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Opportunities in Marine Science and Technology for Developing Countries

Board on Science and Technology
for International Development
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in cooperation with the

Board on Ocean Science and Policy
Commission on Physical Sciences,
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Board on Science and Technology
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Preface

Changes in the regime of the oceans in recent years has focused attention on investigation and management of marine resources. Having recently extended their maritime boundaries, both developed and developing coastal countries are exercising new responsibilities over the exploitation of renewable and nonrenewable marine resources. This has come about in part from advances in ocean science and technology. In many cases, however, efficient management and exploitation of these resources and protection of the marine environment will require increased understanding of ocean phenomena and strengthening of marine sciences in developing countries.

In many developing countries, fisheries are an important part of the national economy. They provide widespread employment, generate foreign exchange, and supply significant amounts of high-quality protein. Yet in numerous countries, the marine sector receives relatively little governmental attention compared with agriculture and land-based industry. Moreover, development funds have rarely been used effectively to promote the growth of new markets for marine resources or to apply new marine technologies.

The adoption of a 200-mile exclusive economic zone by most coastal nations provides an incentive for assessing the resources of near-shore waters, their economic potential and need for management, the training and research implications, and the possibilities for regional cooperation. The newly asserted "sovereignty" over these zones also lays new responsibilities on coastal nations, which become intermediate trustees for the judicious use of these areas. Obvious targets for development include more rational and productive fishing regimes and management for sustained yield, reduction of postharvest fishing losses and the waste associated with fish by-catch, and the development of aquaculture, offshore mining, ocean thermal energy conversion (OTEC), and coastal zone protection.

BACKGROUND OF THE REPORT

In 1981, a conference on international cooperation in marine technology, science, and fisheries, and the future U.S. role in development was held in La Jolla, California. Sponsored by the U.S. Agency for International Development (USAID), the National Oceanic and Atmospheric Administration (NOAA), the U.S. Department of the Navy, and the U.S. Department of State, this conference was attended by scientists from both developed and developing countries. The proceedings of the conference were published in 1981 by the National Research Council.* The volume contains the reports and recommendations of four regional working groups--Africa, Latin America and the Caribbean, the Near East and India, and Southeast Asia and Oceania--as well as a set of papers prepared by participants on various aspects of the marine sciences, with an emphasis on fisheries development (see Appendix B).

This report is based on these papers and on information assembled for that conference. It is intended, however, to acquaint a broader audience, particularly nonspecialist decision makers and planners in developing countries, with opportunities in the marine sciences and ways in which they can contribute to economic and social development. Future applications of marine science and technology, limitations of various technologies, and research and training needs are also discussed.

This report was drafted by Kim Devonald, NRC fellow, and edited by Sherry Snyder and Sabra Bissette Ledent. Cheryl Hailey assisted with the references and illustrations, and Irene Martinez typed various drafts. The final report was edited and prepared for publication by F.R. Ruskin.

National Research Council Staff

Michael McDonald Dow, Associate Director/Studies, BOSTID
F.R. Ruskin, BOSTID Editor
Irene Martinez, Text Processor

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*National Research Council. 1981. International Cooperation in Marine Technology, Science, and Fisheries: The Future U.S. Role in Development. National Academy Press, Washington, D.C., USA.

Contents

1 Introduction

The international ocean regime emerging from the protracted negotiations of the United Nations Conference on the Law of the Sea (UNCLOS) assigns new rights and responsibilities to coastal countries. With or without a universally ratified UNCLOS treaty, the establishment of 200-mile exclusive economic zones has greatly augmented the quantities of living and nonliving marine resources within each coastal nation's jurisdiction. If these nations are able to develop the appropriate assessment and utilization capabilities, these resources will yield increased supplies of food, minerals, energy, and the associated social and economic benefits from expanded resource bases.

These extended zones will mean benefits for the developing nations in particular: increased opportunities for the exploitation of fish, shellfish, and other living resources; extraction of fossil fuels and other minerals; resources for tourism; ocean energy sources; and the construction of facilities to support ocean commerce. However, it should be clearly recognized that full benefit can be derived from the exclusive jurisdiction only by nations that can use and apply the findings of marine science to management and extraction of the living and nonliving marine resources and apply modern technology and marketing skills to their utilization or sale. Inexpert exploitation undertaken without a well-thought-out management plan can lead to rapid depletion of a target resource, to inefficient recovery, and even to major changes in the marine ecosystem, which cause massive destruction of biological resources, physical changes in coastlines, and damage to coastal enterprises such as tourism or recreational ocean use. It is important, therefore, to recognize the key roles played by the various branches of ocean science in understanding marine environments and how scientific knowledge can be applied in resource management.

To manage and exploit their natural marine resources efficiently, developing countries must enhance their own scientific capabilities. During the early stages, this may require seeking scientific capabilities from abroad. However, here should be a rapid development of in-country capability by nationals through national or regional training and institutional development. Instruction and research institutions should be developed locally so that experimental training will be immediately relevant and scientific investigation will address problems of local importance.

In identifying the marine technical capabilities a country requires, it is important to recognize that each area of applied science depends on information about oceanic conditions and processes that only basic research can provide. Basic marine research is commonly categorized according to four scientific disciplines: chemistry, geology, physics, and biology. Although this categorization is especially useful in describing or planning programs in marine education or technical training, any object of marine research is affected by all four scientific areas, which are outlined in Appendix A.

Applied and social science disciplines also contribute to the day-to-day management and exploitation of marine resources. The principal applied science disciplines are ocean engineering and naval architecture, fisheries management and mariculture, and sanitary engineering for sewage and waste management. In the social sciences, there is a need to evaluate the economic, legal, administrative, and cultural aspects of the use of marine resources, so that national priorities can be set for their development. Methods, current concerns, and new capabilities found in a number of these fields are described in later chapters of this report.

2 Coastal Zone Development and Management

IMPORTANCE OF COASTAL DEVELOPMENT PLANNING

A large part of a coastal nation's valuable natural resources, from the extractable petroleum and other mineral reserves of the continental shelves to the harvests of fish and shellfish, are found in its coastal lands and waters. Coastal lands are also valuable for their accessibility to waterborne transport, their use as waste release and cooling-water sites for industry, and their special attractiveness for residence, recreational use, or tourism development. Unless proper precautions are taken, however, developing countries may find, as have many industrialized nations, that very difficult problems can arise from the use of their coastal resources. As populations grow and development proceeds, demands on limited coastal areas increase, and serious conflicts may arise among different users.

The impact of rapid and generally unplanned coastal development has created problems for industrialized coastal countries for decades. Unplanned development can lead to health hazards, environmental problems such as erosion and pollution, and declines in lucrative fishing and tourist industries. Industrial and urban waste and pollution from ports and harbors may contaminate coastal waters to the point that beaches must be closed to the public, or regional fish and shellfish are banned as unsafe for human consumption. Coastal earth-moving and building activities (dredging, landfilling, and wetland reclamation) can have major effects on suspended silt levels in coastal waters, coral reef survival, or erosion of beaches, embankments, and coastal properties.

The many uses of unpolluted, uneroded coastal lands can help support the basic needs of its residents and its economic development. If a nation's chief objectives in the use of its coastal regions are set out early in the course of development, decisions can be made on how best to allocate the limited coastal space, time, and money among the various types of land use. Early, coordinated planning of coastal development will allow time to identify economic opportunities and minimize the social and environmental problems that could result from land-use conflicts, erosion, or pollution.

Conflicts likely to occur during coastal development can be anticipated by considering the potential uses of the shoreline. These include:

- o Ports and harbors
- o Sewage and industrial outfalls
- o Power plants or other industrial plants with cooling-water intakes
- o Fishing ports and processing plants
- o Human habitation
- o Recreational beaches, marinas, and coastal parks
- o Commercial activities
- o Agriculture and mariculture
- o Ocean mining facilities.

Coastal nations need individuals with technical expertise and managerial competence and authority to identify and resolve the potential conflicts among uses of the coastal zone and to encourage and plan new kinds of development. To these ends, planners must analyze the economic and social costs and benefits of different uses. In this sense, coastal planning is as much a legal and political capability as it is a science. Management decisions may have to be made amidst political opposition from various groups, each of which wishes to obtain a maximum amount of coastal land for its own particular needs. Planners in all countries can benefit from exchanging ideas, technical information, and experience in managing coastal problems.

Another objective of planning is to preserve portions of some critical environments in their natural or relatively natural states--for example, coastal wetlands, mangrove forests, salt marshes, and coral reefs. These areas are valuable as nurseries for fish and shellfish, and they protect coastlines from erosion by retaining soil or buffering water movements. The goal is not to keep an entire coastline in pristine condition but rather to set aside certain areas as parks, preserves, or low-impact zones. Coastal preservation has two benefits: (1) it provides safe, clean breeding areas to ensure the continuation of important fish species (Figure 2-1), and (2) it provides coastal parks for tourism and recreation,

FIGURE 2-1 Coastal estuaries and marshes are rich in nutrients and planktonic food organisms, making them exceptionally good locations for the growth of many marine animals. Numerous fish and shrimp species of open coastal waters come into sheltered, shallow areas like these to spawn. (U.S. National Oceanic and Atmospheric Administration)

forest conservation, waterfowl and wildlife preservation, and the maintenance of nondestructive, traditional cultural pursuits such as collecting wild plants for domestic purposes or small-scale, nearshore fishing.

Several available reference works and practical manuals are specifically designed to meet the needs of coastal management planners in developing countries. Workshops on coastal management and development issues have been held for Asia and the Pacific (Asian Development Council 1978, Valencia and Neuman 1979) and the Caribbean region (Intergovernmental Oceanographic Commission 1979). A detailed review of coastal issues is included in a recent collection of articles on Southeast Asian development needs (Chia and MacAndrews 1982). The National Research Council (1982) recently reported on the principal coastal resource management and development needs of developing countries, and a guide to establishing coastal zone management programs in tropical developing countries is part of a recent general work on natural systems and development (Maragos et al. 1983).

EROSION AND WATERSHED MANAGEMENT

The transport of sediment along coastlines is a very serious problem. Fine silts and muds suspended by dredging or released by deforestation can smother and kill coral reefs and drive away fish along downshore coasts. Furthermore, sand can be stripped away from beaches when dams, harbors, or groins are built in the wrong places on adjacent rivers or coastlines. One short-term measure that helps alleviate beach erosion is the use of bulldozers to spread new sand on eroded beaches. When erosional conditions exist, however, new sand will also be washed away in a few months unless authorities undertake large-scale coastal engineering projects, such as sand diversions at nearby harbor mouths (which act as sand traps) or properly located protective groins. Sand also creates major problems when it accumulates unexpectedly in improperly designed marinas and harbors.

Coastal engineering projects of all kinds--dredging, harbor construction, marsh or estuary draining, landfilling, stream diversions, or the damming of rivers--have major effects on the transport of coastal sediment. Altered transport, erosion, and deposition rates often produce changes quite different from those originally anticipated. Coastal planners must ensure that the necessary sediment transport stabilizing and "buffering" properties of some shoreline features such as mangroves and marsh vegetation are not eliminated by excessive destruction (Figure 2-2). Two reports have focused on problems resulting from excessive mangrove destruction (UNESCO 1979, International Union for the Conservation of Nature and Natural Resources 1981).

Along "high-energy" (exposed to heavy surf) tropical coastlines, coral reefs often function as the principal erosion buffers. Their destruction by coral mining, channel dredging, or dynamite fishing can result in the loss of adjacent beaches and increased saltwater contamination of brackish and fresh waters near the shore. A description of the effects of certain widespread tropical environmental problems on the health and survival of coral reefs is given by Johannes in a volume

FIGURE 2-2 Mangrove trees help prevent erosion. Extensive mangrove destruction for land clearance or, in some fuel-poor areas, simply for firewood, often results in a major receding of the shoreline and the washing out of soils into coastal waters. (U.S. National Oceanic and Atmospheric Administration)

summarizing a number of tropical pollution problems (Wood and Johannes 1978).

The coastlines of large lakes, such as the Great Lakes of North America or Lake Malawi in Africa, are similar in many respects to ocean coasts and are subject to similar erosion problems. The United States recognizes the comparability of lake and ocean management needs, and states with extended lake shores are included in the national coastal management program. One method of shoreline stabilization that has proved effective along the Great Lakes is planting specially selected, fast-growing grasses under the auspices of the coastal zone management programs of individual states.

POLLUTION CONTROL AND MONITORING

Planners must keep in mind the "externalities" (factors outside the basic economic profit-and-loss calculations) likely to be produced by some kinds of coastal zone use, particularly the industrial pollution of nearshore and estuarine waters.

FIGURE 2-3 Blights, such as this polluted salt marsh (above) and this detergent-filled estuary (opposite page) whose populations of fish, shellfish, or wildlife are being destroyed, can sometimes be prevented or reversed if nearby industries are required to moderate their releases of organic wastes into rivers and estuaries or to divert their discharges into better-flushed coastal waters. (U.S. Environmental Protection Agency)

Of the principal kinds of pollutants found in the ocean, some, including organic pollutants (such as partially treated domestic sewage or detergents) and agro-industrial wastes (from breweries, canneries, sugar refineries, etc.), are harmful to marine organisms because they upset ecological balances and produce harmful conditions such as oxygen depletion or excessive algal growth and decay (Figure 2-3). Although organic pollutants are not highly toxic to humans, they can kill fish and shellfish and make beaches unpleasant for recreational use. Their release into the ocean should be monitored, and dispersion methods should be developed to prevent their buildup to harmful levels. Other kinds of pollutants, including various chemicals and some forms of disease-causing microorganisms, are directly toxic to humans. Their release into marine environments must be carefully controlled to prevent poisoning, sickness, birth defects, or other health problems.

Toxic Wastes

The dangers posed by chemical contaminants released into the ocean from industrial or agricultural pest control sources are in many cases not yet well described. It is possible that a number of chemicals that appear to have harmful biological effects in laboratory tests are not likely to build up to dangerous levels in ocean waters once plant effluents have been dispersed through well-designed ocean disposal systems.

Many substances are much more highly concentrated in the tissues of marine animals and plants than in surrounding waters. For example, some harmful chemicals become increasingly concentrated in animals at successively higher levels in the food chain, so that the largest fish, fish-eating birds, sea mammals, and humans are found to have higher levels of the chemicals in their bodies than are found in lower animals. Some of these chemicals have not, in fact, been shown to be harmful to people. The pesticide DDT, for example, may cause improper eggshell production in pelicans, but it has no proven effects on mammals or people. But certain other industrial chemicals and pesticides that pollute coastal waters have proved capable of causing serious health problems and, in a few cases, have been documented as causing illness, birth defects, and death in humans who ate fish or shellfish from the polluted water. Toxic heavy metals, mercury, and lead, for example, used in a number of industrial processes, are often released in high concentrations in industrial effluents. The most widely known case of human mortality from marine pollution--the "Minamata Bay incident" in Japan in the early 1950s--involved birth defects, illness, and deaths among people who had eaten fish from a bay polluted by mercury from a local chemical plant. Pesticides, which are used in very large quantities in many developing countries, are carried in rivers and groundwater systems or even by air (dust borne) to coastal waters, where scientific studies find them concentrated in the tissues of shellfish and fish (National Research Council 1982).

While research on the toxicity of many of these chemicals to higher animals and man has typically not been completed or fails to be conclusive, certain pesticides used extensively throughout the world have been proved to cause cancer or be harmful in other ways. One of the best studied of these is toxaphene, a cancer-causing pesticide sprayed on cattle and used for other agricultural purposes in dozens of countries. The buildup of this and other pesticides in nearshore ocean waters is a serious contamination problem because these substances can be harmful in even very tiny amounts, and they are detectable in marine animals only when technically advanced chemical assays are made (Goldberg 1981). Thus the effects of toxic chemical pollution are not immediately identifiable, unlike the obvious environmental effects of eutrophication (algal overproduction) associated with simple organic pollution.

Methods for preventing and monitoring toxic waste pollution must be applied systematically, based on the best technical information available to health officials and coastal managers. Toxic waste management involves several steps. First, sources are identified by analyzing water, sediment, or animal tissue from coastal or estuarine water, and from factory-release points or principal farm runoff sites. Second, for especially dangerous substances, regulations are applied to reduce their release to the environment by purifying wastewater or transforming solid waste into more manageable (or at least retrievably stored) forms. Finally, in cases where coastal oceanographers and health experts agree that proper environmental dispersal will produce concentrations low enough so as not to harm humans and important marine animals, dilution and release methods calculated to maximize dispersion are applied. When constructing coastal waste release systems, it is extremely important that information on nearshore current patterns and ocean flushing rates be available. Simply placing an industrial or sewage outfall pipe at an alternative site, or extending it farther offshore into better flushed waters, can result in greatly decreased concentrations of pollutants in water along the shore (Maragos et al. 1983).

Sewage

Of the contaminants contained in domestic sewage, the various disease-causing microorganisms can present the most direct threat to human health. In developed countries, effective methods for sewage treatment, monitoring, and safe release into the environment are known and widely used. While eutrophication still causes substantial difficulties in developed countries, the spread of disease from treated sewage is generally not a major problem. In most developing countries, however, sewage treatment (or its absence) remains a primary health concern.

When waste is released into the marine environment, sanitary engineers familiar with marine hydrographic patterns and impact studies can be of great assistance in developing cost-effective systems of sewage release. For example, the sanitary engineers and scientists affiliated with major institutions of coastal engineering and related private firms could help with such an effort. Chemical or biochemical treatment methods found commonly in developed countries are quite elaborate, but effective, less expensive systems can be used in developing nations. Considerable money can be saved by advance planning and selection of release sites.

Oil Spills

As the volume of oil transported by sea has increased, pollution of oceans and coastlines is viewed with growing concern around the world. The risks of large spills grow with the increase in numbers of large supertankers.

Oil spill contingency plans have been developed in many regions, and detailed information on how to prepare for oil spill emergencies is available from several international organizations and assistance programs such as the Regional Seas Programmes of the United Nations Environment Programme (UNEP), the Oil Spill Contingency Planning reports of the U.S. Agency for International Development, and others (see "Selected Readings"). Information is not yet complete on the dangers to marine animals and plants (or to people who eat seafood) caused by chronic or catastrophic marine oil pollution. However, it appears that the principal dangers to food chains are caused by certain chemical components of oil (that is, by certain of the petroleum hydrocarbons--PHCs), so that oils of different PHC compositions may have different effects. In addition, many of the detergents used to disperse spills are at least as harmful to marine life in the water or on the seafloor as the oil itself. One serious consequence of an oil spill in tropical regions--especially in areas where reefs are important fishing grounds, or where tourism associated with deep-sea diving and beach use is a major industry--is that a slick might drift onto a coral reef, smothering and damaging the tiny coral polyps and often killing the entire reef.

Pollutant Monitoring

Ocean pollution is most serious in partially enclosed seas surrounded by heavily populated or industrialized land areas such as the Mediterranean, the Baltic, the Caribbean and the Gulf of Mexico, the North Sea, the Persian Gulf, and the archipelagos of East Asia. In all these areas, the bordering countries (encouraged by the United Nations Environment Programme) have entered into regional agreements to cooperate in monitoring and if possible in mitigating pollution.

Off the coasts of the United States, Indonesia, and a number of other countries, the "mussel watch," initiated at the Scripps Institution of Oceanography (Goldberg 1975), has proved to be an effective device for pollutant monitoring. These filter-feeding organisms extract and concentrate heavy metals, chemicals, and infectious organisms in the seawater. A similar "oyster watch" has been recommended in East Asian waters (Intergovernmental Oceanographic Commission 1976).

Safe radioactive waste disposal presents a separate problem of determining whether safe disposal areas in the ocean even exist, for example, the tectonically inactive centers of oceanic crustal plates where these wastes might remain undisturbed for millenia (Frosch et al. 1978). The issue of nuclear waste disposal is very difficult, and the best interim solution seems to be use of retrievable storage modes while alternative final disposal methods are evaluated.

General information on principal tropical marine pollution problems and their causes is provided in a review edited by Wood and Johannes (1978). The details of a cooperative international marine pollution monitoring program suitable for all countries, based on the regular collection of shellfish samples for either local analysis or shipping abroad to better equipped analytic facilities, are given in the 1980 National Research Council report, The International Mussel Watch, and in Goldberg (1978). The Food and Agriculture Organization (FAO) of the United Nations publishes guides for monitoring shellfish and finfish contamination and, through a special international group of experts formed to study worldwide marine pollution problems, has published a series of reports on various scientific aspects of marine pollution (Group of Experts on the Scientific Aspects of Marine Pollution 1971, 1977, 1980). More specific pollution management references are given in "Selected Readings."

