutilized or unutilized "non-traditional" species wherever they exist in adequate concentrations in the world oceans.

Concerning aquaculture, a federal interagency committee is at present drafting a national aquaculture plan for the United States, and aquaculture development bills have been introduced yearly (without success so far) since 1977. The National Oceanic and Atmospheric Administration (NOAA) supports aquaculture research and development programs at several of its National Marine Fisheries Service laboratories and through grants to universities from its Office of Sea Grant. The Department of Interior is responsible for fresh-water aquaculture, and other federal agencies are involved in lesser ways. The Department of Agriculture was named lead agency for aquaculture in the Food and Mariculture Act of 1977. Internationally, FAO has an active program of fishery development in many nations, with aquaculture one of the foci. The International Council for the Exploration of the Sea has taken new interest in marine aquaculture since 1977, and has a number of working groups involved in areas such as pathology, introductions of non-indigenous species, and genetics. Additionally, there are numerous bilateral activities around the world, such as the United States-Japan Natural Resources Panels on Aquaculture (UJNR), encouraging joint projects and exchange of technology.

This paper attempts to look broadly at food production from aquatic sources, with emphasis on marine contributions -- present and potential. The emerging role of aquaculture, despite significant constraints, is also considered against a background of continued production from fisheries on natural stocks.

FISHERIES ON NATURAL STOCKS

Despite the limitations of our vision, there is cause for reasoned optimism when considering food production from the world's oceans. During the period 1950 to 1970 harvests from fisheries on natural populations of marine animals tripled, with an average annual increase in landings of about six percent, from eighteen million tons in 1950 to 60 million tons in 1970. (The catch from fresh water in 1970 was estimated at just over 10 million tons, making a grand total from aquatic sources of about 70 million tons). Beginning in the 1960's, fisheries on natural stocks were dominated by highly efficient fleets of modern fishing vessels, principally from the European socialist countries (Figure 1). Production peaked in 1970, then leveled off and even declined slightly during the current decade, due in part to a reduction in herring and Peruvian anchovy catches and to the very recent restriction of fisheries resulting from extension of fisheries jurisdiction out on the continental shelves by a number of nations, including the United States.

Constraints on increases in food production from marine fishery sources are severe. A number of stocks of "traditional" food species, such as cod, haddock, certain flounders, lobsters and redfish, are fully exploited, and have been in some instances overexploited; landings in recent years have

