Chapter 7

Management of Aquatic Resources: Nearshore Fisheries and Aquaculture

CONTENTS

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Management of Aquatic Resources: Nearshore Fisheries and Aquiculture

INTRODUCTION

Common Uses of Aquatic Species

Since prehistoric times, coastal and insular cultures have harvested tropical aquatic organisms for a wide range of utilitarian, symbolic, and ornamental functions. The sea was traditionally and chiefly important as a source of food; it was estimated to supply, 90 percent of the Pacific islanders' animal protein (81). Fishing was an integral part of traditional high island socioeconomy and essential to life on atolls. Today, as in the past, consumption of large quantities of marine organisms, including finfish, algae, mollusks, crustaceans, echinoderms, and turtles is essential to life throughout the U.S.-affiliated tropical islands.

Nonfood resources of the marine environment were traditionally used as fuel; currency; ornaments; weapons; medicinal; religious, magic, and funerary symbols; and construction materials for dwellings, roads, and vessels. Contemporary nonfood uses also include a range of biomedically and industrially important compounds, including pharmaceuticals and hydrocarbons (48,49,114). Harvesting technologies range from use of simple dugout canoes to deep-diving, manned submersibles.

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The shells of marine mollusks have been valued as ornamental objects since prehistoric times. Various cultures and societies have attributed powers of magic, religion, and virility to shells and valued them as currency and curios (1,38). Shells were also harvested as raw materials for the manufacture of tools, utensils, weapons, and ornaments. Turtle shells were used in the manufacture of fishhooks and other items (106). Pearl shell (mother-of-pearl) was one of the most important raw materials for the manufacture of fishing tackle in traditional systems. Hooks and lures were made from the nacre of several families of gastropod and bivalves, particularly Pteriidae. Mother-of-pearl was also harvested for use in producing ornamental items, and was highly prized on the European market for jewelry, buttons, and other ornamental objects. Today, souvenir hunters purchase shellcraft at resorts throughout the world.

Precious corals have been highly treasured for millennia. Approximately 95 percent of the world harvest has come from the Pacific. The skeletons of precious corals (including *Corallium, Gerardia, Lepidisis, Acanella,* and *Antipathes)* are hard and dense enough to be polished to a high luster suitable for jewelry manufacture. Stony corals *(Scleractinia),* although too porous to be polished for jewelry, are sold as curios and decorations in many parts of the world (85) and used industrially for building materials and lime production (172). Similarly, the large amount of calcium carbonate contained in mollusk shells has given them a number of industrial uses, primarily as constituents of fine pottery glazes, toothpaste, and poultry food (171).

Marine plants or seaweeds are used for human and livestock food, fertilizer, soil conditioners, and as a raw material for various chemicals. Many marine organisms produce compounds that are pharmaceutically active. Extracts from brown algae have been used as hypotensive drugs in oriental medicine for centuries (10). Neurotoxins from other algae are being studied for their potential as anesthetics (34). Certain marine algae produce polysaccharide thickening agents (phycocolloids) used as additives in food, pharmaceuticals, cosmetics, paints, and ink.

A variety of biological and inanimate resources are harvested from coastal waters for uses as either construction materials (sand and limestone), fuel for biomass conversion (algae), building materials (mangrove species, coral) or food and artifacts. Several mollusks are harvested for shells in the Caribbean including conchs, helmets, volutes, cones, tritons, spiny oysters, and scallops. Many tropical fish are harvested for sale in the aquarium and curio trade. Colorful fish from coral reefs are prized by aquarium hobbyists around the world. Several exotic species from the Pacific command high prices. Pufferfish, for example, are killed, inflated, varnished and mounted for sale in curio shops locally or on the U.S. mainland.

In addition to providing an important source of food and other products, nearshore marine resources are a vital part of the tourist industry: coastal environments (beaches, sheltered lagoons, coral reefs) are among the islands' primary attractions.

Ecology of Coastal and Nearshore Habitats

The biological complexity and variability of tropical nearshore environments are exceeded only, perhaps, by tropical rain forests (168). Taxonomic composition, overall community structure, topography, and oceanographic conditions vary widely within and among islands, even over short distances (60). Nevertheless, nearshore ecosystems in the islands commonly comprise three distinct, but intimately interdependent habitats: mangrove forests, coral reefs, and seagrass meadows and unconsolidated sand or mud bottoms (60,139,159). Some atolls, however, may not support mangroves or seagrass beds (99). The ecological and economic importance of these habitats extends beyond the particular exploitable species within them.