PROTECTION FROM NATURAL HAZARDS

Protection from climatic and ocean phenomena is needed for both the inhabitants and the artificial and natural structures of the coastal zone. Residents and their buildings must be protected against catastrophes such as tsunamis, hurricanes, floods, and erosion Figure 2-4). Reviews of natural hazard protection methods for coastal countries are given in White et al. (1978) and Mitchell (1979).

In the late 1960s, a giant storm surge caused by a hurricane in the Bay of Bengal killed 500,000 people in low-lying land near the coast of Bangladesh. In subsequent years, similar monstrous waves claimed many lives on the northeastern coast of India. To prevent such catastrophes, a warning system and places of refuge are needed, recognizing the enormous problems of warning a dispersed rural population without modern communications. An understanding of how storm surges are generated in particular locations (in relation to the motion and intensity of hurricanes over the nearby ocean), as well as the development of forecasting methods based on satellite and other weather data are also required. Oceanographers and meteorologists are trying to develop analytic hydrodynamic capabilities for these tasks, and their work should be incorporated into coastal management planning programs. Finally, resettlement programs near coastal areas must consider the possible dangers of catastrophic flooding or storm damage in new settlement areas.

FIGURE 2-4 Structures built on sea cliffs may be subject to hurricane winds and the resulting erosion. Improved weather prediction capabilities are available, but good communications systems and emergency preparedness plans are also needed so that early warning systems can allow coastal inhabitants to evacuate danger zones in time. (U.S. National Oceanic and Atmospheric Administration)

HARBOR AND PORT DEVELOPMENT

Cost-effective construction and maintenance of port and harbor facilities must take into account a broad range of physical, economic, administrative, and political factors, particularly unique hydrodynamic traits and sediment-trapping characteristics. Certain generalizations can be made about the ocean processes that affect harbors and sometimes damage or even destroy their usefulness and about the effects of harbors on neighboring regions.

Problems of how to encourage flushing by tidal and other currents, diminish siltation, and provide waveand storm-surge protection are characteristic of many ports. For example, surges from the Adriatic Sea into the lagoons of Venice frequently flood the Piazza San Marco. After World War II, a violent storm surge came into the estuaries of the Scheldt, the Rhine, and the Meuse, killing many people and causing great property damage. Bristol, England, and Ostia, Italy, are harbors that once were thriving centers of commerce, but they have silted up and are now useless for shipping. A similar fate may overcome the port of Calcutta in eastern India. Flooding of the port of London is prevented only by enormous man-made barriers on the Thames River. Another hydrodynamic problem is that large standing waves, reflecting and being reinforced by harbor walls, can occur if a harbor is built with particular relationships between harbor dimensions and incoming wave frequencies.

The problems of design and modification of harbors are continuing ones, as new structures, each with individual hydrographic and terrestrial characteristics, are built in response to changing economic needs. Technical information and guidelines for port facility design and construction are available from the Intergovernmental Maritime Consultative Organization of the United Nations (1980a, 1980b).

The remainder of this section discusses three principal categories of physical factors that must be evaluated in harbor and port development: (1) site selection, (2) design considerations, and (3) environmental factors. These discussions are based on information from the companion report on coastal zone management in developing countries (National Research Council 1982).

Site Selection

A number of physical factors affect the selection of sites for port or harbor development. Numerous examples around the world (such as those cited above) illustrate the costly and potentially dangerous consequences of failure to consider one or more of the following elements:

- Natural protection at a site. The presence of headlands or interior bays makes siting much easier. A natural bay may also provide a particularly desirable location for a new facility by reducing the need for costly dredging and construction of protective structures.

- Exposure to waves. Wave activity at a site dictates the extent to which protective structures are necessary. Offshore features such as submarine canyons and ridges can affect the waves, and locations separated by as little as a few kilometers may be unequally suited as harbor sites.

- Wind exposure. Dominant wind direction and intensity can affect the utility of different sites as harbors and have an important impact on design considerations.

- Frequency of storms and other natural hazards. The prevalence of such events as storm surges, hurricanes, typhoons, tsunamis, and earthquakes influences harbor site suitability.

- Tidal flows and navigation. Effects of tidal currents, winds, and other factors on navigation are a major consideration in port or harbor site selection. Strong currents can increase shipping times or create potential hazards of collisions or grounding, and generally affect ease of navigation.

- Ease of providing deep-water access. Substrate type and bottom stability will influence the ability to create stable, low-maintenance navigation channels. Coral reefs or bedrock outcrops can increase harbor development costs.

- Longshore sediment transport. The amount of sediment moving along the shore will affect harbor sediment-trapping behavior. Harbor siltation and downdrift erosion can result from siting harbors in areas of excessive longshore sand transport. Proper positioning and alignment of harbor entrances, among other design aspects, can minimize siltation and erosion problems.

- Local geology. The consolidation state of the surrounding sediment and bedrock (for instance, sandy barrier beach conditions as opposed to a rocky headland) will affect both development costs and the upland influx of sediment and transport through the harbor environs.

Design and Construction Considerations

In addition to construction and engineering concerns, geological and oceanographic factors must be considered, including:

- Local wave and wind conditions. Once a suitable site has been selected, specific local factors will determine the structural details of designing harbor protection and loading facilities as well as navigation; a harbor entrance should not be directly exposed to incoming storm waves, for example. These factors may require local research and analysis.

- Harbor oscillations. Large-amplitude, low-frequency wave motions can be amplified by resonance within harbors. The entrance, planform geometry, depth, and size must be carefully designed to eliminate these oscillations.

- Provision for maintaining navigation channels. Prevention of net influx and buildup of sediment is critical to a navigable harbor. Materials from both land and sea must be prevented from entering the harbor, or periodic dredging will be necessary. In addition, certain types of bottom sediments may slump or slough into navigation channels, often during times of storm activity. Failure of slopes to prevent accumulation of sediment may require particularly costly and frequent maintenance to assure navigability.

- Downdrift erosion. Provisions for bypassing sediment need to be made to ensure that neighboring coastal regions do not suffer from a loss of sediment as a result of harbor construction. Such downdrift starvation can affect coastal stability and thus industry, tourism, and recreation.

- Cost and availability of construction materials. Feasibility of harbor and port development is affected to a large degree by the costs, source locations, and transportation costs of construction materials.

- Harbor flushing capacity. As harbors commonly trap both pollutants and sediment, careful consideration must be given to the natural flushing potential of a new harbor. When necessary, provisions must be made to increase flushing and to protect water quality.

Environmental Impacts

Port and harbor development can have profound environmental effects. These include:

- Effects on land runoff. Harbor development can decrease availability of fresh water in coastal areas and change the quantities of sediment flowing to coastal waters from upland sources. Increased sediment concentrations can have deleterious effects on a large percentage of marine organisms of all kinds.

- Downdrift starvation. Removal of sediment from the nearshore system through harbor development can affect environmental or ecological factors and make coastal areas less fit for human use by decreasing or altering biological habitats, for instance, or decreasing geological stability through erosion of coastal bluffs.

- Increased pollution. Trapping pollutants such as sewage, industrial wastes, or oil in ports and harbors can increase pollution levels both in harbor waters and adjacent regions.

- Seawater intrusion resulting from lowered water tables. Lowered water tables due to coastal development can accelerate saltwater intrusion into freshwater aquifers, reducing potability.

- Introduction of alien species. Foreign organisms can be introduced into an area via the release of bilge water or bilge oils, creating significant ecological problems in some locations. Research on this subject is not yet conclusive, but the introduction of parasites, and competition with, or predation on, local species have been reported in some areas.

- Harbor construction. Dredging and filling activities during construction can impair water quality and damage organisms in adjacent areas unless these activities are properly conducted and contained. The disposal of excess dredged materials off-site can also cause damage. Disposal on land or at sea of spoils from periodic maintenance dredging can also have adverse environmental effects.

OCEAN RECREATION AND TOURISM

The coastal zones of tropical oceans offer a promising opportunity for recreation. Careful development of coastal recreational areas, to prevent unhealthful increases in levels of pollutants and maintain the enjoyable characteristics of the environment, will increase the recreational opportunities for local citizens and encourage the expansion of foreign tourism, which can be a major source of foreign exchange and of employment.

To increase the attractiveness of their coastal regions as tourist centers, countries can build onshore structures, improve public access to the shore and nearby waters, prevent pollution, construct marinas and recreational harbors, and protect coral reefs against pests, suffocation by sediments from nearby land areas, or indiscriminate or unduly destructive coral harvesting. Localities that want to support their tourist industries should provide services that warn and protect tourists against poisonous or hazardous marine organisms such as lionfish, large sharks, sea urchins, and sea snakes. They should develop such coast guard services as navigational aids, weather warning signals, and search-and-rescue operations for small sailing and power vessels. Further, they should study the location, abundance, and life cycles of local game fish and take measures that will ensure the food supply and diminish predation of these fish at different stages in their life cycles. In many places, underwater parks and reserves can be established as special attractions.

Scientific and technical advice from marine specialists in developed countries will be useful in conducting these activities. Marine biologists can advise on the protection and identification of valuable and unusual sea creatures and the establishment of coastal parks, as has been done in Costa Rica, several Caribbean islands, and a number of Southeast Asian countries. Fisheries managers can advise on the protection of game fishes. Assistance also may be available from agencies in developed countries (for example, the U.S. Coast Guard) that provide rescue services and navigational aid to recreational and commercial sea vessels.

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3 Marine Mining and Drilling

FOSSIL FUELS: DRILLING FOR OIL AND GAS

Resource Assessment

With the rising prices of oil and natural gas, the import costs for these commodities have become an excessively large fraction of the budgets of many developing countries. As a result, exploration for and exploitation of local sources of these fossil fuels are very important. Small quantities of oil are present throughout much of the continental seabed, but recoverable deposits are found only in certain types of seafloor formations that can concentrate the oil and gas (see Figure 3-1). Sulfur may also be associated with these deposits, typically when a deposit has been formed by trapping oil in a salt dome.

For some coastal nations, significant offshore petroleum deposits are most likely found on the relatively shallow continental shelves and on the slopes just beyond these shelves. Even if deposits are too small (usually less than 10-20 million tons of recoverable oil reserves) to be sufficiently profitable for extraction by the major oil companies, they could be of great help in reducing the foreign exchange bills of developing countries.

Most developing countries need assistance in using geophysical and geological exploration techniques for offshore oil and gas fields (see Figure 3-2 and "Marine Geology" in Appendix A). Their own scientists, engineers, and technical support personnel need to be trained as soon as possible in these techniques and in methods for evaluating the data obtained, perhaps with international assistance, so that they can help their governments in negotiations for leases, royalties, and bonuses.

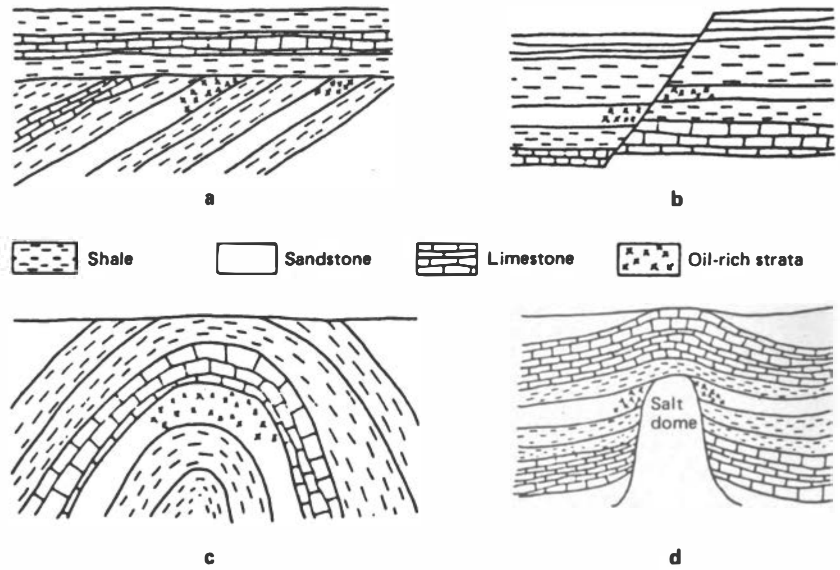

FIGURE 3-1 Different types of oil traps. For simplicity, the reservoir beds are always indicated as sands: (a) stratigraphic trap, (b) structural trap, (c) anticline, (d) salt dome or diapir. (Reprinted from Ross 1982b)

Locating petroleum deposits in coastal shelf regions is an expensive undertaking. It requires not only ships and drilling equipment, but also appropriate shore support facilities and analytical laboratory facilities on land and at sea. Highly trained ship personnel and laboratory technicians are needed to work with the scientists. These scientists should have a range of geological and chemical knowledge required for site selection, analysis of sediment samples, and analysis of acoustic geophysical data, as described in Appendix A.

Unfortunately, the seabeds off a number of coastal countries do not contain extractable petroleum reserves, and many oil-producing countries have extensive seabed regions that lack oil. Thus for economic reasons it is very important that good scientific evaluations, which need not be extremely expensive, be done prior to mounting expensive test-drilling operations. The first step in seeking oil deposits should be to gather existing data in the public domain about the geophysics of a nation's

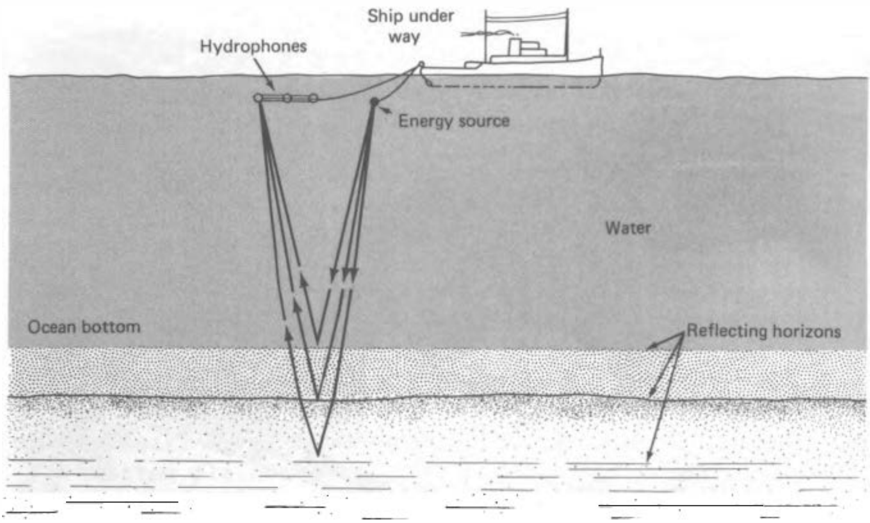

Figure 3-2 In acoustic surveying, geological and geophysical data are collected continuously along the ship's cruise track. A picture is thus created of the seafloor topography, sediments, and deeper layer structures such as those in Figure 3-1. (D. Ross, Woods Hole Oceanographic Institution)

seabeds; computer searches of the world's scientific literature will be useful.

If insufficient or no scientific data exist to determine the likelihood of offshore oil locations, but knowledge of the marine geology of adjacent or similar regions indicates the possibility of conditions suitable for petroleum deposits, it is then appropriate to conduct geophysical surveying expeditions. Should the research cruises indicate the existence of sedimentary rock formations capable of trapping petroleum in extractable form, the high cost of test-drilling operations would then be justified. Where no likely formations exist, however, public funds should, in most cases, not be used for test drilling.

Marine geologists at oceanographic institutions in developed countries can help find and evaluate relevant data for a given area. Some of these institutions have already conducted widespread research cruises (Figure 3-3), and their scientists and data managers can

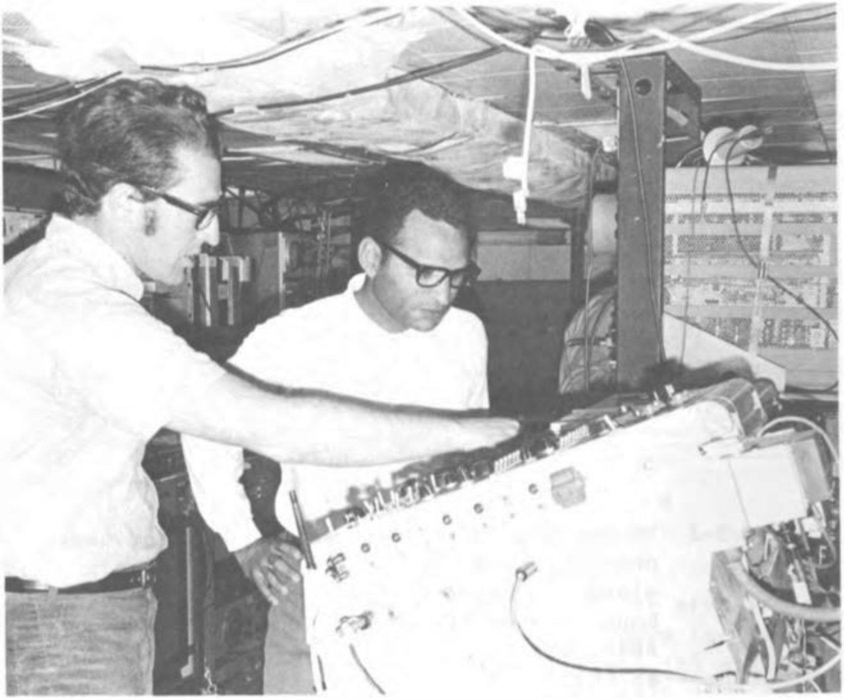

FIGURE 3-3 Marine geologists from the United States and Egypt aboard the U.S. research vessel "Chain" examine the ship's echo sounder. On this cruise, the geophysical structure of the seafloor in the Nile Delta region was studied for the first time. (Woods Hole Oceanographic Institution)

assist with literature searches and training in data analysis techniques.

In many instances, oil and gas exploration is done more efficiently when the results of land-based geological surveys, for both local and neighboring regions, are available. These surveys determine the ages and morphology of sedimentary and deep rock formations. When coupled with the results of conventional marine survey work and preliminary test drilling, such analyses increase the abilities of geologists and geochemists to identify those nearshore marine areas most likely to contain fossil fuel deposits.

Extracting and Processing Fossil Fuels

After exploitable petroleum reserves ("reservoir rocks") are found, the oil and gas must be extracted and transported to shore. Knowledge of the range of seafloor, water, and meteorological conditions is necessary to install and operate offshore drilling rigs and pipelines. The safety and security of these difficult operations cannot yet be fully assured even in industrialized countries, as evidenced by the rare but tragic oil rig disasters. At present, the ability to construct drilling rigs and to counteract serious operating problems or potential disasters such as blowouts still lies primarily in the developed countries.

For continental shelf areas less than about 180 meters deep, drilling platforms can be either fixed to the seafloor or semifixed, to be moved after drilling. Floating platforms are used for greater depths. Oil drilling at depths greater than 1,000 meters (a portion of the way down the continental slope) is currently done only rarely by a few specially outfitted ships. As technical capabilities improve, future oil production may extend to the continental rise areas (3,000-4,000 meters deep). The rises, with their relatively thick wedges of built-up sediments, are expected to be particularly good petroleum sources.

The complete transfer of marine oil, gas, and sulfur production technology to developing countries can be accomplished over time, as local scientists and technicians are trained. In most cases, however, a country will achieve the full benefits of oil production only when associated technologies (e.g., for power production, laboratory maintenance, transportation, and servicing port facilities) are also developed. A variety of channels for public and private transfer of technology are available, including training and exchange programs, joint ventures, direct purchase of technology, and acquisition of consulting and engineering services. In coastal nations that lack relatively advanced domestic technological capabilities, joint venture operations will often be the only way that marine drilling programs can be instituted.

How can developing countries increase the effectiveness of technology transfer? Efficient transfer of marine mining capabilities will require both short- and long-term projects. Short-term training of technicians and support personnel will allow them to work on drilling and geochemical analysis in joint venture operations. This experience should be coupled with the simultaneous but necessarily longer term development of domestic scientific capabilities, including the education of marine geologists, geochemists, and engineers, requiring 2-4 years after the introductory university-level mathematics and science courses. Further, academic, governmental, or industrial research and engineering facilities must be created or expanded. In each country, policy-makers, resource managers, and scientific administrators must be prepared to determine the appropriate investments in short-term and longer term personnel training and equipment acquisition.

MARINE MINERALS OF THE CONTINENTAL MARGINS

As described in Appendix A, the shallow shelves and bordering slope and rise areas of the continental margin surround all major land masses but vary greatly in width from one region to another. Pacific Ocean margins are almost always relatively narrow and often drop off rapidly into deep-sea trenches within a few hundred miles of shore. Atlantic coastlines, much of the Indian Ocean, and semienclosed seas are, in contrast, typically bordered by wide, gently sloping shelves. In these shallow areas, types of minerals different from those located in the deep sea are found, and mining is much less difficult technically than in deep water.