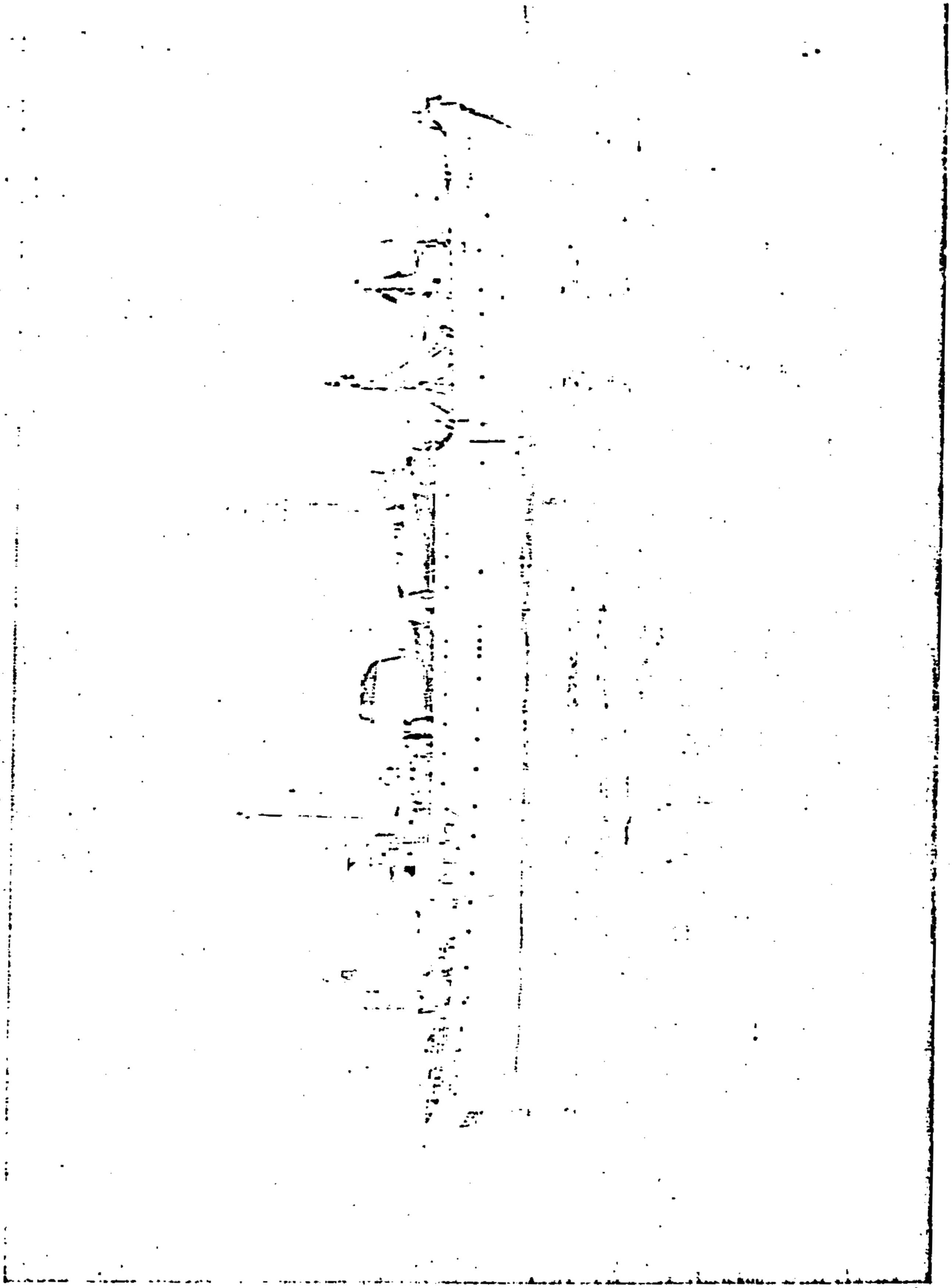

Figure 1. Soviet factory trawler of 2500 tons photographed on Georges Bank in the Northwest Atlantic in 1969.

been sustained by development of fisheries for non-traditional species. Costs associated with fishing -- particularly fuel costs -- have escalated alarmingly, and concern has been expressed about impacts of coastal pollution on fisheries.

Despite these constraints, estimated production from United States commercial fisheries in 1978 was a record 3 million tons, with an ex-vessel value of $1.8 billion (the previous record was 1962 with 2.7 million tons). Leading species in 1978 were (in quantity) menhaden, crabs, shrimp and salmon) and (in value) shrimp, crabs, salmon and tuna). These are all food species with high unit value, except for menhaden which is processed for fish meal and oil. This record catch still constitutes only about 5 percent of the world total, despite the fact that the continental shelves of the United States are among the most productive in the entire world. (By comparison, the estimated harvests by Japan and USSR were each in excess of 10 million tons).

Many knowledgeable fishery scientists have accepted an annual global production of roughly 100 million tons of traditional fish species as a maximum expected yield from the oceans, with an uncomfortably large range -- from 21 million tons to two billion tons (and with one estimate by Graham and Edwards (1962) at 60 million tons). More recently this figure of 100 million tons has been revised downward (Hennemuth, 1979), and the present catch of 60 million tons of traditional species seems more plausible on a sustained basis. (It should be recognized, though, that this estimate would be considered very conservative by some authorities, who cling to the 100 million ton or higher sustained yield estimate. Also, the estimate does not take into account changes in marine climate, which may affect future yields of important species).

Further increase in world food production from the sea is feasible, but it will depend more and more on utilization of natural stocks of non-traditional species now underharvested (such as squids, Antarctic krill, and some of the small herring-like fishes) or not harvested (such as lantern fishes); on technological advances that increase the efficiency of capture; on better utilization of fish that are harvested (a greater percentage of the catch used for direct human consumption, rather than for fish meal and oil); and on solution of economic, environmental and institutional problems which now suppress expansion of marine aquaculture. World food production from aquaculture now constitutes about ten percent of total fisheries production, and there have been substantial advances in the technological base for aquaculture, for marine as well as fresh-water species.

In examining world fish catch statistics, it is important to note that over one third of the total is not used directly as human food, but is processed into fish meal and oil and the meal is fed to domesticated animals in those few countries that can afford such expensive animal protein. Thus the fish become food for humans, but in a somewhat inefficient way, considering the loss during conversion of fish protein to pig or chicken protein (a loss of 60 to 70%). The inefficiency becomes much less significant, however, when fish which are considered inedible or undesirable as food for people are turned into pork or chicken. Despite this, there is still a challenge to find ways in which fish proteins now fed to domestic animals can be prepared in forms acceptable for direct human consumption, to avoid the inevitable loss in conversion.