Valuable petroleum and sulfur deposits are typically found in continental margin areas, although this may include the deep slope and rise zones (from 200 to as many as 3,500 meters deep). Although extremely valuable, petroleum is only one of the many materials that can be profitably taken from continental seafloors. In fact, most substances that can be mined on land are present in extractable form in some portions of the world's shallow oceans. These substances include coal; tin, iron, and other industrial metals; certain types of chemically enriched rocks such as aragonite and phosphorites; and precious metals, including gold.

Nearshore Metals and Coal

The location of marine minerals is often indicated by their presence in nearby land areas. Coal and tin mines, for example, have been extended successfully in some regions into adjacent coastal waters, where the mineral seams continue beneath the layers of surface sediment--for example, tin mining in Thailand. These nearshore mining operations can be very profitable, and the search for similar resources may be a valuable undertaking for developing countries with extensive, shallow coastal waters. However, because serious environmental problems can result if uncontrolled mining pollutes waters, beaches, and fishing grounds, appropriate preventive steps should be planned before extensive mining begins. (See Chapter 2, on coastal management, for a discussion of ways to reconcile competing uses of coastal waters.)

For some relatively dense minerals--for example, magnetite, rutile, ilmenite, zircon, platinum, gold, and even diamonds (although mineable diamond deposits are rare)--nearshore surface deposits (placers) are formed when waves and currents sort heavier materials from surrounding sands and muds. As with marine deposits of tin and coal, the nature of placer deposit minerals usually reflects the mineral composition of nearby land areas. A list of some of the better-studied geographic areas where various types of marine placer and other minerals could be mined is given in Table 3-1.

Marine Mining for Construction and Fertilizer Materials

Some materials particularly characteristic of ocean environments but unexploited offer potential for marine mining. Notable among these are phosphorites, deposits rich in the phosphate materials which, when mined on land, command a high price as sources of agricultural fertilizer. The chemical transformation and deposition of excess phosphates, or those not taken up by the ocean's microscopic plants, create seafloor phosphorites. Phosphorite deposits are widespread in upwelling areas--those nearshore regions where cold, nutrient-rich water rises and supports unusually bountiful fisheries and high productivity of all forms of marine life. As the demand for fertilizers increases, the costs of mining and transporting this rocky material are expected to be more than repaid. Thus future marine phosphorite mining operations may be undertaken in both developed and developing countries.

Another continental shelf mineral used as a source of fertilizer and to provide lime for cement is aragonite. This calcium carbonate-enriched rock exists in numerous coastal margin areas; its deposition depends on the seawater chemistry of the region. Aragonite mining

TABLE 3-1 Mineral Deposits on the Seafloor of the Continental Margin

Mineral	Use	Possible Mineable Marine Area[a]	Value[b] (US$)
Marine placers			
Gold	Jewelry, electronics	Alaska, Oregon, California, Philippines, Australia	350 or more/oz
Platinum	Jewelry, industry	Alaska	500 or more/oz
Magnetite	Iron ore	Black Sea, USSR, Japan, Philippines	6-11/t
Ilmenite	Source of titanium	Baltic, USSR, Australia	25-35/t
Zircon	Source of zirconium	Black Sea, Baltic, Australia	45/t
Rutile	Source of titanium	Australia, USSR	100/t
Cassiterite	Source of tin	Malaysia, Thailand, Indonesia, USSR, Australia, England,	
Monazite	Source of rare earth elements	Australia, USA	170/t
Chromite	Source of chromium	Australia	25/t
Sand and gravel	Construction	Most continental shelves	
Calcium carbonate (aragonite)	Construction cement, agriculture	Bahamas, Iceland, southeastern USA	
Barium sulfate	Drilling mud, glass, paint	Alaska	
Diamonds	Jewelry, industry	Namibia	
Phosphorite	Fertilizer	USA, Spain, Japan, Australia, India, South America, South Africa, Mexico	6-12/t
Glauconite	Source of potassium fertilizer		
Potash	Source of potassium	England, Alaska	

[a]Does not necessarily include all areas, because in many localities exploration has been nil or minimal.
[b]Can vary depending on degree of refinement; data are from various sources and may not reflect current economic conditions.

SOURCE: Ross (1980).

has been successfully conducted off the Bahamas and several developed countries.

Sands and gravel of various types are often overlooked by resource managers and developers. The demand for these important materials for construction of buildings, highways, and airports increases rapidly as development occurs. Concurrently, land supplies tend to become both depleted and covered over as development spreads. When construction sites exist close enough for economical transport from marine sand and gravel sources, marine aggregate mining can be developed profitably. Done to excess or improperly located, however, this mining can cause serious problems, including water pollution by suspended sediments, changes in bottom currents, which may then erode adjacent beaches, or the burial of shellfish beds. Nevertheless, equal or more serious environmental damage can result from large-scale land mining or from the common practice of taking sand directly from beaches. Environmentally and economically, marine mining may thus be the preferable source of aggregate materials. Planning to minimize the harmful environmental effects of whichever types of aggregate mining are used should be a part of coastal management policies.

A number of international technical assistance agencies and scientific associations have recently focused attention on the development of marine aggregate mining. Several reports and workshop proceedings on the subject are available, and the United Nations Intergovernmental Oceanographic Commission has recommended technical developments to member states, under its program on ocean science and nonliving resources.

DEEP-SEA MINERAL SOURCES

Most of the deep-seafloor areas of the world lie beyond the 200-mile limit that nations may claim as exclusive economic zones under the Law of the Sea Treaty. These sediment-poor seabeds lack most types of valuable mineral deposits found on continental margins. Other forms of deposits are, however, found only in the deep sea, principally manganese nodules and the recently discovered polymetallic sulfides and heavy metals associated with mid-ocean ridges which might in time prove to be sufficiently valuable to extract. Profitable collection of these minerals is not yet feasible, because of the enormous costs and technical difficulties of working at great depths far from shore. World demand for metals, however, may make commercial mining of deep-sea deposits feasible before the end of the century.

Manganese Nodules

These small rocklike objects, found in many of the world's deepest ocean basins, are the subject of widespread technical and political controversy. The nodules contain variable quantities of many industrially important metals, including copper, nickel, and cobalt as well as manganese. Only a few experimental projects to retrieve these nodules have been undertaken to date. Costs of mining are quite high relative to the value of the metals and are expected to remain so for some years since a large portion of the cost is for fuel to operate the large mining vessels. A number of private corporations in the United States and other countries have developed preliminary plans for future deep-sea mining but do not anticipate undertaking commercial operations until world metal prices increase sufficiently to justify the investment.

In addition to these purely economic considerations, political factors related to the provisions of the Law of the Sea Treaty and to the failure of the United States to sign it, are affecting corporate decision making about deep-sea mining. Under the treaty, resources of the seafloor beyond nations' areas of jurisdiction may be harvested only if provisions are made to transfer relevant technical knowledge and a portion of the resulting profits to a central fund for distribution among all participating nations. (This provision reflects the way in which the treaty assigns rights to all nations to share high-sea resources, regardless of a nation's current technical capabilities to extract or harvest those resources.) Some knowledgeable observers feel that if the United States continues to remain outside the treaty, U.S.-based corporations will be less likely to risk investment in manganese nodule mining, because they may encounter substantial difficulties in obtaining bank loans for ventures perceived as being of somewhat uncertain legitimacy under new and yet untested aspects of international maritime law (Richardson and Ratiner 1982).

Because much of the existing expertise in manganese nodule extraction resides in U.S. corporations, and because the United States has not ratified the treaty, this matter may remain at a standstill for some time. In any event, profits to be made from this barely embryonic industry are unlikely to be very great in the near future. These nodules may become a source of industrial metals after a decade or more, but this will depend principally on land-based mineral supply factors, especially of so-called strategic minerals in the United States, whose particular importance lies in their value to the military and their limited supply in the United States and her allies.

Metal Deposits at Mid-Ocean Ridges

As shown in Figure 3-4, each of the major oceans contains large submarine ridges. The major ridges run down the center of both Atlantic Ocean basins, from central Mexico due south almost to the Antarctic regions, and to the south and then southeast through the Indian Ocean. Smaller, related systems exist as branches of these ridges. A seafloor ridge is produced wherever the tectonic plates of the earth's crust move apart from one another. Ridges are formed by the massive upwelling through the separating seabed of relatively low-density

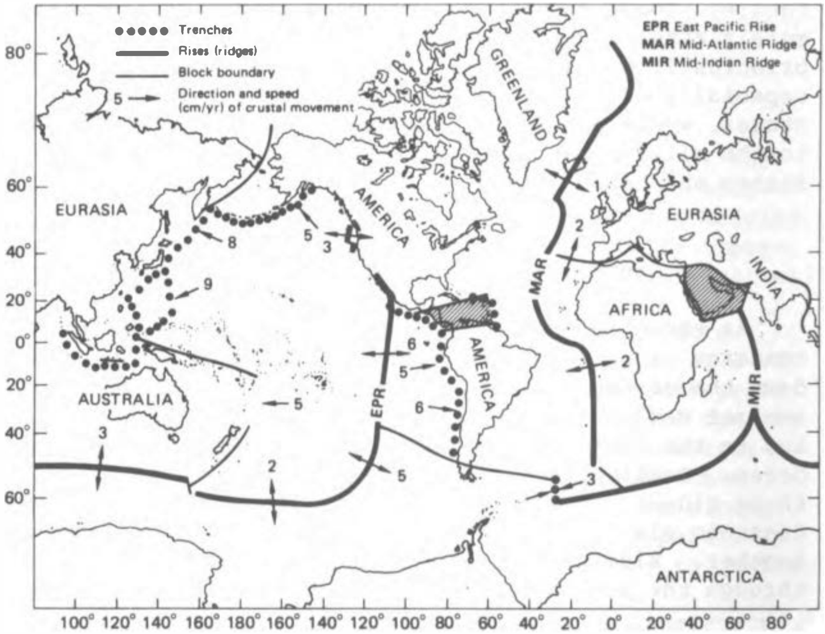

FIGURE 3-4 The earth's crust consists of units that move as rigid blocks. The boundaries between the blocks take the form of ridges (or rises), trenches (or folded mountain belts), or faults. (Gross 1971)

basaltic magma--molten rock from the earth's mantle 100 km or more beneath the seafloor. This material fills the gap left as the slabs of the crust separate, moving apart at rates of a few centimeters per year. As the new material cools, it solidifies and adheres to the separating plate edges, becoming itself the most newly formed portions of the plates.

Physical and chemical reactions associated with exposure of the magma to seawater, and the resulting hydrothermal activity at ridge crests, include mineralization processes that produce relatively purified deposits of metals and other valuable substances. Metal deposits found by scientific sampling along ridge crests include copper, zinc, iron, silver, gold, nickel, vanadium, lead, chromium, cobalt, and manganese.

Most spreading centers are now old enough to be far from land; surrounding land masses have spread apart to great distances over time and the intervening spaces have been filled by a new seafloor. One major spreading center, however--between the African and Arabian plates--is so young that the resulting Red Sea is still very narrow, and the central rift area is close to land. This is a rare situation in which the exclusive economic zones of a few nations encompass a metal-rich, active spreading center site. Scientific study in the area has revealed exceptional metal deposits, including uranium and mercury in addition to the more commonly found seafloor metals. These "metalliferous muds" may be mined commercially as early as the mid-1980s.

Discoveries and chemical analyses are currently being made of metallic deposits--polymetallic sulfides--from several other hydrothermal ridge crest areas. These discoveries confirm the hypothesis that valuable metals are present in recoverable amounts in many areas around the world, although the mining costs are not yet known. In a number of regions other than the Red Sea, the presence of active mid-ocean ridges suggests that such deposits may be found not too far offshore. These areas can be located very roughly by consulting a tectonic map. They include Iceland (a land mass that sits directly across a ridge crest), waters off the central Pacific and Gulf of California coasts of Mexico, the coast of the Pacific Northwest of the United States, and the southern Pacific coast of Canada, the coasts of Yemen and Oman, the geophysically complex region near the Galapagos Islands off Ecuador, and possibly the small rise off southern Chile.

Finally, while active spreading centers are now known to be particularly enriched in metal deposits, it is also possible that adjacent areas of the deeper seafloor, formed as ridge material separates and subsides, will prove to have deposits similar to those of ridges. Extensive sampling for this type of deposit has not been done and would be quite expensive, but occasional discoveries of very pure buried metal deposits during scientific operations of the international Deep-Sea Drilling Project suggest that this may be the case.

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4 Fisheries Science and Management

FISHERIES MANAGEMENT CONCERNS FOR DEVELOPING COUNTRIES

Until recently, the fisheries off the coasts of many developing countries were thought to be underexploited or fished primarily by distant-water fleets from developed countries. Consumption of fish products in the developing world itself has been limited by problems with the preservation, marketing, and distribution of these products. With the recent establishment of exclusive economic zones (EEZs), however, many developing countries have authority and responsibility for significantly expanded fishery resources. Development of these fisheries can generate a variety of benefits, including the provision of protein-rich food, foreign exchange earnings, increased employment opportunities, and a higher standard of living for communities dependent on income from the sea.

In developing countries, artisanal (self-employed) fishermen provide a substantial amount of the protein intake of coastal dwellers, particularly the poor, yet these fishermen are frequently among the poorest members of society themselves. The modernization of their fisheries will substantially help alleviate underemployment as well as improve local food supplies. To increase the economic benefits to be derived from the sea, developing countries must acquire the appropriate scientific and technical capabilities. They must also establish marketing initiatives to support new fisheries and new processing enterprises made possible by technological advances.

Both technological development and financial investment are necessary to expand commercial fishing industries. Particularly important for the "land side" (post-harvest) operations is the construction of processing plants for fish meal, fillets, or minced fish. The types of processing undertaken should depend on both regional and international demand and on marketing capabilities. Deep-freeze storage capacities should also be developed. Where this is not technically or economically feasible, improved preservation and storage methods must be implemented if the commercial fishing industries of developing countries are to compete successfully in world markets.*

Where fleet capacities are too low to fully exploit stocks in the new EEZs for which good market potentials exist, funds must be expended to buy or modernize offshore vessels. When buying ships, however, it is important to avoid dependence on overly expensive technologies. This problem is occurring in both developed and developing countries, where some fishing fleets face serious economic problems following overcapitalization in large, fast ships with high fuel requirements and hold capacities greater than those that can be supported by the available fish resources. Many developing countries will be better served by a mix of large, capital-intensive and smaller, labor-intensive fishing capabilities. This combination should result in the most efficient and sustained exploitation of fishery resources in both onshore and offshore regions, at times of both high and low natural fish abundance.

New Markets for Fisheries Development

Expansion of a nation's fishing industry through harvesting new types of fish is limited by the fact that food consumption habits are not easily changed. Experience with toxic species or those traditionally believed to be poisonous has compelled consumers, especially in warm climates, to demand that fish remain whole to permit identification of species and inspection for freshness. It has also generated local acceptability of only particular species for human consumption; species that are desirable in one place may, for a number of reasons, be quite unacceptable in others.

Of the 20,000-25,000 species of fish known to exist in salt and fresh waters, only a few dozen species are used at present on any sizable scale, although many others are used on a small scale in specific locations (National Research Council 1978). Patterns of economic activity are, however, likely to respond to changing

*See National Research Council (1978) for a detailed discussion of postharvest food losses in developing countries.

market conditions and to technical improvements available for already established fishing industries. Thus even a country with relatively low or inelastic domestic demands for seafood may have excellent opportunities to develop profitable new industries to supply seafood for international markets. International demand is increasing for certain types of very high-quality or highly processed seafood, such as breaded and frozen minced-fish products or fresh tuna to be eaten raw as Japanese sashimi. With the establishment of 200-mile extended economic zones, many developing countries have unexploited marine fish resources that could provide the raw material for such products.

There are two main obstacles to expansion of seafood harvesting and processing industries in most countries: (1) a lack of awareness of the market potential for certain seafood products, and (2) perhaps more important, the lack of proper storage, transport, and processing capabilities for these highly perishable products. For example, high-quality fresh fillets are needed to supply the extremely lucrative Japanese sashimi market. The albacore, bluefin tuna, and other species commonly used are available in the offshore waters of many tropical developing countries, but only a few of these countries have established the highly coordinated fishing, fresh packing, and rapid shipping operations required to supply fish of the quality required. (There is also a smaller demand in the sashimi trade for a smoke-dried form of tuna used primarily as a flavor additive.) The market for sashimi should continue to be very strong and offers excellent commercial opportunities for the more economically advanced developing countries with access to tropical open-water fisheries.

Most of the international fish trade involves shipping a large array of processed products, primarily frozen but in some instances preserved using less energy-intensive methods. Processing capabilities and world demand are now increasing for minced-fish products, in which the basic material is processed into a wide variety of frozen, canned, and occasionally dried forms. Many of these products, which employ different styles of preparation (e.g., breading and frying, shaping variously, and packaging for use as bases for canned or homemade soups and stews), have excellent appeal for consumers of various cultures. Mixed collections of fish, such as those that account for a large portion of the catch and by-catch (the so-called "trash" fish) of many tropical countries, are technologically well suited to minced processing. The principal economic drawback of minced-fish production is that the governments of certain markets (primarily that of the United States) require detailed labeling of fish types in the mix.

The development of processing technology and marketing analyses for both standard and new forms of minced-fish products is well advanced, and the United States has made a number of technical contributions through research and product trials conducted at publicly supported sea-grant institutions (New York Sea Grant Institute 1976a, 1976b, 1977; North Carolina State University 1975). Many international market analysts and fishery managers believe that as heavily fished stocks decline while world demand for fish products continues to rise, the marketing of fish previously regarded as low value (including "trash" fish) will provide a substantial new source of income for developing countries that can successfully establish the necessary processing facilities and marketing coordination. In less-developed areas where inexpensive power supplies do not exist and technological capabilities are limited, improvements in methods of preparing smoked and dried fish products may stimulate the local fishing industry. Maynard (1982) discusses the international marketing potential of dried, salted, and smoked fish produced by developing countries, with an emphasis on methods used in Southeast Asia, a leading area for consumption and production of these products.

The expansion of fishing industries is often as much a problem of marketing as of insufficient harvesting or processing capacity. Some new types of processing enterprises, recently employed successfully by several developing countries (e.g., Guyana and Sri Lanka), demonstrate that it is beneficial and perhaps essential to decide in the early stages of commercial development which methods are most suitable for marketing the new products through established domestic and international distribution systems. It must also be determined which methods will create interest among vendors and consumers who may be unaccustomed to purchasing the fish or fish products to be offered. These methods might include village demonstrations or distributions of samples, perhaps complemented by printed posters or information notices if literacy rates among food preparers are high and such items are likely to be well received. The improved productivity possible with technological development will be more quickly converted to high economic returns when households, vendors, and other purchasers are immmediately made aware of the existence of new or improved fishery products.

Stock Estimates and Evaluation of Stock Dynamics

In addition to developing their own fishing industry, coastal states should decide on the year-to-year allocation of fishing rights within their economic zones to vessels of other countries. This requires estimates of stock sizes and the catchability (i.e., the relevant distribution and behavior patterns) of major fish stocks, as well as the abundance of new fish year classes (those about to mature to the size at which they are caught by nets). For migratory species, nations may need to cooperate in estimating total stock size and recruitment (the numbers of young fish of catchable size entering the stock) over a wide ocean area. From a strictly national point of view, knowledge of likely variations in stock size and availability over an extended period of years is essential to evaluate the potentials for investment in fishing vessels and human capital. Even in a well-managed fishery, interannual variations in catch may be very large, apparently due to fluctuations in the ocean environment.

Knowledge of oceanic events during the early life stages of some commercial fishes may in time be used to predict population sizes 2-3 years hence and thus to determine appropriate changes in management strategies. However, where environmental conditions affect the behavior or availability of the adult fish, or where the life cycle is short, this lead time is not available. For example, the large year-to-year variation in the availability of skipjack tuna off Hawaii can be explained by the year-to-year variation in the flow of the north equatorial current and the surface wind-driven currents (Seckel 1972). Similarly, year-to-year variations in the formation of ocean currents in the eastern North Pacific affect the availability of albacore tuna (Laurs and Lynn 1977). Climatic predictions several months in advance, which have recently become possible with seasonal climate modeling techniques, would allow preparation for the changing availability of these resources.

International cooperation in the form of technology transfer and the exchange of information and experiences among countries can be beneficial, and in some instances essential, in providing the best possible estimates of stock sizes and recruitment needed to establish policies for optimum sustainable yields.

STOCK ASSESSMENT METHODS

Until recently most fisheries management methods, including resource assessment techniques, were developed in high-latitude (Northern Hemisphere) countries for their own highly exploited fisheries. The population dynamics models in use were thus developed mainly for cold-water, single-species stocks. The techniques employed rely on relatively advanced field survey capabilities; well-developed, shore-based scientific support; and access to good statistical data on landings and fishing effort. New, simplified assessment methods, some of which allow stock size values to be estimated even when many target species coexist, as in tropical waters, are now being developed and taught through several development assistance research projects. One such project has been proposed and is in the planning stages through support of the U.S. Agency for International Development (USAID). Similar work is already under way through the International Center for Living Aquatic Resources Management (ICLARM), the United Nations Development Programme (UNDP), and with the support of the governments of France, Canada, Denmark, Norway, and the Philippines.

Improvements in the collection of statistics will mean more reliable estimates of total landings from small-scale and artisanal fisheries. One example is the modification of sampling procedures used by Bazigos (FAO, 1974) for African inland fisheries for possible application to marine systems. Gulland (1980) has shown how valuable information on fishing efforts or similar indices can be obtained through small improvements in national annual statistical data on number of fishermen, boats, gear, and the like, given the reluctance of fishermen to change their practices over time. In this regard, improved data collection procedures must take into account sociological problems at the fishing village level (Munro 1980).

Sustained-Yield Management of Multispecies Fisheries

The most efficient long-term use of fishery resources results from management systems that set levels of catch that can be sustained beyond the very short time period during which unregulated harvesting operations might otherwise deplete available stocks. Management information needed for the long-term maintenance of sustainable catches includes:

- o Biological data, especially "life-history data," relating to fecundity and ages of reproduction of the fish or shellfish being harvested
- o Information about changes in the level of populations or of certain age groups in the populations, to help determine stock sizes and fluctuations
- o Information about major changes in abundance of nontarget species, if the other species interact importantly with commercial species as prey, competitors for food, or as predators on adults or young of the commercial fish.

As a result of the experiences and scientific and practical studies of developed countries, the sustained-yield management approach is fairly well established for fisheries in which the catch is primarily a single species of fish. Many of the world's higher latitude and high-seas fisheries such as those for many tuna species, are of this single-species type, and some of them are being successfully maintained at sustained yields over extended periods of time by applying standard methods of single-species management.

Unfortunately, most fisheries of tropical and even subtropical nations are multispecies fisheries, in which are caught a great many finfish varieties and often one or more types of shrimp. Management methods based on the assumption that all fish taken are of one type are often quite inappropriate for these fishing operations (Food and Agriculture Organization 1978). Problems that can arise in managing multispecies fisheries include the possibility of seriously depleting one species, if it happens to form an unexpectedly large proportion of the catch, or failing to foresee how a valuable species is affected by depleting the young or adults of another species that serve as its principal prey. The multispecies fishery management problem is also encountered in the Antarctic, where fisheries for the small crustaceans called krill (euphausiids) must be managed in the face of large-scale direct and indirect interactions with the krill population of numerous other organisms (primarily finfish, whales, seals, and even seabirds) whose own populations may be fluctuating in response to both natural events and harvesting pressures from man.

In most regions there is, regrettably, insufficient information on catch sizes and composition to provide a basis for true multispecies management, pointing to multidisciplinary cooperative research among countries as probably the best way to collect such data. Fish species of similar climatic and geographic regions (e.g., northern Chile and Peru and California, or equatorial Latin America and portions of Indonesia and Malaysia) often display similar behavior and responses to fishing pressure. Thus because few countries can afford individual, adequate studies of the behavior of fish stocks, sharing of basic biological findings or technological advances will mutually benefit the countries involved.

Scientists, fishery managers, and associated experts including resource economists are currently developing new multispecies management methods that can apply even in the absence of detailed information on the composition of catches throughout a region. Seminars, publications, and training courses in new methods are now being designed. Information on acquiring the new capabilities as they are developed may be obtained from several international fisheries research or technology centers. Funding for such centers and for much of the basic research needed to create fishery models is provided by a combination of public funds (often from development assistance agencies of individual countries such as the United States, Canada, several European countries, and Japan, as well as from international agencies) and funds from private philanthropic foundations.

The International Center for Living Aquatic Resources Management (ICLARM) in Manila, Philippines, is especially active in training and the dissemination of information about practical fisheries management methods for developing countries. Several publications and training opportunities available through ICLARM for developing country personnel, working on single-species and multispecies fisheries development problems, are listed in the reference section at the end of this chapter, along with references to other similar international and bilateral donor programs. ICLARM, which publishes a detailed quarterly newsletter (ICLARM Newsletter), also has an international information network that enables tropical fishery scientists to exchange technical information and work together on mutual problems.

One potentially useful approach to the multispecies problem is to combine single-species assessments. The problem then becomes one of determining the relative effectiveness of each type of fishing gear at taking each of the most commonly caught species. Theoretical models can gradually enhance understanding and on occasion can produce very useful results for management, once practical management approaches are properly derived from data collected over several years. For example, the complex, data-rich, multispecies stock assessment models developed for temperate areas, such as the model developed for the North Sea by Andersen and Ursin (1977), may be refined and applied to tropical fisheries as additional scientific information is obtained for each tropical fishing region.

Information is also needed on stock recruitment relationships--that is, the relationship between the numbers of adult fish and the numbers of offspring that they produce and that will survive to a catchable size. Depending on the quantity of other adult fish and competitive fish of other species present in a given season, and on environmental and climatic conditions, the numbers of offspring produced and the numbers that then survive to fishable size can vary remarkably from year to year, resulting in the very common phenomenon of annually fluctuating sizes of fish stocks and commercial catches of various species.

Factors affecting the growth and survival rates of young fish of various regions are currently being investigated by a number of U.S. marine scientists; some of the work is being coordinated through the University of Miami's Center for Marine and Atmospheric Sciences (Rothschild and Booth 1982). In 1982, the Intergovernmental Oceanographic Commission identified the study of ocean environmental effects on young fish survival as "one new research project area for cooperative work by its member nations" (International Council of Scientific Unions 1982). To some extent, the available information, primarily on the spawning characteristics of various fishes and the ecology of their early life stages in temperate waters, can be used in creating management models for developing countries. Detailed scientific papers on this subject are found in the proceedings of symposia convened by the International Council for the Exploration of the Sea (Blaxter 1974, ICES 1981).

Short-Term, Rapid Stock Assessment

Standard Survey Methods

In the short term, when complete biological data are not yet available but management decisions must nevertheless be made, methods are needed to make preliminary, rapid stock assessments. These will be "best-guess" methods, and long-term management goals may not be reached if they are used exclusively over extended periods. They may prove, however, to be useful guides to preventing overfishing for several years while allowing profitable fishing industries to develop or continue.

New assessment techniques of greater practical use for short-term decision making include utilization of approximations and generalized assumptions about data to take into account the biological mechanisms and environmental effects that set upper and lower limits on such factors as rates of growth, mortality, and fecundity. Information about predator-prey interactions (positions in the food chain) may also be incorporated in some models. Very useful information about the stock assessment and management methods being developed for use in developing countries is provided by Pauly (1978a, 1978b, 1979a, 1979b, 1980a, 1980b). Marten (1978) suggests departures from conventionally applied methods of analyzing the sizes and numbers of fish caught that may prove more practical for fisheries management in the tropics. Problems of tropical stock assessment for artisanal fisheries are emphasized in a report of the 1979 International Workshop on Stock Assessment for Tropical Small-Scale Fisheries (Saila and Roedel 1980).

The data on catch composition and the amounts and types of fishing operations ("effort") undertaken, needed for standard "catch-and-effort" stock assessments, should be relatively easy to obtain from large-scale commercial operations. It will be much more difficult, however, to determine the abundance of fish and the effects of fishing on stock sizes in the small-scale and artisanal fisheries in similar geographic areas using similar stocks. These catch data are less readily obtained, and the number of fish killed by each type of gear is not well known. Experimental studies using various kinds of artisanal gear in different fishery regions would be especially helpful in determining the gear's effectiveness, relative efficiencies, and effects on fished populations.

To permit fishery managers in coastal nations to benefit from the experience and scientific and technical results of other developing and industrialized countries, regional and international organizations should produce regional inventories of existing information on tropical fisheries. Although valuable information is often available, fishery managers or even scientists who might have applied it to their own nation's problems are frequently unaware of its existence. For example, the West African hard- and soft-bottom habitats, dominated by snappers and croakers, respectively (Fager and Longhurst 1968, Williams 1968), are similar to those of northeastern South America, the Bay of Bengal, and the South China

Sea. Yet there have been no attempts, except for the first two regions (Lowe and Longhurst 1962, Lowe-McConnell 1977), to compare regions to determine what biological and ecological information may be applicable generally or at least in several areas.

The next step in the field of stock assessment for tropical fisheries, as discussed in the previous section, is to seek theoretical advances equivalent to the population dynamics models applied to fisheries in the north temperate zones in the period after World War II (Schaefer 1954; Beverton and Holt 1957; Ricker 1954, 1958). Population models of this type should be applied to determine how certain levels of fishing will affect the size of stocks, catch measurements and counts, market surveys, and fishing effort surveys, some of which are needed for short-term assessment purposes. It would be useful to have regional estimates of the number of fish caught in tropical ecosystems (such as coral reefs and mangrove areas) by various types of boats using indigenous gear (traps, or hook and line) that differs in timing and rate of deployment from gear used in temperate regions or more open tropical waters.

Studies are also needed to permit identification of fish from various stocks and thus gain a better understanding of stock structure and geographic stock distributions in major fisheries. This can now be done by biochemical and genetic methods, as well as by the usual tagging and release studies (fishermen or marketers are asked to report the numbers of fish they find with tags), by life history parameter comparisons, and analysis of catch-and-effort data. Gulland (1977) has commented on the need for only one country in a given area to perform biochemical and genetic work, while the other countries provide the fish and the participants.

High-Technology Methods: Acoustic Surveying and Remote Sensing

The present state of acoustic surveying in fisheries is described by Cushing (1978). In the next decade, especially rapid advances will be made in acoustic survey techniques applicable to underutilized and unutilized resources such as krill, squid, and midwater fishes. The major remaining problem is the need to identify acoustic targets, which is particularly difficult. Although research on target identification for tropical fisheries will be very useful for improving fishing efficiencies, the sophistication needed to operate and maintain the more advanced acoustic assessment systems poses problems for many countries. One solution may be the use of joint scientific ventures between developed and developing countries to realize the potential value of the equipment in locating and quantifying resources.

Remote sensing from satellites has distinct advantages in certain ocean areas for determining the occurrence and geographic extent of physical phenomena, such as upwelling, the development of warm and cold water fronts, transition zones, and related short- and long-term biological events such as plankton blooms. Locating such phenomena is often of great tactical value even in small-scale fisheries, particularly for pelagic fish, which move from one region to another. The use of airplanes to sight fish schools is standard practice in many large or well-capitalized commercial pelagic fisheries. The applicability of remote sensing techniques to the fishing enterprises of developing countries, and availability of assistance in acquiring the advanced technology required for satellite data interpretation, is discussed in Chapter 6.

FISHING TECHNIQUES AND EQUIPMENT

Efficiency of Vessels and Gear

The rising cost of fuel over the last decade points to the need to increase the energy efficiency of fishing vessels and gear and ensure that the fishing methods used yield the maximum usable catch landed at the dock per unit of fuel consumed. Concentrating on stocks located close to shore, probably best accomplished by harvesting previously unexploited or underexploited stocks, may also be necessary to conserve fuel. In some regions this approach may result in improved international markets for certain kinds of products (e.g., squid or minced fish from mixed catches).

Technological improvements in the design and manufacture of fishing vessels to raise fuel efficiency, including that of fuel used for freezing and other onboard processing, are now being developed and implemented by many shipbuilders (Figure 4-1). Efficient ships must be of primary concern for people involved in the development or expansion of any nation's fishing efforts. The potential for energy conservation may be substantial. For example, in the North Sea fisheries, an estimated 8,000 kcal of fossil fuel energy is used for every kilogram of whole fish landed (Holt 1978). With the cost of fuel at US$1 per gallon, the direct energy cost, not counting human labor, is about US$0.25 per kilogram of whole fish and much higher for the edible portion.

Largely due to rising energy costs, sail is reappearing as an auxiliary source of power in some northern developed countries and will be used increasingly on many fishing boats in developing countries now, using outboard and small inboard engines (Bardach 1981, Fyson 1981). Designs are still needed, however, for more fuel-efficient small fishing boats for coastal seas, as well as for lakes and rivers.

A 1980 study in the South Pacific region focused on the use of more efficient boats that permit artisanal fishermen to reach new grounds and use new gear (Fishing News International 1980b), but problems were encountered, mainly concerning design of the boats and propulsion systems. Principal observations of the 1980 study were that no single design is suitable for use throughout the region and that the introduction of new types of boats will not be very effective unless they are tailored to the particular needs of a given area. For example, traditional boat-building in Sri Lanka is well suited to the new "stitch-and-glue" technique of low-cost plywood dories appropriate to local fishing conditions (Wright and Herklots 1980). Lightweight, air-cooled diesel engines could radically alter the propulsion systems of many small fishing craft during the coming decade. Wray (1980) has discussed the virtues of these units, especially portable ones, which can be used on shore for other purposes and which were design-tested on a Philippine outrigger "banco" canoe (Fishing News International 1980a).

Methods are available in the developed world for virtually automated trawling operations: locating fish, steering the vessel, lowering and aiming the net, capturing the fish, and returning the net to the deck. Innovations in gear design and materials have led to the use of automated longline gear in northern European vessels, pole-and-line machines for tuna fishing on Japanese vessels, and midwater trawls for krill and mesopelagic fish. During the coming decade, better detection and assessment techniques for squid will lead to development of improved methods for their capture, probably specially designed, large midwater trawls. How far the introduction of new fishing options will progress in any region in the 1980s will depend on the savings in operational costs compared with the initial capital outlay for the equipment, as well as on catch efficiency.

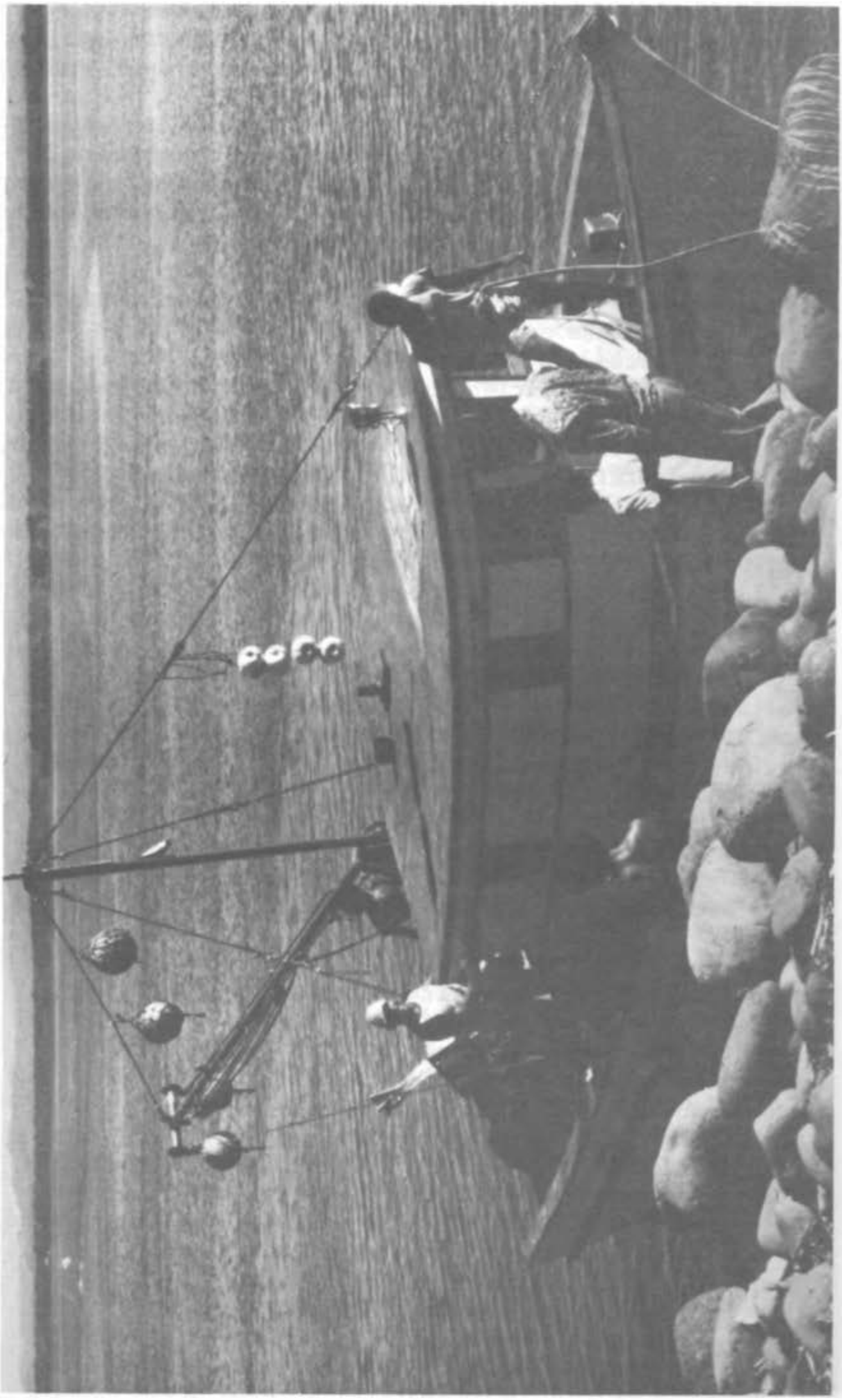

FIGURE 4-1 The use of motor-powered boats has increased productivity in small-scale fisheries throughout the world, but higher fuel costs and difficulties in acquiring engine parts hamper fishermen in many areas. More fuel-efficient boats, and increased availability of spare parts, repair manuals, and training courses in engine mechanics can greatly increase fishermen's working efficiency, and improve their ability to support themselves and feed their families. (S. Saila)

Fishing in less-developed or energy-poor nations will be most efficiently pursued by some combination of traditional methods and moderate-level technological methods already well established and in common use. The initial cost of much high-technology fishing gear can probably not be supported by local purchasing power or capabilities, and maintenance and repair problems can be prohibitive for many kinds of electronic gear. In some areas, however, certain types of new gear will aid in exploiting species previously underutilized for various economic reasons but which are now more desirable targets in light of declining traditional catches. For example, one fairly simple type of electrical surveying gear of widespread utility is the acoustic "fish finder," an echo-sounding device that senses schools of finfish or shrimp. Finally, if processing methods are changed to use species now harvested for fish meal for direct human consumption, modifications in gear and handling of the catch may be required.

In the past, fishermen from tropical regions have occasionally purchased fishing vessels and equipment inappropriate for tropical fisheries. Attention must be paid to modifying existing boats and gear or developing new ones in ways that are appropriate for individual regional fisheries (Schärfe 1979) and are acceptable within the often conservative lifestyles of artisanal and small-scale fishermen, their families, and their communities. For a given country, the most successful mix and rates of development of large-scale, small-scale, and artisanal fisheries can be determined by consultations with fishermen, larger boat owners, fish vendors (wholesalers and retailers), administrators, and scientists.

Recently, the increased cost of fuel, necessary concentration on stocks within national exclusive economic zones (EEZs), and reductions in stock sizes have resulted in the design of highly efficient combination fishing vessels of all sizes. Combination fisheries, in which gear and vessels are adaptable to a variety of target species and habitats, can be very efficient, leading to greater profitability for each boat and diminishing somewhat the problems of underemployment. In some developing countries, the canoe fisherman is already a combination fisherman, using various gear or stocks as the seasons change, but in many areas almost all fishermen use only specific gear and fish for specific species. For example, they may fish with traps for high-value export species such as spiny lobsters and return to port during the trap soak time. This time could be spent more productively hook-and-line fishing for other species such as snappers and groupers (Robins 1980). Investment in the local design and production of combination boats most appropriate for local technology and available fish species should be a profitable undertaking in many developing countries.

Fish-Attracting Devices: Floats and Artificial Reefs

There are now trends worldwide toward less random hunting of pelagic species and more use of artificial, free-floating attractant devices (Klima and Wickham 1970), some of which have long been used in traditional artisanal fisheries (see references in Matsumoto et al. 1979). Recent examples of such devices are the bamboo payao rafts used in the Philippines (Murdy 1980) and the attractant devices used experimentally, principally for tuna, in the western equatorial Pacific (Pacific Tuna Development Foundation 1980), off Hawaii (Matsumoto et al. 1979), Samoa (Pacific Tuna Development Foundation 1980), and the Marquesas Islands (Inter-American Tropical Tuna Commission 1980).

Considerable information has been gathered during the past decade about the ability of fixed platforms such as oil drilling rigs to attract fish. Coupled with studies of chemical and mechanical fish attractants, more detailed research should be undertaken on fixed and free-floating attractant devices in areas where there are no fish concentrations or migrations suitable for exploitation by small-scale and artisanal fishermen.