AQUACULTURE

Aquaculture, defined as the culture or husbandry of aquatic organisms in fresh or salt water, yielded an estimated six million metric tons of food in 1975 -- less than ten percent of the world production of fishery products*. Yields from aquaculture doubled in the period 1970 to 1975, according to FAO statistics; much of the increase was in high-unit-value species in developed countries. Some countries now depend on aquaculture for a significant part of fish and shellfish production. Japanese aquaculture production increased fivefold (to 500,000 metric tons) in the period 1970 to 1975 (Figure 2), while Israel now derives almost half its finfish production from aquaculture. Additionally, there has been expansion of traditional culture practices for carp, milkfish, tilapia, and other species in many countries, particularly in Asia.

Aquaculture in the United States

United States aquaculture production in 1975 was estimated at only 65,000 metric tons -- slightly more than two percent of U. S. fish and shellfish landings and about one hundredth of estimated world aquaculture production. Even this limited amount still constituted (in 1975) about a quarter of our salmon production, about two-fifth of our oyster production, and about half of our catfish and crawfish production.

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*This may be an underestimate, in that estimated aquaculture production from fresh waters of the People's Republic of China has recently been revised upward by some informed observers (Ryther, 1979), to be in excess of 10 million tons.

Figure 2. Extensive system of racks from which shell strings are suspended to catch oyster seed, Matsushima Bay, Japan.

Aquaculture in the United States must look to fresh water for its past successes. Aquaculture of trout, salmon, and catfish in fresh water is well established. Trout and salmon culture began early in the century to be an important factor in sport fishery production and stream rehabilitation; catfish culture in the southeastern states has been a viable and expanding industry for over a decade. Recent exciting developments in fresh water include the successful expansion of introduced populations of salmon in the Great Lakes, pilot-scale polyculture of fish in ponds, and the commercial success of crayfish and minnow culture in the southeastern states.

Future expansion of United States aquaculture should be in estuarine and coastal waters, with salmon, shrimps, and bivalve molluscs leading candidates (Kaul and Sindermann, 1978). The history of salmon production on the west coast of the United States includes a number of dramatic changes -- high levels of natural production in the early days of the 20th century; drastic decline due to overfishing, building of dams and increasing industrialization; partial rebuilding of stocks with the development of a system of public hatcheries; and most recently, the exploration of pen culture in sea water and the beginnings of private ocean ranching of salmon in the Pacific Northwest.

Shrimp production in the United States has long been dominated by the Gulf of Mexico fishery on penaeid species. Recent developments include expansion of shrimp fisheries elsewhere in the United States, gradual but significant annual increases in imports of shrimp, and initial attempts at commercial culture of penaeids as well as fresh-water shrimps of the genus <u>Macrobrachium</u>.

Molluscan shellfish production is still dominated by landings from fisheries on natural stocks, particularly from Atlantic surf clam populations. Oyster production methods have long employed simple culture techniques, but the development of commercial hatcheries as a source of seed is becoming an important method of augmenting production.

Aquaculture is a logical aquatic counterpart of agriculture. A reasonable assumption would be that the development of the animal husbandry component of aquaculture in the United States and elsewhere could follow the same sequence of steps as did modern agriculture (selective breeding, disease control, diet formulation, automation, etc.). Unfortunately, there are fundamental differences which emerge when comparing agriculture and aquaculture. Agriculture development met a specific 20th century need for increased food production; it was built on a core of already-domesticated species; and it was supported by relatively generous funding for both applied and fundamental research. None of these factors have existed or now exist for aquaculture.

Attempts to find parallels with agriculture must be carefully circumscribed, since it is highly unlikely that aquaculture will ever replace fisheries on natural populations to the extent that terrestrial animal husbandry has replaced hunting as a protein food source. Aquaculture production in estuarine and near-shore waters could conceivably surpass production from wild stocks of the continental shelves and open ocean, but such offshore areas are unlikely candidates for the effective environmental control required for aquaculture and will probably remain for the foreseeable future as a source of food only from fishing. Only estuaries and protected coastal waters are amenable to the manipulations required for aquaculture, and even these environments are often resistant to man's attempts at control. Despite such resistance, these margins of the sea are where significant protein food should be produced by aquaculture in the decades ahead. The extent of potential production can be perceived only dimly, but is substantial.

A recent well-researched report (1978) by the National Academy of Sciences, titled "Aquaculture in the United States" offered a number of perceptions about the future of aquaculture in the United States. Significant among the conclusions reached were these:

"...in the United States, aquaculture will have only a minor impact on food production in the near term, in comparison with other food production systems".

"...in the long term, aquaculture will be a means of increasing protein supplies".

"...aquaculture has the potential to contribute to increased food production. If this potential is to be tested, expenditures for current programs and for research and development must be increased".

"Constraints on orderly development of aquaculture tend to be political and administrative, rather than scientific and technological".

"Aquaculture in the United States has lacked coherent support and direction from the Federal Government. Poor coordination, lack of leadership, and inadequate financial support have traditionally characterized programs relating to aquaculture".

World Aquaculture -- Projection

From an international perspective, there is cause for reasoned optimism when considering increased food production from aquaculture. Despite institutional, economic, environmental, and technological constraints, global yields are increasing. Intensive culture of high-unit-value species, such as pen-rearing of yellowtail in Japan, is now the basis for a large and economically-viable industry; salt-water rearing of salmon is approaching the point of economic feasibility; and pond and raceway culture of shrimp is now in pilot-scale production. Additionally, extensive culture of animals which utilize very short food chains -- such as oysters, mussels and mullet -- has the potential for enormous expansion with existing technology. The recent (1976) FAO Technical Conference on Aquaculture reported encouraging progress in aquaculture in the past decade; realistic estimates place future yields at twice the current (1976) level (6 million tons) by 1986, and five times the current level by the year 2000 "if the necessary scientific, financial and organizational support becomes available".

This optimistic report must be tempered by the observations that the recent increases in aquaculture production may reflect better statistical collection rather than any real increases in production, and that further increases will be determined largely by the kind of support provided. The overriding force in development of modern aquaculture is clearly a perceived national economic need. Those countries which have recognized such a need and developed a national aquaculture policy (Japan and Israel, for example), have moved furthest toward significant production, while other countries (such as United States), without a recognized need or policy, have made little progress, except to increase the amount of available technical information.

Development of energy-intensive, high-technology culture of species requiring high-protein diets will undoubtedly continue in the next two decades, especially in industrialized countries, but substantial production of herbivorous or omnivorous species in natural waters -- designed to yield relatively low-cost animal protein -- should expand even more rapidly, *particularly in developing countries, and particularly in tropical and* subtropical areas with year-round growing seasons. An important role for the industrialized countries (probably functioning through FAO) will be to improve and promote the use of the technology required for extensive culture production of inexpensive animal protein in less-developed parts of the world (by such methods as genetic selection for high food-conversion efficiency and rapid growth, testing of low-cost diets from natural products, training of technicians, etc.). Additionally, there is a significant educational role beyond training for production -- a role in encouraging changes in diets and in encouraging acceptance of aquaculture as a major occupation. The role of aquaculture in integrated rural development, through provision of better diets, jobs, and cash crops, can be significant in developing countries. Aquaculture there would be primarily in the form of small-scale, low-technology, labor-intensive operations, conducted in lakes and ponds or in coastal waters.

The potential of ocean ranching -- not only of anadromous species, but also of coastal-migratory species -- will be exploited within the next two decades, and substantial increases in yields (as well as augmentation of fished stocks) can be expected in proportion to public and private investment in this exciting new approach to fish production, which involves rearing and release of juveniles to forage in natural habitats. An important qualifying comment here would be the need for consideration of impacts of introduced populations on natural stocks, and the need to determine and consider the total carrying capacity of the ocean areas involved.

Expansion of food production through aquaculture must be a matter of national policy and national priority -- much as the expansion of distant-water fishing fleets was in many countries (particularly the European socialist countries) during the decade of the 1960's. Included in such policy would be improvement in the technological base, development of legal protection for aquaculture enterprises, control of coastal/estuarine pollution in grow-out areas, and encouragement of capital investment. With increasing restriction on harvests from fish stocks in continental shelf waters of other nations brought about by extended fisheries jurisdictions, the aquaculture option should become much more attractive and compelling on a world-wide basis as a protein food source.

EFFECTS OF POLLUTION

We must, if we are to realize the potential food production of inshore waters, reduce the massive and increasing pollution load that has already had significant local impacts on a number of commercial fish and shellfish species. Destruction and degradation of estuaries is of particular importance, since many of the fishes of the continental shelf are dependent on these inshore waters, particularly during the early part of their lives, and most shellfish are produced in estuaries or close to shore. In these very important estuaries, environmental degradation includes physical modification by diverting fresh water outflow, dredging channels, and filling marshlands -- in addition to chemical and biological alterations caused by domestic and industrial pollution. Estuarine populations of commercial species decline and disappear as industrial pollution makes conditions for life untenable -- or the survivors of these species are legally excluded from markets because they are contaminated and represent a danger to the health of human consumers. This process continues and accelerates at the present time. For example, each year there is a net loss nationally of about 1.2 percent of United States shellfish growing areas due to legal closure because of increasing coastal/estuarine pollution. As human populations on the rims of the oceans (the bays and estuaries particularly) increase, pressures increase proportionately to remove water areas from both production of food and from use as recreational areas, and instead sacrifice them to so-called "industrial progress". We cannot talk sensibly about potential food production from areas that have been abandoned in this way.