The use of artificial reefs to enhance both commercial and recreational fisheries has been successful in developed countries. Such "reefs" have been created by dumping rocky materials, cement blocks, or even discarded objects such as tires and clean waste metals. Some controversy remains as to whether such artificial habitats merely move fish from one area to another with little increase in an area's total catch, or whether they in fact concentrate fish or even increase their feeding success and production of young, thereby increasing total catches. Apparent localized successes, however, suggest that trials of this approach are worth conducting in developing countries.

REDUCING POSTHARVEST LOSSES

By-catch Retention and Processing

About 10 percent (4-6 million tons) of the world's fish catch is discarded at sea as "trash fish," even though it could serve as human food. In tropical shrimp fisheries, for example, millions of tons of small fish, both marketable and unmarketable, are now dumped over the side (Purcell-Maschke 1978). In many tropical fisheries as much as 3 tons of edible fish by-catch (3-4 million tons annually) are thrown overboard for every ton of shrimp landed, because the volume of hold space in shrimp vessels is limited.

The adoption of methods to reduce losses during processing and capture could help decrease the tragic waste of food currently found in the shrimp industry. The technology exists to separate the so-called trash fish in the trawl net during the tow, but economic incentives, and in some cases technological capabilities, are lacking to encourage landing and processing of by-catches. If suitable storage space is available aboard the vessels, new marketing approaches could enable such fish to be sold profitably to middlemen (as was done in Nigeria in the late 1960s by some local vessel operators).

The by-catch often can be processed to minced fish or fish meal, possibly in the same plant where the shrimp are processed. This was undertaken at the Vikingos S.A. plant in Cartagena, Colombia. Sri Lankan scientists (Etoh 1982) have reported that fish meal can be profitably made from shrimp by-catch using simple equipment on a "cottage-industry" scale. Another shrimp by-catch processing project in Guyana is achieving considerable success with the production and marketing of an extensive variety of fish products, ranging from high-quality whole fish and market fillets to more highly processed products such as packaged food items and oil for industrial use.

Reducing Postharvest Losses on Land

It is estimated that as much as 35 percent (about 8.75 million tons) of the annual world catch of fish destined for human use is lost between capture and consumption (Pariser 1979). This is two to three times the postharvest loss in the agricultural sector. Such losses are particularly large in the artisanal and small-scale fisheries of developing countries in the tropics and subtropics, and in many areas losses may approach

50 percent of the catch (Day 1980). In many such countries, fish are an important and sometimes the only source of animal protein and often a principal source of income for the poorest sector of the population.

The dissemination of information about techniques for reducing postharvest losses could be a nation's most immediate and successful means of increasing both food availability and fishery profitability. A 1976 meeting devoted to this topic suggested approaches that can best be used to achieve the goals of safer and more successful methods of preservation, handling, and storage (Tropical Products Institute 1977). Basic improvements that would substantially alleviate this problem include the use of more off-ground and protected initial fish-processing facilities. Introduction of low-cost, though relatively inefficient, energy generators such as windmills may be used to help traditional processing methods (drying, smoking), particularly in areas where there is a shortage of fuelwood. Nontoxic chemicals of local origin may also be used to prevent fish spoilage (National Research Council 1978). Recent work suggests, for example, that lactic acid bacteria may be effective in preserving fish (Fishing News International 1980c).

In certain areas, medium- to large-scale commercial operations for high-volume fisheries such as sardines and for high-value species such as shrimp have introduced modern refrigeration methods. This is occurring primarily in larger urban coastal centers and in the major riverine systems in central and southeast Asia and lakes in Africa. The export value of the product may encourage the provision of refrigeration facilities, often on a cooperative basis with international marketers, as has been done for the spiny lobster fishery in Belize and in the development of live-fish transportation on the rivers of Asia, Africa, and South America. Although such joint ventures may reduce postharvest losses in large commercial fishing operations, and although advanced techniques may filter down to smaller commercial operations, such a process is unlikely to have much effect on local artisanal fisheries. Thus small-scale fishermen, who produce perhaps more than half the total catch in developing countries, will still need assistance in preserving their catch.

The significant losses of fresh or locally processed products, resulting from infestation by insects and rodents before delivery to the consumer, can be reduced by improved packaging. For example, simple packing methods have been used successfully for fresh fish in India (Perigreen and Nair 1977) and for processed fish in the Lake Chad area of Africa (Day 1980). Considerable advances are possible in this field, especially in methods using locally produced materials.

Future plans to reduce postharvest losses should take into account the technological, sociological, and cultural aspects of the problem. Attempts should be made to understand why the major categories of traditionally processed fish products, and imports, are preferred by consumers in each country. How would consumers react to improvements and changes in taste, quality, costs, species, and shelf life? How would the processor react to improved yield, better transportation, and the like? Surveys of consumer and processor preferences and needs should consider that in many countries it is women who are principally involved in fish processing at the village level and in subsequent marketing at the consumer wholesale and retail levels. Thus any advisory services must convince these women as well as the fishermen of the economic advantages of change.

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5 Aquaculture, Mariculture, and Saltwater Agriculture

Enhanced food production and increased income are the dual objectives and benefits of aquaculture. Aquaculture is the general term applied to the cultivation of aquatic animals and plants and includes true aquaculture, in which freshwater animals or plants are grown, and mariculture, the cultivation of organisms requiring salt water. Aquaculture and mariculture are ancient processes that have been used in most parts of the world to produce food. In the modern world, with improved technologies for food storage and transportation, they provide foodstuffs for domestic consumption and, when exportable species are grown, generate foreign exchange. They are also a productive means of using domestic and agricultural wastes or the waste heat of industry. In addition to the relatively well-established techniques of animal mariculture, new but promising forms of plant cultivation using saline or brackish water are now being developed. With use of "saltwater agriculture," some species of vegetables, cereals, or sources of biomass can be grown where fresh water is scarce.

In the past 20 years, aquaculture has produced significant quantities of food, income, and employment around the world. According to a survey reported in Ocean Yearbook I (Pillay 1978), aquaculture is widely practiced in 66 countries. Of these, 35 are developing countries, where in 1975, aquatic farmers produced over 4 million tons of fish, shellfish, and seaweed--more than two-thirds of the total world aquacultural production and about 10 percent of the world's annual capture fishery harvest (Figure 5-1). Current average aquacultural yields are between 1.5 and 2.0 tons per hectare, but, depending on the levels of intensity and technology applied, they can range from less than 1 ton to more than 20 tons per hectare. With improved techniques, average yields in many areas could be increased two- or threefold

FIGURE 5-1 The combination of widely used and successful traditional pond culture methods with technical improvements developed through modern aquaculture research is allowing fish farmers to increase their yields and cultivate new varieties of fish with hardier characteristics, faster growth, or especially high commercial appeal. (S. Saila)

in a relatively short time; as much as a tenfold expansion of aquacultural areas is considered feasible (Pillay 1979). Thus world aquaculture production could double in the near term and perhaps experience as much as a five- to tenfold increase over 30 years, if adequate fertilizer and the necessary labor or energy inputs are made available. But this will require the accelerated transfer of technology, additional research, suitable legislation, financial investment, and the training and organization of technicians and management personnel.

The increased importance of aquaculture globally results, in part, from the continuing demand for animal protein. Other contributing factors are the overfishing of some wild stocks, the establishment by many nations of limitations on foreign fishing within their newly extended zones of national jurisdiction, the high cost of fuel, and the need to provide more employment opportunities, especially in rural sectors. These factors, and the periodic food crises brought on by natural or man-made causes, will continue throughout the 1980s and beyond, so that advances in both traditional extensive aquaculture and more technically demanding intensive methods will continue to be in demand by both developing and industrialized countries.

AQUACULTURE: EXTENSIVE AND INTENSIVE SYSTEMS

The control of breeding and rates of larval production is important in all aquaculture systems, but control requirements differ, depending on the cultivated organisms and the type of culture operation. For example, the desired improvement may be to increase production rates or, conversely, as in the case of the commonly used fish Tilapia, to prevent frequent breeding to avoid overpopulation of ponds and consequent stunting of the adult fish. Additional concerns include reducing feed costs, and energy costs where mechanical or electrical systems are employed; improving the efficiency of design and maintenance of ponds, pens, and cages; disease and pest control; and improving harvesting technology. Pillay and Dill (1979), in a collection of detailed technical papers, provide information on various aspects of culture for specific organisms. International research centers, such as the International Center for Living Aquatic Resources Management (ICLARM) in Manila, Philippines, are also excellent sources of technical and marketing information.

In most developed countries and a few of the more prosperous developing countries, high costs of land, labor, or available water have led to the development of intensive culture systems. In such systems, the areas under cultivation are small, but large amounts of energy and expensive energy-intensive inputs such as highly processed feeds and fertilizers are required. Species cultivated in these countries are primarily of high value--for example, prawns and shrimp, salmon, trout, or oysters, or specialty items such as the catfish reared and marketed very successfully in the United States and in a few Asian and Southeast Asian countries. Many of these species demand high levels of feeding and care, but they compete well with other high-quality protein sources in the marketplace.

The rising costs of labor and feed are currently encouraging the development of culture methods that give increased yields. The United States is engaged in aquaculture and mariculture research through its academic institutions and other publicly and privately supported facilities. Administrative coordination for two fishery technical assistance programs are provided at Oregon State University for mariculture, and at Auburn University in Alabama for primarily freshwater aquaculture. Successful results have been obtained from scientific and technical studies related to nutrition, physiology and behavior, production of "seed" stock, optimal stocking densities, genetic selection and hybridization, and studies of aquatic disease organisms. For economic reasons, studies of high-energy, intensive aquacultural and maricultural methods throughout the world will probably be limited for some time to those fish and invertebrate species for which the basic technology of culture is already known and the market is assured. As the potential for profits from aquaculture increases, so will the probability of a wider variety of species being cultured intensively. In the meantime, traditional "extensive" culture methods, in which well-understood species are grown at lower densities in more natural environments, will continue to provide high-quality protein food at low cost in many countries.

Whether investment in high-yield, but expensive, intensive aquaculture and mariculture operations is economically worthwhile depends on a country's state of development, on the extent to which aquaculture has been employed historically, and on its national plans, especially for the use of the traditional extensive aquaculture methods. Applying selected aspects of the techniques used in intensive aquaculture can, however, greatly increase yields in extensive aquaculture, as many of the more advanced developing countries have already learned. Polyculture methods, in which several species are reared together, are being successfully established in India. Thailand is developing a profitable catfish culture industry, and new types of cage cultivation, more concentrated than traditional open-pond or rice paddy fish culture, are being used in riverine areas of Southeast Asia.

ANIMALS AND PLANTS SUITABLE FOR MARICULTURE AND AQUACULTURE

An extremely important development in mariculture technology is the ability to rear some fresh- and saltwater shrimp and prawns (particularly the freshwater genus *Macrobrachium*), as well as some molluscs such as conchs through all stages of the life cycle. Another technical development of great promise is the ability to direct artificially the reproductive behavior of finfish: Chinese and Indian carp and gray mullets have been induced to breed in the laboratory by injections of pituitary hormones. Well-established techniques are also available for the controlled reproduction of oysters and hatchery production of oyster seed. This important development has helped in the genetic selection of strains for special qualities such as resistance to diseases.

In many developing countries, the most successful aquaculture will be that of freshwater fishes, including species native to Africa and South America as well as the widely used *Tilapia*. Such fish may be reared in local lakes, ponds, reservoirs, or even seasonal aquatic pools. However, the shortage of fresh water and abundance of marine or brackish coastal waters or wetland will make the cultivation of saltwater organisms (fish, shellfish, and plants) more attractive for many coastal developing countries.

The importation of fish and shellfish species for cultivation has become widespread. While it should be stressed, as noted in Mann (1979), that not all introduced exotic species are harmful, in some cases there may be severe adverse effects from introduced species that compete with or prey on local fauna and flora. Another serious problem is the transmission of communicable diseases to native organisms. In many regions, greater use of local, nontraditional species of fish and shellfish rather than exotics may be more appropriate and more economical for aquacultural development.

Traditionally exploited living aquatic resources have always included fresh- and saltwater plants and animals. Plants are used for food and for other purposes such as the manufacture of mats and woven baskets from reeds, or alginates and other industrial emulsifying agents from seaweed. Although aquatic plants are not widely eaten outside coastal Asia--being somewhat lower in starch content and not as universally appreciated in flavor as terrestrial plants--considerable potential exists for their enhanced culture and harvest for both human and animal food. Plants eaten as food include the high-protein, filamentous alga *Spirulina*, grown in alkaline tropical lakes (where it is the staple food for some local populations), and watercress, another freshwater plant. But the primary aquatic food plants of the world are the various seaweeds (marine algae) cultivated in large quantities in the Orient and in other regions.

Recent important technological advances have led to greater yields and energy efficiency in the culture and harvesting of seaweeds such as Laminaria or Macrocystis (kelp), Porphyra (nori), and Undaria (wakame). In Asia, these crops are usually cultivated in ponds or greenhouses, as natural stands have been severely depleted. In the United States, however, pilot projects have demonstrated the feasibiity of cultivating kelp on rafts or other small-scale support structures. Kelp farming has been suggested as a possible source of energy-rich biomass for fuel production (see Ryther 1979b, and Chapter 7 of this report). Artificially upwelled, nutrient-rich deep water has been used successfully as a growth stimulant to seaweed in Hawaiian and Japanese standard enclosure production and in a raft-based pilot project in California (Ryther 1979b). For freshwater plants, especially promising recent developments lie in the use of nuisance weeds, such as the water hyacinth for beneficial purposes such as feed, fertilizer, or wastewater treatment. However, the large water content and dispersal of these plants make the cost of collection per unit of dry weight high.

Saltwater Agriculture

A still relatively new but potentially significant development in agriculture is the cultivation of specially selected strains of terrestrial or marine crop plants in salt water. U.S. scientists at the University of Arizona and the University of California at Davis have been experimenting with salt-resistant (halophytic) plants (Epstein et al. 1980). Successful saltwater cultivation usually involves increasing the salt tolerance of conventional crops by intensive selective breeding or other kinds of genetic manipulation. An alternative approach to expanding the profitable cultivation of plants in marine coastal waters is increasing the quantity of useful products manufactured from plants that thrive naturally under marine conditions. Both of these technologies, even in the present early stages of development, could find applications in the coastal regions of arid lands.

"Planting" of Organisms in Marine Environments

The culture of genetically selected species and hybrids of both animals and plants for subsequent "planting" in rich estuarine and protected coastal environments will become even more widespread than it is at present. ("Planting" is the term used to describe placing young organisms on racks or lines, or in baskets and cages.) As developing and developed countries gain technological expertise, "semicultivation," making use of the natural environment, of a great number of species of algae, invertebrates, and fishes, especially those with short life cycles, will come into use. Such artificially planted stocks could be extended to more open coastal waters affected by the presence or occasional intrusion of upwelled or otherwise nutrient-rich waters close to shore, or the presence of a permanently well-mixed region such as an island or peninsular wake.

The transplantation of exotic fish species, such as Pacific salmon which were brought to Chile and the North Atlantic, and "sea ranching," in which juvenile fish are released to migrate and feed in the open sea and then return, may soon become more common, but this depends highly on the results of recent and ongoing experiments. Mann (1979) discusses criteria for transplanting and introducing new fish species. The recent natural spawning of the Pacific bluefin tuna (*Thunnus thynnus*) in an enclosed population in Japan has shown that controlled culture may be possible for even a large, long-lived, oceanic migratory species (Otsu 1979).

A great deal of work on sea ranching has been done in the universities and government laboratories of the Pacific Northwest coastal region of the United States. By selective breeding, scientists at the University of Washington in Seattle have produced salmon varieties that reach full maturity and should be ready to return to release areas after only 18 months at sea. Young salmon have been successfully "imprinted" in a particular saltwater bay on the coast of Oregon, so that some adults return directly to a processing plant on the bay shore with saltwater ponds, where selected animals can be milked for eggs and sperm to produce a new generation.

Nonfood Aquaculture Products

Profitable industries can result from culturing marine animals for other than food products--for example, seaweeds for alginates, shellfish for pearls, live bait fish for tuna fishing in areas without natural bait fish stocks, and ornamental fish for the aquarium trade (FAO 1975). The systems in use, especially for bait and ornamental fish culture, are becoming more efficient in terms of yield and energy costs. These industries and the food production aquaculture industries often benefit considerably by borrowing techniques from one another. For example, selective breeding and disease control methods developed in the ornamental fish trades are now applied in commercial food fish aquaculture.

IMPROVEMENTS IN TECHNOLOGY

Although extensive aquaculture such as the traditional pond cultures of finfish and crustaceans in Southeast Asia (see Ling 1977) requires more land than intensive systems, energy requirements and the use of higher technology products such as processed fertilizers, feeds, and disease control substances are lower. In the immediate future, capabilities in extensive aquaculture will be considerably enhanced. At the same time, it is expected that the low costs, hardiness, and relative ease of care of traditional culture systems will continue. Advances will depend on recent improvements in understanding the requirements in captivity of all life stages of such species as freshwater prawns (*Macrobrachium*), some marine shrimps (penaeids), milkfish (*Chanos chanos*), mullet, and some other finfishes.

In the next decade, research on the functioning and efficiency of the pond culture system, especially the low stock-density systems used in many tropical countries, should yield results. Basic aquacultural and maricultural research can provide a more detailed understanding of the pond ecosystem, particularly of optimal nutrient and energy flow, food chains in the lower trophic levels, and the effects of predation in polycultures. This knowledge will lead eventually to increased yields and the cultivation of species not traditionally "farmed," as well as the extension into new regions of the polyculture techniques practiced in China (Ryther 1979a) and Southeast Asia (Ling 1977) and the managed use of tropical mangrove areas as sites for mariculture facilities.

Improved mass-rearing techniques have already been developed in the aquarium trade, including new methods of intensive breeding control to allow manipulation of phenotypes--the actual "expressed" characteristics of organisms as opposed to the genetic or genotypic traits they carry and can pass on to offspring but may not themselves display. Hybridization is being successfully applied to increasing numbers of fish breeds. Finally, the use of vaccines and drugs for bacterial and viral infections is becoming highly sophisticated and may make a contribution to the control of product quality, reducing disease problems in selected strains.

RECYCLING ENERGY AND NUTRIENTS INTO AQUACULTURE FROM DOMESTIC AND INDUSTRIAL SOURCES

Wastewater, waste heat, industrial effluents, municipal sewage, and agricultural wastes (plant and animal materials) sometimes serve as important sources of water, nutrients, and food for aquaculture systems (Figure 5-2 illustrates the wastewater fertilization of shellfish culture). The developed world is learning from many developing countries about how to design less wasteful systems of aquaculture that utilize farming and domestic inputs and outputs (see National Research Council 1981). Present regulations in many developed countries prohibit the use of farm or domestic waste for culture purposes, although highly efficient systems that recycle wastes from homes and farms into culture ponds (and often back into the land from cleaned or drained ponds) have been used successfully and safely for centuries by traditional aquaculturists in Asia, Africa, and other regions. Because chemical fertilizers are energy-intensive, expensive commodities that require transport from sources far removed from sites where aquaculture farms may be established, it may be especially efficient and profitable for aquaculturists and mariculturists in energy-poor countries to take advantage of locally available domestic or agricultural wastes as sources of fertilizer.

Integrated agriculture-aquaculture farming systems such as those for poultry-fish, rice-fish, or pig-fish are being used very successfully in a number of developing countries. These systems are more efficient economically than single-cultivar systems, because little or no artificial fertilization is needed to enhance pond productivity. Water fowl-fish systems are especially efficient, because ducks or other fowl obtain their own nutrition from pond plants and prevent rapid pond overgrowth.

A very recent "high-technology" development, now in the planning or testing stages in a few tropical nations, is the use of large quantities of nutrient-rich water pumped from ocean depths below the surface mixed layer

FIGURE 5-2 In this Woods Hole experiment, it was found that diluted inputs of treated sewage were an excellent nutrient supply for planktonic pond algae, which in turn provided the food supply of shellfish grown on racks in adjacent raceway enclosures. (Woods Hole Oceanographic Institution)

(so-called artificial upwelling) for either shore-based aquaculture or offshore enclosures. Although this technique incurs high engineering costs, it may become economically feasible by the end of the decade, especially if coupled with a direct energy production method, such as the ocean thermal energy conversion (OTEC) power systems now being tested in Hawaii and Japan, which give excellent results in seaweed culture fertilization. Another possible but untested power supply for artificial upwelling could be a wave-pump system.