In terms of pollution impacts on abundance of natural populations of fish, it is important to make as realistic an assessment as possible. This is difficult because pollution is only one of many environmental factors that affect survival and well-being of marine organisms. At present it is possible to identify severe <u>localized effects</u> of pollutants on fish and shellfish in bays and estuaries, and it is possible to demonstrate <u>experimentally</u> that contaminants such as heavy metals, petroleum hydrocarbons and synthetic chlorinated hydrocarbons, can kill or injure individual animals, but it is almost impossible to demonstrate general effects of environmental pollution on the abundance of resource species. It may be that such effects are occurring, but our baseline data and our monitoring programs do not yet provide adequate data to separate pollution effects from the "background noise" of effects of natural factors on changes in abundance of marine species.

Severe localized pollution problems exist in many bays and estuaries, which are, of course, prime aquaculture areas. Use of inshore waters for food production is absolutely incompatible with their use as waste dumping and discharge sites for an expanding human population. There can be no question of multiple use of these waters -- we must make a firm and permanent commitment of certain water areas to food production, if marine aquaculture is to have any future in the industrialized nations. Water quality is an overriding consideration.

An alternative might be culture of marine species in complete artificial environments -- totally withdrawing from dependence on the natural environment at any stage in the life cycle of the cultivated species. This may be feasible, especially for shellfish, where brood stocks could be maintained in trays (Figure 3), where larvae could be fed with cultured algae in artificial sea water, and where growth to market size could occur on racks in fertilized artificial ponds. At present these closed cycle artificial systems are well outside any cost-effective level, and, somehow, this retreat to artificial, energy demanding systems seems like an admission of defeat. Surely we should be intelligent enough to devise ways to take advantage of the tremendous productivity of unfouled inshore waters as a principal source of protein food for the human species.