PUBLIC POLICY FOR THE DEVELOPMENT AND OPERATION OF AQUACULTURE

Managerial or operational difficulties often hamper the profitable development of aquaculture (Matsuda 1978). These difficulties may result from scientists lacking concern for economics, or from a lack of consideration for the social costs, resulting from private development of aquaculture in the absence of clear government policy guidelines. Unfortunately, the governments of both developed and developing nations frequently lack well-defined policies regarding the development of aquaculture and effective means of implementing government regulations or guidelines.

There is need for additional dialogue among policymakers in both developed and developing countries to consider the potential of aquaculture and the resources required to achieve its potential. In some countries, notably Ecuador, recent achievements in growth of the aquaculture industry have been nothing short of staggering, and this potential may be shared by other developing countries. The development of an international network of scientists, linked to funding organizations and the private sector, such as the proposed International Aquaculture Foundation, may provide the stimulus this field appears to warrant.

Even in rural areas where alternative food production methods may be sufficient, the social value of providing additional protein and work opportunities through aquaculture is often immense (Palacio 1979). In Latin America, one important problem is a shortage of well-trained people to work in the field as extension agents (Luna 1980). Another impediment is the land tenure system, which discourages aquaculture because most of the land is worked by tenant farmers.

Because the future growth of aquaculture will be much enhanced by the transfer of technology, regional and interregional cooperation assume special significance. The Consultative Group on International Agricultural Research (CGIAR) has recognized the need for Latin America, for example, to undertake interdisciplinary research in aquaculture. Cooperative research arrangements are common in many other regions of the developing world. Most countries, however, still lack experienced personnel who could assist aquaculturalists through national or international extension services. Better education and training of aquacultural scientists and technicians are thus urgently needed in most countries to take advantage of the increases in food production and economic opportunities offered by the development or expansion of mariculture and aquaculture facilities. In some of the more advanced developing countries, where substantial numbers of aquaculture specialists are just now being trained, it is very important that administrative coordination help direct trained people to locations where their knowledge will be of most use. It is essential that new enterprises be assisted technically and that programs, once begun, are given follow-up support to get them through the critical first few years of development. Thus in a few years, they should be firmly enough established to stand on their own as productive, self-supporting "aquafarm" operations.

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6 Remote Sensing

Satellite and Aerial Monitoring of Coastal and Ocean Regions

In developing countries, remote sensing has been used primarily for agricultural and geologic surveying, but the repetitive wide-area coverage available from satellites and airplanes using photography and other methods is also well suited to surveying the properties of coastal and marine regions. These remote sensing methods can produce visual images, or they can be used to map the land, surface waters, and atmosphere with many varieties of infrared or microwave imagery, giving information on various environmental conditions. They are often the most practical techniques for identifying and tracking large features such as the positioning of ocean surface currents, erosion along a coast, or the spread of polluted effluents.

A number of satellites, varying in the types of features each monitors best, have been put into orbit by developed countries. Much of the meteorologic, geographic, and oceanographic data that they transmit can be picked up directly anywhere that there is a receiving antenna installation (Figure 6-1). The construction of such an installation is prohibitively expensive for any but one of the most advanced developing countries to undertake alone. However, groups of countries, with help from development assistance agencies, have combined their resources to build regional remote sensing centers that receive data for subsequent dissemination and analysis within each country.

New remote sensing methods especially useful for marine studies include infrared radiometers for mapping surface temperatures; synthetic aperture radar (SAR) for wave studies; microwave radiometers for wind speed, surface temperature, and perhaps salinity measurements; and portions of the multispectral scanner spectrum (MSS) and the coastal zone color scanner (CZCS) for detecting factors related to plankton densities. Table 6-1 indicates

FIGURE 6-1 Satellite-receiving facilities are very expensive to build, but developing countries are now able to obtain satellite sensing data through both international data transfer arrangements and the development of multi-country regional receiving centers. (National Oceanic and Atmospheric Administration)

many of the ocean sensing applications of instruments carried in satellites and aircraft, and Table 6-2 gives information on the technical capabilities of satellites of particular interest for surveying the ocean conditions and resources of developing countries. Such activities would, however, require a concerted effort by several national governments, working with assistance agencies, to set up and sustain a regional center, sponsor mapping programs, and conduct training workshops.

TECHNOLOGY FOR THE ACQUISITION AND ANALYSIS OF SATELLITE DATA

Landsat

In developing countries, the term "remote sensing" has become almost synonymous with the use of the Landsat satellite. Governments of numerous developing countries, with the strong support of such agencies as the U.S. Agency for International Development, the World Bank, and

TABLE 6-1 Ocean Sensing Applications of Instruments Carried in Satellites and Aircraft

Platforms and Instruments	Temperature	Salinity	Chlorophyll	Color	Suspended Sediment	Sea State	Fronts	Oil	Ice Boundaries	Wetland Extent	Wetland Productivity
Satellites											
Landsat-4, Thematic mapper	0	0	2	3	?	?	?	?	?	?	?
Landsat, MSS	0	0	1	2	3	1	2	2	1	3	2
Nimbus-7, CZCS	0	0	2	3	3	1	2	1	1	?	?
-7, SMMR	3	0	0	0	0	1	2	0	1	?	?
NOAA-5, VHRR	3	0	0	0	0	1	3	1	1	?	?
-6, AVHRR	3	0	0	0	0	1	3	1	1	?	?
DMSP	3	0	0	0	0	1	3	1	1	?	?
Seasat SAR, SMMR, SCAT, altimeter (no longer in operation)	3	1	0	0	0	3	2	3	3	?	?
High-altitude aircraft											
MSS (OCS)	0	0	2	3	3	1	3	3	3	3	2?
Photographic	0	0	1	1	2	1	2	2	3	3	1?
Medium-altitude aircraft											
Photographic	0	0	1	2	2	2	3	3	3	3	?
MSS (M2S)	3	0	2+	3	3	2	3	3	3	3	?
Infrared (thermal scanner)	3	0	0	0	0	1	3	2	1	3	3
Microwave	2	2	0	0	0	3	2	1	1	0	?
Radar	0	1	0	0	0	3	1	3	3	0	?
Small aircraft											
Helicopter fluorosensor	0	0	2+	1	1	1	2	3	0	?	?
Small aircraft photographic	0	0	1	1	2	2	2	3	1	3	?

MSS = Multispectral scanner
CZCS = Coastal zone color scanner
SMMR = Scanning multifrequency microwave radiometer
NOAA = National Oceanic and Atmospheric Administration
VHRR = Very high resolution radiometer
AVHRR = Advanced very high resolution radiometer
DMSP = Defense meteorological satellite program
OLS = Optical line scanner
SAR = Synthetic aperture radar
SCAT = Scatterometer
OCS = Ocean color scanner (10 bands)
M2S = Modular multispectral scanner (11 bands, including thermal infrared)
0 = Not applicable
1 = Limited value, or future potential
2 = Needs additional field testing
3 = Reliable (operational)

SOURCE: Klemas 1981, Stewart 1981 and 1983, Weeks 1981.

TABLE 6-2 Satellite Instruments Used for Development Projects

Satellite	Wavelength Region (micrometer)	Spatial Resolution (meter)	Repetitive Coverage	Required Environmental Conditions
Landsat-2	Visible, near infrared (IR)	MSS = 80 = 0.465 ha	Every 18 days	No clouds
Landsat-3	Visible, near IR and thermal (10.4-12.6)	MSS = 80 = 0.465 ha	Every 18 days	No clouds
Seasat	Synthetic aperture radar (23.8-cm L band)	25	No longer in operation (Satellite-based SAR perhaps to be launched again in 1980s)	Penetrates clouds
Nimbus-7 (CZCS)	Five visible narrow bands (± 10 nanometers)	800	Every 6 days	No clouds; low concentration of suspended sediment
Nimbus-7 (SMMR)		21-121 km		No heavy clouds or rain At least 600 km away from land
NOAA-5 (VHRR)	Visible daytime, thermal at night	High = 4,000 Low = 1,000	Every 12 hours	No clouds
NOAA-6 (AVHRR)	Visible and thermal IR	900	Every 12 hours	No clouds
TIROS-14 (AVHRR)	Visible, near IR	900/4,000	?	No clouds
GOES	Visible and thermal	2,000/5,000	Every half hour	No clouds

SOURCES: U.S. National Aeronautics and Space Administration and U.S. National Oceanic and Atmospheric Administration, Washington, D.C., and Stewart (1981).

the Inter-American Development Bank, have successfully instituted Landsat-related investigations. These have included land use, food resources, and mineral deposits, or more specifically, desertification, irrigation, crop management problems, deforestation, and exploration for minerals and metals. About 55 countries and more than five international organizations are involved in Landsat investigations. Landsat data-receiving stations or data analysis centers have been set up in Brazil, Egypt, Kenya, India, Thailand, the Philippines, Zaire, and other countries. Additional receiving stations are scheduled for Argentina and Chile.

While both terrestrial and marine data can be received from several satellites, the information processing and dissemination systems, particularly for use by developing countries, are by far the most thoroughly organized for data from Landsat.* However, Landsat's optical sensors do not offer the types of data most needed for coastal and marine studies, which require thermal infrared and microwave sensors as well as optical ones. Whereas most developing countries are covered by all of the currently operating scientific satellites--Landsat-2 and -3, Nimbus-7, NOAA-5 and -6, TIROS-14, and GOES (Geostationary Operational Environmental Satellite) --most of these countries currently receive and analyze little or none of the many kinds of available data useful for coastal or oceanographic purposes. For instance, several countries, including Chile, Peru, and India, have a long-standing involvement in satellite tracking networks or meteorological data analysis and are therefore receiving and analyzing low-resolution (8-km), thermal infrared imagery from satellites such as GOES. However, these stations and new remote sensing centers being established in Argentina, Brazil, Chile, Ecuador, Egypt, Syria, Kenya, Thailand, and the Philippines do not have the capability to process high-resolution thermal infrared data from NOAA-type satellites or microwave data from Nimbus-7, both of which are needed for oceanographic applications.

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*A detailed description of the technology of remote sensing satellites, data reception and storage, and information processing techniques is presented in: National Research Council (1977) Resource Sensing from Space: Prospects for Developing Countries, National Academy of Sciences, Washington, D.C., USA. A very useful, updated collection of papers on many aspects of satellite use for basic and advanced marine scientific purposes is presented in a single volume of the journal Oceanus, Vol. 24, No. 3.

Possibly the best approach to the effective transfer of this ocean-related remote sensing technology is the establishment in developing countries of regional centers similar to those already in use for Landsat data but with the necessary additional receiving and processing capabilities. Such centers, each typically servicing several countries, will allow these countries to apply remote sensing to coastal and oceanographic problems on a permanent basis. Regional centers have the advantages of establishing continuing local access to the technology, involving local support, and ensuring long-term program continuity.

An important consideration, however, is that such centers require expensive, long-term commitments. The typical cost of establishing a Landsat receiving station with the associated data analysis equipment, for example, is about $7 million; maintenance and operation costs average about $3 million per year. But once such a station is in place, the additional cost of conversion to receive kilometer-resolution NOAA satellite thermal infrared imagery is in the range of $50,000-$200,000. This type of conversion is highly recommended for countries that already have Landsat or GOES receiving stations and an interest in adding high-resolution ocean observation capabilities to their land and cloud observations. Countries that lack receiving stations but want to develop ocean and coastal monitoring capabilities should plan regional remote sensing centers for their area or should begin to contribute to and participate in the operations of an existing center. Information on regional center programs is given in this chapter's final section on "Institutional Arrangements."

APPLICATIONS OF AERIAL AND SATELLITE DATA TO MONITORING MARINE AND COASTAL RESOURCES

The principal applications of coastal and marine resource remote sensing, some of which are fully operational and some still experimental, are:

- Monitoring man-made and natural changes in the geology of the coastal zone, such as the impact of land use or coastal engineering projects on the sediment contents of coastal waters, erosion, and positions of barrier beaches or sandbars

- Determining the identity, concentration, and dispersal patterns of pollutants such as oil slicks, sewage, and industrial effluents
- Mapping the extent and quality of coastal vegetation and wetlands, including diversity of plant species and effects of pollution
- Mapping chlorophyll-rich upwelling regions, which is relevant to studies of fish stock productivity and other biological processes
- Charting ocean current patterns and surface water mass distributions for physical oceanographic work and for studies of the transport or aggregation of plankton, fish eggs and larvae, and adult fish
- Mapping seafloor topography as reflected by sea surface elevations.

These applications of remote sensing involve a range of data analysis techniques: basic visual interpretation of color infrared film is used for wetland boundary mapping; techniques for interpreting the digital format of thermal infrared data are needed to map temperatures of surface waters; and sophisticated mathematical methods are required to analyze the data collected by the multispectral scanner for the quantitative evaluation of marsh biomass and dissolved chlorophyll concentrations on wetlands, among other uses.

When either development or natural factors cause erosion and other geologic changes, numerous techniques allow the monitoring of potentially serious effects on the structure of coasts and wetlands. Remote sensing also assists in the management of living resources. Coastal vegetation coverage is evaluated by direct photographic and infrared mapping; the health of the plants is analyzed through infrared monitoring. Biological changes affecting aquatic animals such as fish and shellfish are studied indirectly through evaluations of the productivity and distribution patterns of planktonic organisms in the food chains on which they depend. Scientific oceanographic studies of current patterns and indirect mapping of seafloor topography are possible through interpretation of wind stress data and direct sea surface elevation data provided by scatterometer and synthetic aperture radar such as those from Seasat.

Once the original investments in equipment and training have been made, extensive information about coastal areas is provided for minimal time and expense. Field measurements of such environmental factors, on the other hand, are very costly in terms of time and manpower as well as support costs, and the results are specific to sample sites and thus may not be completely representative of surrounding areas.

Coastal Surveying

Particular types of remote sensing data are most useful for particular coastal surveying tasks, as shown in Table 6-1. Color and color infrared photography have been used to map tidal wetland boundaries, vegetation species, and net primary production (Anderson and Wobber 1973, Reimold et al. 1973, Bartlett et al. 1979, Klemas 1971). Multispectral digital satellite techniques have been employed to map plant types, density and height of the standing crop, and other properties related to the quantity and quality of marsh biomass (Carter and Schubert 1974, Anderson et al. 1975, Klemas et al. 1975, Bartlett and Klemas 1979).

The various aerial and satellite data sources have different advantages and limitations with respect to the cost and accuracy of data provided. Landsat digital multispectral data processing is a least-cost method of producing maps, showing large areas of vegetation cover. Planning studies, however, require more detailed information on coastal vegetation and habitat types than is usually available from the Landsat data. In these studies, manual interpretation of aerial photography may be more desirable. However, once satellite images are available, it becomes a relatively more expensive and time-consuming process, as it yields a very detailed categorization of wetlands and habitats.

Workshops to train technicians in detailed aerial interpretation methods are held occasionally throughout the world. A number of U.S. agencies and international organizations sponsor conferences, training workshops, and joint research projects that give foreign scientists experience working with the advance remote sensing techniques used in the United States and Europe. These organizations include the U.S. National Oceanic and Atmospheric Administration through its Sea Grant International Program (information on participating U.S. universities is available from the NOAA Office of Research and Development); the United Nations Intergovernmental Oceanographic Commission through its Working Committee for Training, Education, and Mutual Assistance; the U.S. Agency for International Development (USAID); and the International Council of Scientific Unions through its

Committee on Science and Technology in Developing Countries and Committee on Space Research.

Methods are currently being tested for monitoring primary productivity of coastal surface waters and for scientific studies of the outflow of plankton and detritus from marshes and estuaries by analyzing the data from multispectral scanners (MSS) and laser fluorosensors. For the fluorosensor method, four particular wavelengths of laser excitation data are used to measure indirectly chlorophyll fluorescence in the water; the fluorescence reflects the amount and types of phytoplankton present. MSS data, on the other hand, are used to map concentrations of organic and inorganic substances dissolved in coastal waters. Interpretation of these data requires use of multivariate analysis, which permits identification of the separate types of input from each of the numerous substances being mapped (Philpot and Klemas 1979). Both of these techniques require additional field testing to establish their reliability. It is likely, however, that one of these or some other variant of such methods will be available within the 1980s for making at least relative measurements of marine plant productivity.

Satellite data may eventually be useful for oil slick observations (see Table 6-1). At present, excellent oil monitoring results can be obtained with high- or medium-altitude aerial surveillance using MSS and with the use of both photographic and fluorosensing methods on small, lower flying aircraft.

Observations Related to Fisheries

"Spotter" aircraft are very useful in locating schools of many types of pelagic fish. Although fish schools cannot be seen directly from satellite altitudes, satellites have been used to locate areas of high probability for fish availability, such as the highly productive, nutrient-rich upwelling areas off the coasts of Peru, the western United States, and western Africa. Upwelling areas can be mapped by MSS because of the strong thermal gradients caused by the colder upwelling water, and because of its spectrally different nutrient and chlorophyll content (Clarke et al. 1970, LaViolette 1974).

Studies are now being undertaken on the relationships between certain coastal water properties, such as water color, turbidity, and chlorophyll concentration, and the presence of fish. A computer classification using Landsat MSS data of high-probability fishing areas off the coasts of Louisiana and Mississippi has produced promising results (LaViolette 1974, Kemmerer 1976).

For practical fishery purposes, perhaps one of the most helpful aspects of large-area remote sensing data is for locating positions of currents and oceanic fronts. Where water masses of different temperatures meet, some fishes, including high-seas tuna as well as smaller fish types, aggregate. Furthermore, for most marine fishes the period of egg and larval drift is believed to be the most critical survival period in the life cycle. Scientists in many areas believe that when surface currents do not provide favorable transport, fisheries may be severely affected. Measurement of surface winds and currents by microwave sensors such as the scatterometer, altimeter, and radar mapper (see Table 6-1) could provide the information needed for scientific models of fish egg and larva drift patterns between estuarine and other nearshore nursery habitats and more offshore waters (Brucks and Leming 1977, Born et al. 1979).

Oceanographic Information

The evaluation of surface water current patterns by satellite sensing will almost always be the only way to obtain wide-ranging transport data that are direct and synoptic (simultaneously taken over an area). The usual method for calculating transport is indirect estimation, based on wind speeds and directions calculated from surface atmospheric pressure data measured at sea by weather services and other organizations. This approach produces estimates limited in accuracy to approximately 300 km in range and about 1 month in time (Brucks and Leming 1977). In contrast, a satellite-based scatterometer, such as the one employed on Seasat when that satellite was in operation, would allow synoptic sea surface wind stress measurements over greater areas and at shorter time periods. This gives surface motion estimates with a relatively high degree of resolution (field dimensions of 2 x 500 km with 50 km resolution and, in the case of that particular satellite, a 36-hour repetition frequency).

Fronts between water masses that differ in temperature, salinity, or other physical and chemical characteristics also affect the spatial distributions of all planktonic (drifting) and pelagic (free-swimming) marine organisms, including the young life stages of fishes. Changes in strength and position of very nearshore fronts in particular are thought to be important controlling influences on distributions and thus on the survival rates of certain fish eggs and larvae.

LIMITATIONS OF REMOTE SENSING

In planning for the use of remote sensing techniques to provide oceanographic information, the present scientific limitations of this form of data collection must be kept in mind, as well as questions concerning recipient country technological capabilities and cost-benefit analyses.

Perhaps the most serious limitation of satellite sensing at present is that cloud cover interferes with reception. This is a particular problem for coastal areas, as nearshore waters, especially in major upwelling areas, are under cloud cover for relatively large periods of time. A further limitation is that all properties are measured for only the upper layer of the waters under observation. Depth ranges vary for different types of data. In the more productive and thus greener and less transparent waters, chlorophyll or detritus measurements probably indicate concentrations of these substances averaged over shallower depth intervals than in the less productive, more transparent blue waters of the open ocean.

For measuring oceanographic parameters below surface waters, there is no substitute for direct-depth profiling from research vessels. To obtain the most complete and useful oceanographic information, when remote sensing data are available, it is best to integrate satellite or aircraft data analysis with the results of conventional ship-based sampling.

FUTURE DEVELOPMENTS IN OCEAN REMOTE SENSING

In the next decade, two new sensors will dominate satellite sensing using the visible light wavelength bands. The coastal zone color scanner (CZCS), launched in 1978 on Nimbus-7, measures radiance from the ocean waters in infrared (thermal), near-infrared, and visible light bands. The visible bands are divided into four wavelength groups, selected to correspond with the optical properties of chlorophyll, certain other plant pigments, and suspended matter in water (Austin 1979), while the infrared bands serve to map land-water interfaces and temperatures of coastal and ocean waters. Although the spatial resolution of 800 meters from the

Nimbus-7 altitude (955 km) limits its use for estuaries and nearshore waters, the CZCS on this satellite provides scientifically useful results on relative chlorophyll concentrations in the wider areas of the open ocean.