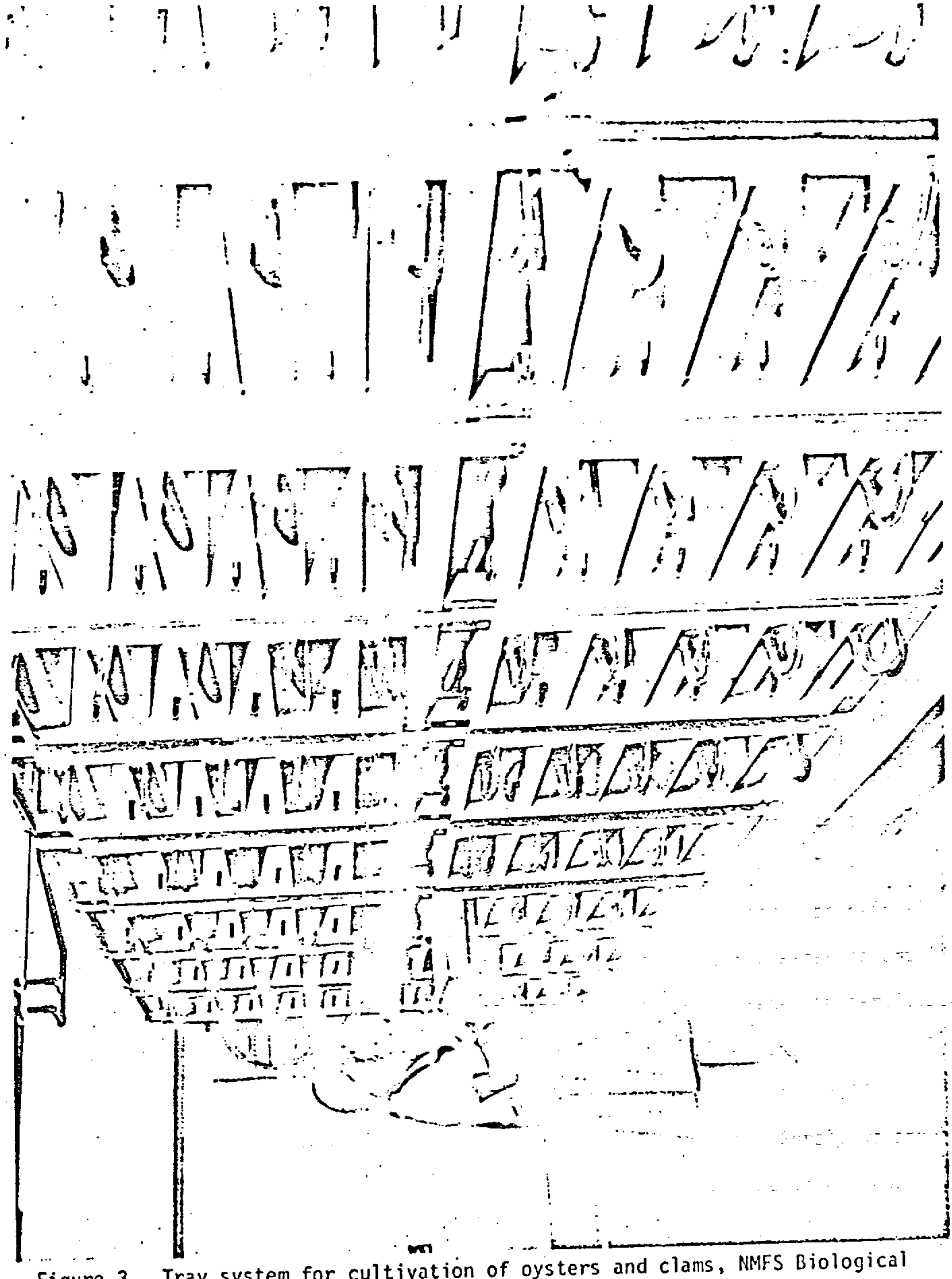

Figure 3. Tray system for cultivation of oysters and clams, NMFS Biological Laboratory, Milford, Connecticut.

*There has been much talk of cleaning up the aquatic environment, and much publicity given to a few fish reappearing in rivers that until recently were too foul for their survival. Unfortunately, much of the gain in rivers and canals has been at the expense of the estuaries and coastal waters -- we have simply moved much of the pollution problem seaward.

Decisions made now about the extent to which degradation of estuarine/coastal waters should be allowed to continue can have a very important bearing on aquaculture in the future. If the edges of the sea are considered important to the nutrition of future world populations (and I believe they should be) then actions must be taken now nationally and internationally to ensure that such production areas will be available to meet the developing need for protein food. We cannot afford to delay facing realities in food production (as we have with world petroleum consumption) until a crisis is imminent.

As a footnote, there is one positive aspect of what we have termed "pollutants" -- which is that domestic sewage wastes are made up principally of organic nutrients which can enhance natural productivity of coastal/estuarine waters. If very carefully controlled in amounts per unit area of water surface, and if free of toxic pollutant chemicals, such domestic wastes can serve as fertilizers. Growth rates of molluscan shellfish and certain other marine species can be increased dramatically by such limited additions of organics. If proper attention is given to protection of public health (possibly by depuration procedures), there is no reason why the organic nutrient residues cannot become a positive factor in nearshore productivity.

PROPOSALS FOR THE FUTURE

A concise statement of national goals for the United States in fish and shellfish production might be (1) to understand and manage effectively the renewable natural resource base, and (2) to supplement this base with aquaculture production where feasible.

Fisheries on Natural Populations

The continental shelves of the world will continue to produce fish and shellfish in amounts governed by biological principles of sustainable yields, by actions of fisheries management bodies sensitive to those principles, and by fishing power of nations.

Obviously, to fully realize the potential productivity of the oceans we need greater knowledge of the resources and their dynamics, and we need better methods of locating and catching marine animals, especially those in the lower links of the food chains (Figure 4). We must keep in mind that we are dealing with a renewable resource that is highly mobile, vertically and horizontally (except for shellfish); that can change in concentration and location daily or seasonally; and that reacts to variations in a number of environmental factors such as salinity, temperature, and availability of food. We must understand the population dynamics -- birth, growth, reproduction, longevity, death -- of exploited species to permit proper management, and we must also understand how marine populations interact. Only with such knowledge can we manage the entire ecological complex effectively, and predict distribution, abundance, and population responses to human predation.