The second advanced optical scanner is the thematic mapper of the Landsat-D satellite. Although its spectral bands are not optimized for chlorophyll mapping, its high spatial and spectral resolution will significantly improve mapping of wetlands and studies of organic and inorganic suspended matter in coastal waters (Bracken et al. 1979).

A promising technology for coastal mapping in the presence of cloud cover may be the new satellite sensors that operate in the microwave portion of the electromagnetic spectrum (Callio 1979). Another possible application of microwave radiometry is the measurement of surface salinity, an important "marker" characteristic for ocean research, from low aircraft altitudes. Spatial resolution from such aircraft systems should be on the order of 0.5 km (Swift 1980). This method is accurate to one part per thousand, just sufficient to measure differences in ocean surface salinities, which are greater than deeper water salinity differentials. Simultaneous sea surface temperature measurements can be made to within 1°C.

In the future, aircraft and satellite systems will use several methods to observe ocean waves, currents, and ice conditions through cloud cover. Synthetic aperture radar will most likely be particularly important in obtaining this kind of information. SAR was used very successfully aboard Seasat to penetrate to the ocean surface during unfavorable viewing conditions, including major storms such as hurricanes. Features recognized included ocean fronts, sea ice, and land-water interfaces, as well as the characterization of ocean waves up to 50 m and more in length (Born et al. 1979).

Finally, the possibility of penetrating beyond the barrier presently represented by the surface layer, and thus tracking deeper patterns of water motion, may be offered by various laser systems. Subsurface temperature and salinity, for example, may eventually be measurable by a form of polarized light detection called Raman scattering (Chang and Young 1972).

INSTITUTIONAL ARRANGEMENTS: REGIONAL CENTERS

The transfer of satellite sensing techniques to developing countries has been aided considerably by new regional and national centers, staffed and equipped to handle several types of satellite data reception and interpretation. Regional remote sensing centers now being established for some developing countries are expected to encourage closer cooperation between satellite sensing technical specialists and data users. In the past, these two groups were often not in close enough contact to promote the awareness of data availability and its use for scientific and resource assessment purposes. It is particularly important to establish a close working relationship between the multidisciplinary remote sensing technology community and the traditional geographical mapping community. Many remote sensing specialists have tended to focus on techniques for extracting data from satellite imagery and aerial photography, often through relatively sophisticated computational techniques, and have paid less attention to dissemination and usability of the data. It is of equal or perhaps greater importance for remote sensing experts to develop the capability to present those data in map formats useful for planners. This requires some new map-making (cartographic) techniques, including the establishment of ground control values for remotely sensed data and image rectification methods. Basic skills such as the use of various map projections are also needed.

As a country begins to use remote sensing data, it is important to develop methods for systematic storage, retrieval, and analysis. To this end, the large-scale remote sensing technology assistance program managed by the USAID has placed primary emphasis on the development of regional remote sensing centers. The first of these centers was established in Nairobi, Kenya, in 1977, in cooperation with the new Regional Centre for Services in Surveying and Mapping, sponsored by the Economic Commission for Africa. Other centers are being developed in West Africa, Asia, and Latin America. USAID, in cooperation with the U.S. National Science Foundation, already supports a center in Egypt that could be expanded to assist countries in North Africa and the Middle East.

Each center will be staffed by four or five specialists representing different disciplines and by local technicians. Each center will contain analytical equipment, imagery files, a technical library, and ground-truth equipment for recording the directly sampled field data needed to standardize the comparative data collected by satellites. In addition to being able to provide workshops and other forms of training, each center will have a strong extension capability. The staff will be encouraged to learn the specific needs of the participating countries in order to provide the kind of assistance that will satisfy those needs most directly.

The regional centers can act as focal points for the development of information networks. They will be important contact points between local resource managers and experts in the United States and the many other developed and developing countries that have joint satellite programs with the United States (including Western Europe and Japan).

Remote sensing is a tool for resource management just as mathematics is a tool for science or engineering. Thus center personnel should work closely with local universities in the introduction of remote sensing into their curricula oriented toward natural resources. Accordingly, it is not the intent in establishing these centers to create a permanent situation of dependence on outside assistance but rather to establish temporary organizations to satisfy an immediate need until national teaching and technical facilities are able to take this on as their own responsibility.

Conferences and training workshops, which are relatively inexpensive and can be arranged on short notice, are effective for basic training and for creating awareness of the technology's capabilities. The individuals selected to attend workshops must have the appropriate basic education, technical awareness, and computational skills so that they benefit from whatever level of training they receive. Care is needed, however, to avoid the lack of continuity that can result from such short-term training or educational experiences. Individuals who have received such preliminary training must have opportunities in their home countries to use and pass on the information they have acquired. They should also be able to keep abreast of new technical developments.

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7 Future Exploitation of Marine Resources

While the technologies for marine resource exploitation described in previous chapters are, for the most part, already used, those described in this chapter are not yet ready for full-scale application, even in industrialized countries. However, they show promise for eventually expanding the benefits offered by the ocean and its resources.

ENERGY PRODUCTION FROM THE SEA

Ocean Thermal Energy Conversion

Ocean thermal energy conversion (OTEC) is a method of generating electricity by using as a power source the solar heat stored in the upper layers of the ocean's waters. This means of energy production can be developed only in tropical regions, however, where the difference in temperature between the surface layer and deeper waters is great enough to provide an energy source that can support heat exchanger-driven power production (see Cohen 1979). The magnitude of this resource is enormous in the tropical zone between the latitudes 20°N and 20°S (probably 300 quads per year). The system will be most immediately effective as a source of power for tropical island communities such as those of the South Pacific and the Caribbean Sea.

Initial testing of OTEC systems, using small-scale but fully operational, free-floating platforms off both Hawaii and Japan, has been successful (Figure 7-1). In addition to producing electricity, ocean thermal energy systems generate artificial upwelling. In one configuration (open cycle), they also generate fresh water. The use of the nutrient-rich upwelled water as a fertilizing medium for adjacent mariculture ponds has proved very

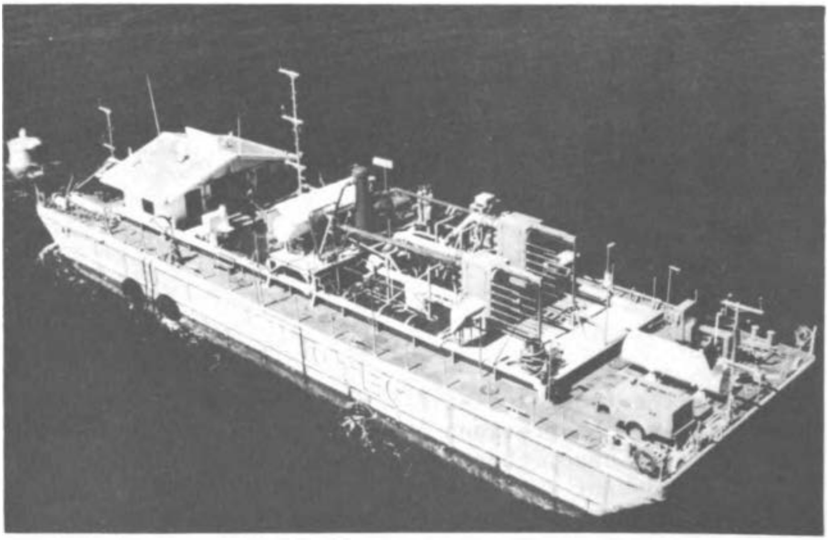

FIGURE 7-1 Trial platform for OTEC research in Hawaii. This "mini-OTEC" project has demonstrated the feasibility of generating electricity through heat exchangers that use the temperature differential between warm tropical surface waters and cool water pumped from lower depths. (University of Hawaii)

successful in pilot projects in Hawaii and Japan, where seaweed (nori) is reported to achieve exceptionally high growth rates in test facilities now in operation. Such developments may substantially increase the economic efficiency of the OTEC operation, as cultivated organisms as well as power will be produced for relatively low additional costs.

Calculations by the Johns Hopkins University Applied Physics Laboratory and others suggest that a full-scale operating system will be economically competitive with fossil fuel and nuclear power. The U.S. Department of Energy and agencies in several other nations are planning to construct larger scale demonstration plants, and a number of developed countries are undertaking or considering technical assistance to tropical developing countries for establishing trial plants: the Netherlands with Indonesia and Curaçao, France with Tahiti, and Sweden with Jamaica. Thus ocean thermal energy may be available commercially by the year 2000.

Harvesting Marine Plants for Biomass Energy Production

Another, quite different mechanism for converting the solar energy that penetrates the ocean's surface layers takes advantage of the capacities of various marine plants to trap large quantities of energy, convert it into living matter, and store it in accessible forms. Just as various terrestrial crops are being used in some countries for extraction of liquid or gaseous fuels, a number of marine plants are being proposed as candidates for large-scale "biomass fuel" harvesting.

As with OTEC, the potential for efficient and profitable energy production to be obtained from this method is greatest in the lower latitudes, where the annual input of solar energy is greatest. However, while OTEC is not at all feasible in middle or high latitudes, biomass energy conversion is in fact quite possible in most regions of the world, although with lower levels of productivity in areas with lower solar input.

Types of marine plants that could be harvested for energy production are theoretically both numerous and quite varied. In practice, however, certain characteristics may prove necessary for economical biomass processing. Plants that most easily form natural attachments to substrates are most desirable to ensure that the energy crop can be easily contained or restrained. And, of course, plants with the most rapid rates of productivity (all other factors being equal) are the best harvesting candidates.

Research is needed to identify which characteristics of the plant material are the most desirable for efficient processing into solid or fluid fuel form. Some seaweeds in the brown algae group (kelps and related plants) may prove to be particularly good bioenergy cultivars; preliminary work on energy production from these plants is under way in a number of developed and developing countries. Several kelp species have long been harvested from both natural and cultivated populations for the extraction of nonfuel substances such as alginates. Research may find, however, that other algal types, or some of the rapidly growing shallow marine and estuarine vascular plants (sea grasses and their relatives), would be equal or superior subjects for energy harvesting.

Some seaweeds that have been farmed for centuries for food production in Asia are cultivated in partially enclosed natural waters or in entirely enclosed facilities such as greenhouses. In addition, in successful pilot projects large masses of kelp have been grown at sea on artificial floating structures (Ryther 1979).

While the latter may eventually prove to be a profitable, high-volume method of producing biomass for energy, there has been no full-scale demonstration of the economic feasibility of such kelp farms at sea. Growth rates of kelp in nature and in enclosures have proved quite sensitive to available levels of nutrients and sunlight. For that reason, cultivation should be tested under the conditions to be used in a given location before productivity can be estimated.

Fuels can be produced from biomass, using several different processes. The search for the most efficient process for producing fuel from marine biomass is only one part of research being undertaken worldwide on the conversion of marine, aquatic, and terrestrial biomass into energy. The fuels most likely to be produced are methane gas, for which processing methods are already quite well known, or various kinds of alcohol.

Large-Scale Production of Electrical Power from Tides, Currents, and Waves

Great amounts of energy are carried in the ocean in the form of kinetic energy. Many designs and pilot projects for energy systems driven by ocean waves, currents, or tides require advanced industrial technology, which may not be economic or practical in developing countries. Smaller and less complex systems have also been designed, however, and these could be used in less-developed countries, particularly in regions with limited supplies of fossil fuels or traditional fuels such as wood. Articles on a number of the most promising of these designs and prototype projects were collected in a 1979 issue of the journal Oceanus (Vol. 22, No. 4). Some of these designs are described here.

Some large-scale systems requiring advanced industrial technology may supply energy for developing countries in the next decade, through joint international ventures or bilateral assistance projects. These systems include tidal generating stations, which are already in operation in several countries. Current-driven turbines or large, wave-powered electrical generating systems may also prove feasible, but both ideas are only in the preliminary testing stages.

Tide-driven electrical generating plants can be established only in locations where natural tidal fluxes are relatively great and the geographic configuration of the coastline is appropriate. These plants will be similar in scale to conventional hydroelectric plants at river dams. The first commercial tidal power station is located in LaRance, France (Cotillon 1974). Pilot projects have been planned in Nova Scotia, Canada, and South Korea and may be proposed in the United States, United Kingdom, Australia, Argentina, and the Soviet Union (Ryan 1979). The U.S. Army Corps of Engineers (1979) has reviewed over 90 different design approaches for tidal power generation. To obtain information about the practical prospects for tidal power development, one should first contact the ocean engineering or civil engineering departments of technological institutions, such as the Mechanical Engineering Department of Northeastern University in Boston, Massachusetts (USA), or possibly government agencies responsible for electrical power development in countries with plans for pilot projects.

The design of ocean wave-driven systems should take into account the intermittent and variable character of the natural energy source. Various methods of smoothing (evening out) irregular wave impulses must be developed, perhaps using such mechanisms as high-inertia flywheels. In elaborate, technically advanced systems, provision may be made for medium-term energy storage during periods when wave energies are low. Wave-powered devices are, of course, subject to the usual problems of mechanical devices deployed at sea and must be able to withstand exceptionally high surf and wind conditions.

Several uses have been suggested for smaller scale wave-powered devices. One design for the desalinization of seawater by reverse-osmotic pumping on a floating wave-powered device is shown in Figure 7-2. Such devices would be of use in arid, remote areas, such as islands or isolated coastal communities where both fresh water and energy are in short supply.

The values of critical operating parameters for wave-powered systems, that is, the energy conversion efficiencies and production costs of full-scale systems, are not yet known. Nevertheless, according to Newman (1979) and Ross (1979), for some of the innovative wave-driven devices the possibilities for cost-effective power production are sufficiently promising to merit continued research and development.

NONTRADITIONAL SEAFOODS OR SEAFOOD PRODUCTS

Seafoods Other than Fish and Crustaceans

Perhaps because many Asian coastal regions have been quite densely inhabited for centuries, their inhabitants

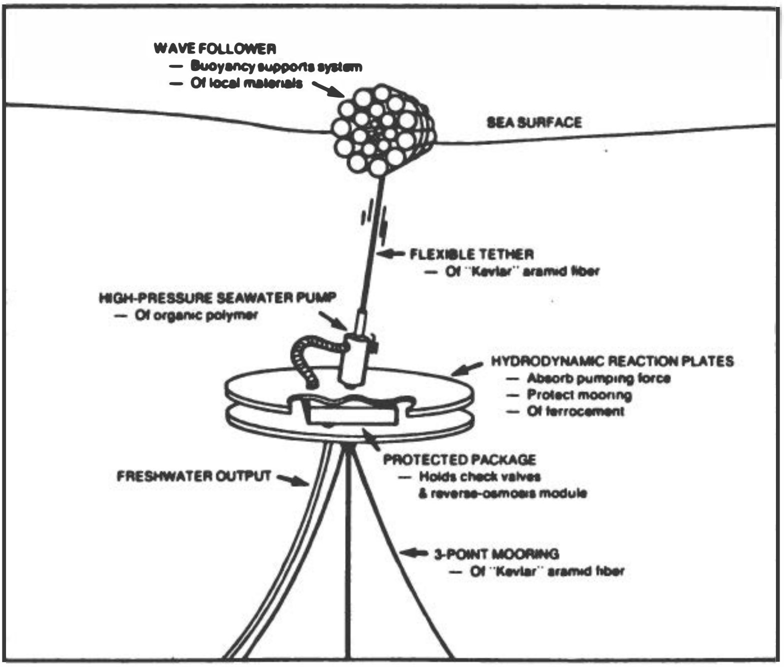

FIGURE 7-2 Pump used in wave energy desalinization device designed by scientists at the University of Delaware. (University of Delaware)

have investigated the edible potential of whatever organisms the sea provides and have developed means of preparing and enjoying many seafoods that are not recognized as edible in other regions. Natural populations of many traditional Asian seafoods are, however, just as abundant in many other parts of the world, where attitudes toward seafood consumption are less extensively developed. In fact, natural supplies will often be more abundant, as they have not been depleted by local consumption.

Lucrative commercial opportunities may exist for developing countries to harvest and process products for which strong international demand already exists, such as sea urchin roe (used as sashimi and in other forms) or abalone (typically cooked and canned for sale in Japan). Conch, a large tropical mollusc served almost interchangeably with highly priced fresh abalone in some U.S. restaurants, is also subject to increasing international demand (much of which may eventually be supplied by mariculture of this organism in the Indo-Pacific or Caribbean regions). Other products that are eaten scarcely at all in most countries, but for which there is a moderate but steady demand in certain Asian countries, include sea cucumbers, octopus, and even certain kinds of jellyfish.

Japan is the principal market for specialty seafood products. Although demand there is not likely to increase, it can be expected to remain fairly steady. It is also possible that demand for such products will increase if some of the Asian countries in which such foods are eaten continue to experience commercial expansion, or if lasting new markets are established in countries such as the United States, where consumption of seafood in general and "Japanese-style" food in particular has been rapidly increasing.

Many coastal countries have the natural stocks to supply at least some of these markets. The only barriers to their entry into such markets, however, are lack of technical capabilities for processing, packaging, and delivering the product in desirable form, and the fact that their fishermen and seafood processors are unaware that appropriate markets exist for such products. Especially, if traditional local fisheries become depleted, even in regions where local seafood consumption is relatively limited in type, such new developments could prove commercially successful if international markets were entered. Under such circumstances, it may prove beneficial for the development and management authorities of local fisheries to encourage investigation of possibilities for harvesting nontraditional species for export to Asian or other markets, or perhaps for domestic sale.

Harvesting Zooplankton for Seafood Cakes and Sauces

In several Southeast Asian countries, traditional industries are based on the harvesting of various types of the tiny free-swimming crustaceans (zooplankton) that inhabit all marine and fresh waters (Omori 1977). Zooplankton are taken with nets and processed by drying, fermenting, or pressing. The resulting nutritious product is locally consumed and commercially distributed in various forms, including solid cakes for use as soup bases, and in dried or liquid form for use as condiments.

Only certain kinds of zooplankton living in especially productive, usually shallow environments are sufficiently concentrated and easily enough harvested to support such a fishery. Harvesting is often carried out in such shallow areas that boats are not necessary; commonly used gear includes large-frame nets pushed through a marshy area and stationary nets erected in a location with rapid tidal flow.

The exceptionally "rich" (biologically productive) coastal waters where sufficiently high zooplankton densities or even swarms may occur are usually shallow, well-protected, and green in color, indicating high densities of the microscopic planktonic plants on which the zooplankton feed. Such conditions are common along the coasts of Thailand and Vietnam, where harvesting and processing of zooplankton for outside trade provide substantial earnings for some villages. If new local or international markets were developed for the dried, salted, or fermented and pressed seafood cakes and sauces that can be produced from such harvests, these products could be supplied through new cottage industries established in coastal villages. But this is possible only if local inhabitants are open to new commercial enterprises. Such new small-scale industries would be very useful in many rural coastal areas, because processing need not involve refrigeration or mechanical methods.

Fish Meal and Protein Concentrates for Human Consumption

The industrial process of making fish meal (so-called "reduction processing") is often done simultaneously with the separation and processing of fish oils. Although this process has been well established for decades in many developed and developing countries, during the past 20-30 years, international and national agencies and some private investors have expressed considerable interest in expanding the use of meals or similar highly processed fish products as human food. By far the greatest commercial use of fish meal is its incorporation into animal feeds, followed by agricultural and industrial uses; incorporation of fish meal into products for direct human consumption is only a minor component of world markets. Substantial research has been done on processing methods, nutritional values, palatability, and marketing potentials of various reduced-fish products. The report of a meeting on this subject sponsored by the Inter-American Development Bank (1981) reviews technical information about nontraditional fish products.

Simple fish meal can be incorporated into human diets as a flour additive or as pure meal, but it is not widely marketed because of low consumer interest in most regions. In addition to the minced or ground fish that is shaped into sticks, cakes, or patties (see Chapter 4), nontraditional, highly processed fish products include relatively taste-free and odor-free meals that can be incorporated into baked products, as well as other forms of fish protein concentrates (FPCs). FPCs are of interest to nutritionists and development assistance planners because of their high nutritional value and intended taste neutrality, which, it is hoped, will overcome the negative responses of many consumers.

Economic and regulatory problems have hindered past attempts to develop commercial-scale FPC production. Government agencies of the United States and other countries are required by law to prevent the sale of food products for which the full species origins cannot be specified quantitatively. (Fish minces or FPCs from processing plants designed to accept different types of fish, in accordance with changing catch compositions, would often not be marketable under such regulations.) However, some of these regulations may now be modified to eliminate this marketing barrier while still assuring wholesomeness for human consumption.

Nonedible Fishery By-products

One by-product of crustacean fisheries--chitins and their chemically transformed derivatives, chitosans--appears to offer economic potential for countries with large shrimping or crabbing industries. Chitin is found in the exoskeletons of insects and crustaceans: prawns, crabs, shrimp, lobsters, crayfish, and their relatives, as well as krill and the smaller planktonic microcrustaceans. Less commercially promising sources of chitin include the hard parts of squid and some microscopic aquatic plants and fungi. An economic evaluation of world chitin resources (Allan et al. 1978) indicates that shrimp and crab waste, and perhaps Pacific planktonic "red crab" (*Pleuroncodes planipes*) and Antarctic krill, would be the most likely sources of chitin from the ocean in future commercial development.

Chitin and chitosan products are chemical polymers, with physical properties that are especially useful in certain industrial or commercial processes. They are naturally resistant to decomposition and are strong even when stretched into thin films or fibers. One particularly important characteristic of chitin is its high binding capacity for certain other substances. Thus chitosans may be used for industrial water purification, for metal recovery from aqueous wastes, or as ion-exchange substrates for chromatographic methods of laboratory analysis. Chitosans also have potential applications in wastewater treatment, because of their ability to coagulate readily and to form strong and yet very thin films for use in electrodialysis. Chitin derivatives could successfully compete with substances that are now commonly used for such functions, including natural resins and a variety of specialized plastics. Chitin derivatives could also be used for medical purposes: they perform well as accelerators of healing processes in humans and animals when applied to wounds on sutures, as films, and in poultices.

General information on fish by-products of potential economic importance is given in a recent monograph by Windsor and Barlow (1981). A brief economic analysis of the potentials for entry of chitosan products into commercial markets is given by Muzzarelli and Pariser in their detailed technical review (1978) of chitin/chitosan product development potential.

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Appendix A

Marine Science

The Basis for Resource Exploitation and Management

The new international ocean regime arising from UNCLOS recognizes both the rights and responsibilities of coastal nations regarding the exploitation and management of resources in near-shore areas. The almost universal declaration of 200-mile zones of control by these nations has institutionalized this situation. This appendix provides a brief review of the principal fields of marine science and the way in which they are important in ocean use and resource management.

MARINE CHEMISTRY

Seawater is a complex solution that contains a variety of dissolved organic and inorganic substances (such as mineral and nutrient salts and metal ions) and particulate matter (both sediment particles and the tiny detrital particles of decaying plants and animals). Marine chemistry encompasses the characteristics of dissolved substances, their sources and distributions, and the properties of their interactions with water, one another, suspended particulate matter, and living organisms. It can also evaluate the rates at which solutes and other materials pass into the oceans from terrestrial and atmospheric sources to be dissolved, return to the air or land, or pass into the sedimentary "sink" of the seafloor. One of the most important aspects of the chemistry of seawater is that the presence of such a complex of substances results in a great variety of chemical interactions, including some forms of chemical bonding that are not yet thoroughly described or understood--for example, chelation (a kind of chemical immobilization) or adsorption onto particles, which may occur simultaneously with the better described classical aqueous chemical reactions of acids, bases, and salts.

Given the diversity of reactions into which a substance may enter, it can be very difficult to predict the fate of substances introduced by man into the marine environment. Work done by marine chemists in conjunction with other ocean scientists enables tentative predictions of what will happen to harmful substances released as a result of industrial activity, municipal waste disposal, agricultural chemical runoff, or ocean dumping, but a great deal of work remains to be done, particularly regarding substances that are toxic in very small amounts. Concentrations that are dangerous to human health or the productivity of fish and other marine organisms may be undetectable by even the more sensitive techniques of chemical analysis that are currently available. For certain highly toxic substances, monitoring techniques have been developed in which the tissues of particular organisms (usually filter-feeding shellfish such as mussels and oysters) inhabiting potentially affected waters are regularly sampled and analyzed. Analyses may be done in laboratories near the collection site or, when appropriate facilities are not available nearby, samples can be frozen and mailed to more fully equipped cooperating laboratories elsewhere.

This bioassay method of pollutant monitoring is of tremendous help in providing an early-warning system for potentially serious accumulations of artificial toxic pollutants (or natural ones, as in the case of poisonous "red tide" plankton blooms). Some harmful pollutants, however, are not concentrated in animal or plant tissues at all, or may be dangerous in such small quantities that it is impossible to monitor them in this way. Thus investigations are still needed using alternative monitoring and analytical methods, and work must continue on the chemical factors that influence the accumulation and breakdown of pollutants.

Studies in marine chemistry are also needed to understand and monitor the productive potential of ocean waters. All living things in the seas depend for their existence on the presence of sufficient quantities of chemical nutrients in the sunlit surface waters to permit the growth and productivity of marine phytoplankton. These single-cell algae are by far the most abundant type of ocean plant, and thereby the most important link in the food web supporting marine animal life. The rate of supply and replenishment of nutrients through physical, chemical, and biological processes thus affects the productivity of an ocean region. Human activities such as damming rivers or creating toxic pollution can interfere with the rates of nutrient input or utilization and decrease the productivity of marine waters. Conversely, in areas substantially affected by release of sewage or nontoxic organic industrial and agricultural wastes, overabundance of organic nutrients can develop, leading to the polluted condition "eutrophication." The excessive stimulation of phytoplankton blooms results in the accumulation of decaying plant matter and depletion of the water's oxygen supply. This in turn can lead to the failure of the water to support most animal life, including pelagic (free-swimming) and bottom-feeding fishes and many kinds of shellfish.

The tools of marine chemists are similar to those of chemists working in any natural environment, with the addition of techniques to identify and evaluate particular reactions and processes as they occur in the sea. The sampling methods used are often the same as those employed by physical oceanographers, for example, the collection of water from various depths using such sampling devices as Nansen bottles. In fact, chemical, physical, and some forms of biological analyses are sometimes done using the same set of samples. However, the types of analyses used to answer questions about chemical oceanographic processes are considerably more varied than those required for physical oceanographic studies. They range from relatively simple measurements such as evaluation of the water's oxygen content, to extremely sensitive and complex measurements of substances that occur in very low concentrations, quickly degrade, combine with other natural substances, or change when in contact with certain types of sampling equipment. Some of the more sensitive measurements require both temperature-controlled transport of samples to land-based laboratory facilities and the availability of very sensitive analytical equipment such as nuclear magnetic resonance spectrometers.

A great deal of important and scientifically interesting marine chemical analysis remains to be done in almost every part of the world's oceans. Much of this work can be accomplished by sampling with Nansen bottles or small-volume pumps, and by equipping analytical laboratories with the standard tools, reagents, and supplies required for basic organic and inorganic analyses.

MARINE BIOLOGY AND BIOLOGICAL OCEANOGRAPHY

The oceans support varied assemblages of animals, plants, and microorganisms, some of which, particularly in coastal regions, are among the most productive biological communities on earth. Studies of the nature and distribution of organisms inhabiting the open waters, seafloors, or shallow nearshore environments of the world's oceans are commonly grouped under the general heading of "marine biology." A number of oceanographic institutions, however, prefer to distinguish biological oceanography--the study of marine organisms as components of oceanic systems larger than any individual organism--from marine biology--the study of physiological, biochemical, anatomical, and behavioral characteristics and processes.

Biological Oceanography

Examples of the interdependent communities of organisms studied by biological oceanographers include the relatively coherent assemblages of fish or free-floating or swimming organisms associated with large water masses, and the groupings of species found in each type of benthic (seafloor) environment. This area of study focuses on the ecological relationships of organisms--their interactions with other organisms and with the features of their environment, particularly larger scale features such as currents, bottom topography, and water mass characteristics.

The population dynamics of various species is a basic aspect of marine ecology that has been thoroughly studied. The study of organisms as populations--for which overall rates of reproduction, growth, and death can be estimated--can be used to determine the number, age, and size of organisms present in an area at any given time. Free-floating organisms--the phytoplankton (single-cell plants) and zooplankton (tiny animals) that occupy the lower trophic levels of oceanic food webs--are primary objects of study for biological oceanographers. The tiniest organisms are collected with pumps and filtration systems, while larger plankton are collected with various types of nets. Special nets, such as the Isaacs-Kidd midwater trawl, have been designed for the collection of small fish and other animals from depths down to several thousand meters. Towed behind a rapidly moving ship, the trawl has revealed new species of fish and large quantities of fish once thought rare. Its use also enables the managers of commercial fisheries to estimate the numbers of juvenile fish present in a region--important evidence of the success or failure of fish stocks at replacing themselves when under fishing pressure.

It is also important to understand how organisms of different species affect one another. Although study of single-species population dynamics is well established, investigations of multispecies interactions have been undertaken only recently for most marine systems. Preliminary research indicates that the impacts of biological interactions such as competition for space or food, or predation, are sometimes more important than the physical aspects of the oceanic environment in determining the population levels of marine species.

Multispecies interactions are particularly important in communities with large numbers of relatively abundant species. In tropical latitudes, biological communities of all kinds--from terrestrial to aquatic and oceanic--tend to be very diverse. Just as tropical forests are more diverse than forests at high latitudes, coral reef communities have a greater diversity of animals and plants than the nearshore, shallow-water environments of cold ocean coastlines. Because most coastal developing countries are in tropical latitudes, marine biologists and fishery managers in those countries must examine the effects of multispecies interactions on the stability of their marine ecosystems and on the abundance of their commercially important species of fish and shellfish.

Where sufficient biological and environmental data are available, population dynamics can be studied and predicted for single species and possibly multispecies systems by applying mathematical models. Such models manipulate information about biological and environmental factors in the form of relatively simple conceptual parameters. The determination of which processes can, in fact, be satisfactorily characterized in this way, and the development of more efficient methods for measuring these factors, are major areas of discussion and investigation in biological oceanography.

Marine Biology

Marine biological research ranges from studies of how the individual aspects of the biology of a species make it well suited for a particular marine environment, to study of the marine creatures themselves; the biological processes being considered are not unique to the marine environment.

Some marine species are particularly useful for general biological research. For example, squids and their relatives are excellent subjects for neurophysiological research, because components of their nervous systems are readily accessible and easily manipulated. Much of the current understanding of the nervous systems of all animals, including man, is based on work done with these creatures. The sea urchins and some of their relatives (members of the exclusively ocean-dwelling echinoderms, which also include starfish, sea lilies, and sea cucumbers) are useful for research on animal development. Echinoderms are the most abundant and accessible group of invertebrate animals whose eggs and very early life stages closely approximate those of vertebrates (the higher, skeleton-containing animals, including fish, larger terrestrial animals, birds, and man). Under marine laboratory conditions, sea urchins produce large numbers of easily collected and observed gametes or fertilized eggs, and investigators have been able to learn a great deal about early development and the factors required for reproductive success--information that is difficult to obtain with nonaquatic laboratory animals.

Topics currently under study in the world's marine laboratories include how the bacteria and microorganisms vital to the breaking down and recycling of organic matter in marine food chains survive under oceanic conditions, and how changes in these conditions produced by nature and man might affect their functioning. Another topic of practical significance is the growth requirements of species of phytoplankton in the subgroup known as dinoflagellates. A few varieties of these plants are extremely toxic and will increase in abundance under certain seasonal conditions, creating the "red tides" that may render local fish or shellfish unfit for human consumption.

Of particular importance to tropical coastal countries are the rather exacting environmental requirements of corals. Only under the proper conditions of temperature, light, and water clarity and purity will these small colonies of animals flourish and lay down the skeletons that form coral reefs. Because these reefs have such great environmental, commercial, and aesthetic importance, information on the limits of environmental conditions that these animals can tolerate is valuable in setting standards for sewage disposal and other forms of pollution along tropical coastlines. Studies of coral reproduction and growth may lead to the ability to "seed" new reefs or replenish old ones.

MARINE GEOLOGY

Marine geology is the study of the structure and composition of the seabed and the underlying layers of the earth's crust. Geological studies are needed to evaluate regional features such as bottom topography, sediment type, and the likely locations of mineral deposits, as well as larger scale phenomena such as movements of the huge tectonic plates that make up the earth's crust (both land masses and seabeds). Understanding and mapping of these plates are based largely on marine geophysical research. In the short term, plate movements are responsible for earthquakes, the generation of tsunamis (tidal waves), and certain kinds of volcanic eruptions. Over the long term, movements of the plates toward, alongside, or underneath one another create much of the topography of land masses and ocean floors--from the folding and upthrusting of mountains and the building up of volcanic islands, to the submergence (so-called subduction) of seafloors into deep trenches. These large earth movements ultimately cause smaller scale bending and crumpling of sedimentary rock layers. The folding of subsurface rocks determines the location of formations that trap substances such as oil, natural gas, and sulfur in extractable reserves.

A better understanding of factors affecting location and availability of marine minerals has been a major benefit of marine geological research. A large portion of the ocean's valuable mineral resources is found on the continental margins, the relatively shallow seafloor regions varying considerably in width and topography that surround major land masses. Minerals of potential commercial value likely found in these areas include oil, natural gas, and coal; sulfur or phosphorite deposits; bedrock metals such as tin and iron; and the relatively shallow placer deposits--concentrations of metals, diamonds, or other dense materials that have been "reworked" or sorted out from the lighter bottom materials by the action of waves and currents. The distribution of and extraction methods for marine minerals are discussed in Chapter 3.

Typically, a relatively flat shelf at a depth of less than 200 meters is bordered by the gradually deepening continental slope beyond which the seafloor flattens out into the broad continental rise region and then merges into the deep-sea floor. This wide, sediment-rich shelf is particularly characteristic of Atlantic Ocean coasts and other regions that have not experienced geologically recent disturbances from tectonic earth movements. Areas of high tectonic activity, such as much of the "Pacific Rim" (along Asia, the Southwestern Pacific, and the Americas), or portions of the eastern side of the Indian Ocean, typically have only narrow continental margins, often bordered by extremely deep trenches. Such features are created when a large section of seafloor, which is basaltic and dense, moves toward and then underneath a continent, destroying portions of the underwater continental margin and forming a trench as it slides beneath the less dense, granitic continental mass.

The deep-sea floor, which is a fairly uniform depth of about 3,000-4,000 meters throughout the world, is relatively poor in sediments and materials of continental or volcanic origin such as hydrocarbons, iron ores, and heavy or precious metals. Furthermore, the great depths and the long distances from shore (except in narrow-shelf locations) present substantial logistical and economic problems for extraction of materials from the deep-sea bed. There is, nevertheless, considerable interest in investigating the abundance and extractability of some of the more commercially valuable minerals in the deep sea--for example, manganese nodules, which contain a number of metals in addition to manganese and are common in many deep-sea areas, and the polymetallic sulfides, which are formed by hydrothermal activity at the deep-sea ridges. The economic and technical feasibility of collecting these and other marine minerals is discussed in Chapter 3.

Geological investigators use several kinds of sampling gear. Sediment corers are used for soft-bottom areas, and grabbing or dredging devices for large samples or collection of rocky materials. The wide array of available acoustic devices such as echo sounders and seismic recorders vary considerably in cost and provide a range of sensitivity and seafloor penetration, corresponding to the requirements of different survey objectives and seafloor types. Such instruments are used to gather information on bottom topography, subsurface structure, and acoustic reflection characteristics of the sediments (indicate sediment type without the collection of samples). More specialized types of electronic sensing equipment measure the magnetic fields, gravitational anomalies, or levels and types of radioactivity, and thus provide a great deal of information on the densities and geochemical compositions of buried rocks and other seabed minerals and materials. Sampling programs require ship- or land-based laboratory facilities to analyze the physical, chemical, and paleontological (fossil record) characteristics of the collected materials.

In addition to studies requiring a research vessel and specialized marine sampling gear, extremely useful information on the geological nature of the coastal seabed can be obtained from surveys and sampling of adjacent land areas. This is an effective way to locate and characterize the probable compositions of offshore minerals of relatively recent terrestrial origin, such as placer deposits or coal.

Much of the equipment used for modern geological research is sophisticated technologically and involves advanced electronic components and systems that are usually supported by computers for initial data coding, recording, and analysis. A decision to engage in a program of marine geological research requires careful consideration of the most useful types of investments to make in expensive equipment. Arrangements must be made to ensure training and availability of technical personnel fully capable of operating, maintaining, and repairing such equipment.

Although computer-based equipment which sometimes requires very accurate navigational capabilities (e.g., multichannel seismic recorders or marine gravimeters) gives the most detailed geological information, useful marine geological research and surveying can still be done using far less expensive tools. Basic requirements might be, for example, a modest research vessel equipped with a good winch, a conventional echo sounder, a bottom-grab, a gravity or box corer, and perhaps a dredge if ship and winch are powerful enough to lift larger and heavier pieces of gear. Particularly in regions where little or no surveying work has been done, the use of such basic but effective and cost-efficient methods can make important contributions to a nation's understanding of the marine resource potential of its coastal waters.

PHYSICAL OCEANOGRAPHY

Physical oceanography is the study of the characteristics and causes of the various patterns of motion of ocean water: currents, tides, waves, upwellings and downwellings, gyres, and eddies. The related distribution patterns of water properties such as temperature, salinity, and density are also evaluated.

The descriptive branches of physical oceanographic research require measuring these physical characteristics over a range of depths, horizontal positions, and times. The most satisfactory data collection technique is often the traditional one of taking water samples at various depths with arrays of Nansen or Niskin bottles. The metal bottles are deployed along the ship's wire instrument cable and triggered, by either mechanical or electronic means, to open at a known depth and collect samples for subsequent analysis in the shipboard laboratory. Electronic equipment may also be used to measure physical oceanographic parameters at various depths beneath a stationary ship or platform or while being towed behind a moving vessel. Data obtained in this way are usually processed and recorded by a self-contained electronic computational unit in the ship's laboratory, or they may be handled for storage and computational purposes by connection to a shipboard computer. Data can be evaluated briefly at sea, but the major analyses will be done after return to shore.

Electronic sensing devices such as temperature-depth recorders permit large quantities of information to be collected and recorded with substantially less expenditure of time and labor than is required for direct sampling methods. The equipment and its related computer software support systems are, however, expensive. Operating personnel require at least some electronics and data processing expertise, and the services of highly trained electronics technicians are needed for periodic maintenance and repair work. Such equipment does not obtain information on most of the chemical characteristics of the water. Thus, in cases where nutrient sampling or other biochemical or geochemical analyses are desirable, bottle sampling is still the preferred technique.

Another branch of physical oceanography focuses on the patterns, causes, and relationships of the various types and scales of motion exhibited by the ocean. Extensive mapping and analysis of such large-scale features as the Gulf Stream and the Kuroshio, Humboldt, and Equatorial currents have yielded much information on the mechanisms by which the huge oceanic gyral and circumpolar current systems are driven by the large-scale gyral patterns of surface wind systems and modified by such regular forces as the earth's rotation or lunar and solar gravitational forces (tides).

Studies of ocean dynamics also include investigations of smaller time and distance scales of motion and changes in patterns of distribution of physical phenomena. These phenomena range from intermediate-sized structures, such as the eddies (often several hundred kilometers wide) thrown off by the Gulf Stream and other major currents, to the very fine-scale motions contributing to the aggregated or "patchy" spatial distributions characteristic of small marine organisms and other suspended particles. This patchiness is of great importance in the operation of chemical and biological processes--for example, in assuring that fishes and other swimming animals are able to find food particles in high enough concentrations to satisfy their nutritional requirements. Research on smaller scale physical oceanographic factors is also needed to describe precisely the forces involved in the microscale dynamics of ocean water, knowledge of which is fundamental to the quantitative understanding of many major processes, including turbulent diffusion, drag, and frictional air-sea interactions.

Meteorology and Climate Prediction

Knowledge of the state of either of the world's two great circulation systems--the oceans and the atmosphere --is useful in understanding and predicting events in the other system. Thus the findings of physical oceanographers are tremendously important to climatologists and those who would benefit from the development of predictive capabilities for large-scale climatic events.

Although much work remains to be done before predictions can be made of short-term, local oceanographic phenomena, the relationships of atmospheric conditions and certain oceanographic features to subsequent changes in ocean current and weather patterns are understood enough to permit predictions of seasonal trends in regional climate and current patterns. For example, the seasonal (quarterly) U.S. climate forecasts of the U.S. National Weather Service are based in large part on oceanographic data sets, involving the influence of world weather patterns on the ocean current system. Oceanographic data are collected over a wide geographical area. The primary data are measurements of sea-surface water temperatures, routinely reported by ships at sea, and fluctuations in sea-level heights in various locations, determined from regular monitoring of coastally moored tide gauges.

The possibility of achieving even a limited ability to predict global oceanic and atmospheric phenomena has far-reaching implications for a wide range of human endeavors. For example, such a capability would enable accurate estimates of how the climate will affect annual agricultural and fisheries production. It would also provide advanced warning of and therefore better preparedness for the potentially catastrophic effects of weather extremes such as droughts and typhoons. Finally, it would yield more accurate information on the timing or forcefulness of regular seasonal events such as monsoons and floods.

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Appendix B

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Marine Technical Assistance Group
Ocean Policy Committee

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