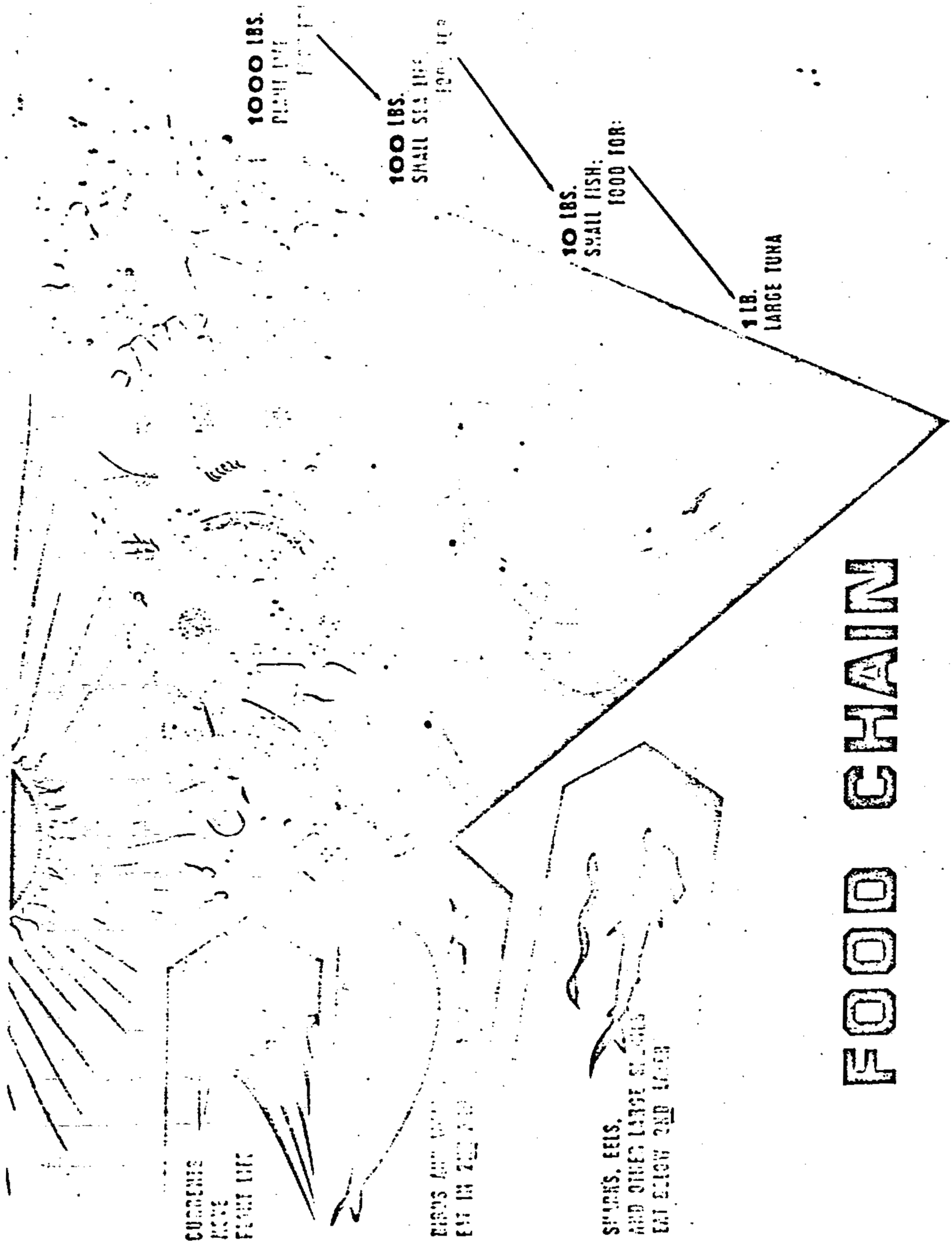

Figure 4. Food chains and feeding interactions in the sea.

The ultimate management form must be "total ecosystem management", which includes the habitat and the populations which act as prey, predators or competitors. This level of resource management is attainable but the level of understanding required will be difficult and expensive to achieve.

Within the concept of total ecosystem management, marine "range management" can be effective in the near term in areas of high productivity on the continental shelves. The degree of control is largely dependent on depth of water and the configuration of the shoreline. Coves and bays may be fenced or diked, predators or unwanted competitors may be selectively removed, salinities may be manipulated, and fertilizer may be applied. In open waters, management might take the form of crop rotation; particularly fishing grounds might be exploited for a certain number of months or years, then fishing pressure could be sharply reduced for a subsequent period. There is some concern that we are depleting stocks of valuable species on some fishing grounds with present selective fishing methods and thereby permitting expansion of populations of less desirable species. Assuming that some market can be found for all species -- either as food, as fish meal, or as fish protein concentrate, a possible management plan could be evolved that would encourage retention and use of all species and sizes taken in trawls, but would restrict fishing to a rather rigid pattern -- to certain squares of a checkerboard overlay of the fishing grounds, or to certain longitudinal tracts through the grounds. Such areas could be shifted annually or in some longer time sequence. This form of management involves the entire productive ecosystem, of which the exploited species are only a part.

Aquaculture

Despite some successes in production of a few fish species in fresh-water aquaculture (principally trout and catfish) in the United States, we cannot claim that marine aquaculture has yet reached a remotely comparable stage. At present marine culture is a high-risk venture with a number of uncontrolled variables. The necessary technology is being developed, but there is still a substantial amount of "art" involved in rearing marine animals. With a few notable exceptions, which involve substantial financial commitments by a few large companies, much of the aquaculture research and development in this country has been done by small underfinanced private ventures, or by underfinanced government programs. Large-scale research and development programs, adequately funded for a number of years, and representing joint industry-university-government action, are needed for each of the species which seem most amenable to culture. Emphasis must be placed on development of inexpensive, chemically defined, probably pelletized food; on genetic selection for rapid growth, disease resistance and suitable market qualities (flavor, texture, color); and on automated production systems. The present methods of poultry production and marketing in the United States provide an excellent model and illustration of what might be accomplished, despite continuing economic problems of the industry.

An interesting possibility is that marine aquaculture may be developed in the United States primarily to provide recreational salt-water fishing -- much as trout hatcheries were developed early in this century to provide fresh-water angling. Cultivated marine fish such as snappers and groupers could be used to stock artificial reefs; cultivated crabs and lobsters could be used to stock skin-diving areas; and cultivated clams could be seeded in inshore recreational areas -- just as examples of the possibilities. It may be that, as with trout hatcheries, a significant amount of the needed marine research and development work could be accomplished for the initial purpose of supplying recreational fishing, and that in time (again as with trout hatcheries) the culture operations would be economically feasible in themselves.

There are of course other channels for aquaculture production. Commercial catches of some species may be augmented by "ocean ranching", an activity in which young animals are reared beyond the most vulnerable early life history stages and then released into coastal waters. Some beginnings are being made with ocean ranching of salmon in the Pacific Northwest, and the Japanese are attempting similar augmentation of coastal migratory species such as shrimp and red sea bream. Such methods could be used as well in the future with certain endangered or severely depleted species.

Another interesting possibility is that marine aquaculture on a large scale may be vigorously supported as a policy by certain countries other than the United States which are interested in large quantities of animal protein. Through deliberate programs of price support, subsidy, or massive government research, development and production, some of the marine and estuarine animals that feed directly on plant plankton (oysters, clams, some herring-like fishes, and others) could be produced in great quantity. Nations with tightly controlled economies might well travel this route, if fishing on natural stocks decreases in productivity, or if vessels are excluded from major fishing grounds because of extended national jurisdiction.

CONCLUSIONS

Keeping in mind the many qualifications and obstacles discussed in previous sections, it seems that a number of general statements about food production from aquatic sources can be made.

1. The oceans will continue to be a very important source of high quality protein essential for human existence and well-being. At present, fisheries (fresh water and marine) provide an estimated 13 percent of the animal protein consumed by man.

2. Production of protein food from the oceans tripled during the two decades from 1950 to 1970, and has stabilized since then at about 60 million tons. There are still stocks of underutilized or unutilized marine animals -- particularly smaller forms (under 6 inches) and especially the herring-like fishes -- that must form the basis for any substantial increase in total ocean food production from natural populations.

3. Annual production of protein food from fresh water has been estimated at about 10 million tons, which may be a very conservative figure. Although some production in industrialized nations is derived from high technology culture of salmonids, most of fresh water production is from carps, tilapia, and other herbivorous or omnivorous species, particularly in Asia. Expansion of production depends on available water supply.

4. Aquaculture offers exciting potential avenues for increased production. Though now an insignificant contributor (less than 10 percent) to total food production from aquatic sources, if properly developed it could easily provide a much larger percentage of the total. Coastal and

estuarine areas seem most suitable for expanded efforts. For the foreseeable future, however, marine aquaculture will produce limited quantities of high-priced seafood, and will become a major source of inexpensive animal protein only if national policies so dictate.

5. Multiple uses by man of fresh and salt waters have led to habitat degradation that has adverse affects on living resources and is a serious deterrent to aquaculture. Because of pollution abatement measures, some improvements have been noted in fresh waters, but pollution of coastal and estuarine waters is increasing. Serious steps toward environmental management must be taken if food production from such waters is to be maintained or increased.

6. Despite decades of research, the problems of understanding and manipulating the dynamics of food production in the sea are still enormous. At present our knowledge is superficial, and much of it may be based on misconceptions. As a noted marine biologist (Walford, 1958) observed two decades ago, the oceans truly represent a frontier, not only in the literal sense, but also as a frontier in the minds of men -- as the boundary between knowledge and ignorance.

REFERENCES

Food and Agriculture Organization. 1976. Report of the FAO Technical Conference on Aquaculture, Kyoto, Japan. FAO Fish. Rept. 188, 93 pp.

Graham, H. W. and R. L. Edwards. 1962. The world biomass of marine fishes. pp. 3-8. In Fish in Nutrition. Fishing News (Books) Ltd., London.

Hennemuth, R. C. 1979. Marine fisheries: food for the future? Oceanus 22(1): 2-12.

Kaul, P. N. and C. J. Sindermann. (eds.). 1978. Drugs and food from the sea. *Univ. Oklahoma Press, Norman*, 448 pp.

National Academy of Sciences. 1978. Aquaculture in the United States. U. S. Govt. Printing Office, Wash., D. C.

Ryther, J. H. 1979. Aquaculture in China. Oceanus 22(1): 21-28.

Walford, L. A. 1958. Living resources of the sea: opportunities for research and expansion. Ronald Press, NY, 321 pp.