Corals and Coral Reefs

Corals and coral reefs are a dominant shallow-water feature of tropical marine environments that are remote from major upwellings or freshwater inflows (118). Broadly defined, a coral reef is comprised of both the physical structure formed from calcareous secretions of corals and other marine organisms. Large coral colonies may contain tens of thousands of individual polyps, and reefs can be hundreds or thousands of years old. It is the carbonate skeletons of these shallow water marine organisms that form the massive reef structures protecting coastlines and creating habitats for the associated biota (168).

Coral reef ecosystems are productive biologically and geologically. An active reef can build islands such as the Micronesia atolls, and erode by wave action to create sand deposits and beaches. If the reef-building processes are disturbed, however, erosion will dominate and the reef will deteriorate (35).

Reef fisheries are considered highly productive, yielding up to 65 tons of biomass per

Photo credit: C. Wah/e

The coral reef ecosystem is comprised of the physical coral structure and an array of other marine species. Interaction among these reef community members gives rise to the high biological productivity associated with coral reefs.

square mile per year in American Samoa (170). Average yields of coral reef fisheries are estimated at nearly 43 tons of biomass per square mile per year at depths less than 100 feet (99). The high biological productivity is maintained by efficient retention and recycling of ecosystem nutrients (35).

Coral reefs serve at least three functions of profound economic importance. The physical structures serve as barriers to storm waves and debris, are an important tourism attraction, and create complex habitats for a variety of economically important organisms. A species that contributes measurably to the trophic structure and energy flow of the reef ecosystem can be considered a member of the reef community. Species that feed in adjacent areas (e.g., seagrass meadows) but shelter in or on reefs and thereby transfer energy to the reef system also are considered part of the reef community. Secondary consumers which prey on reef animals but move to other areas when not feeding are part of the reef system as well (118).

Coral reef fisheries include activities at a commercial, subsistence, or recreational level, which exploit aquatic organisms associated with hermatypic (reef-building) corals. Thus, all edible, marketable or otherwise "useful" components of the coral reef community are included under this definition of the fishery. Commonly harvested reef components include hard corals, mollusks, crustaceans, echinoderms (e.g., sea urchins), fish, and marine plants. The dietary preferences and economic desires of the fishing communities thus define the nature of the fishery (118).

Representatives of virtually every major animal and plant group are associated with coral reefs and, in many cases, are exploited (168). For example, as many as 500 fish species are found in coral reef areas of Kosrae, some 200 of which are harvested for consumption; at least 300 fish species are found in Puerto Rican reef areas, of which 180 are harvested for human consumption (56,61). Also, many reef-dwelling animals are preyed on by migrating and pelagic fish which constitute a major portion of worldwide commercial fisheries.

Mangrove Forests

Mangrove forests consist of salt-resistant trees with stilt roots or pneumatophores growing in the intertidal range along ocean shores or estuaries (35). Mangroves are an integral component of coastal ecosystems and fulfill

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many fundamentally important functions in island ecology and economy (159).

Mangroves supply wood and other forest products on some islands and contribute to the productivity of lagoons and reefs. As prop roots develop and spread, they trap and stabilize terrigenous sediment, building land and protecting reefs and lagoons from agricultural and urban pollution. Like coral reefs, mangrove forests protect coasts from storm damage; support an extremely diverse and ecologically important community of marine plants, invertebrates, and seabirds; and provide shelter and nursery for a range of commercially important fish. Mangrove detritus provides an important nutrient base for food webs leading to commercially important food fish and invertebrates, and augments the growth of adjacent seagrass and coral reef communities (168).

If mangrove forests are carefully managed, they can sustain a high fisheries output and some limited forestry production. Mangroves are harvested in the U.S. Caribbean and Pacific islands for fuel and building materials. However, they have been removed in many areas, often to gain access to sites used for sand mining; navigation channels; waste dumping; and the construction of buildings, docks, and marinas (35).

Storms may damage mangroves, although they tend to regenerate quickly. Human-induced stress can, however, be disastrous. Mangroves are often killed by changes in land runoff or water circulation which alter the salinity balance. Oil pollution, as in postwar Truk lagoon, can degrade mangrove areas for years. Stressed mangroves will drop their leaves and may die if stress is not alleviated. If conditions permit seedling reestablishment, the forest can regenerate in 10 to 15 years (35,47).

Seagrass Meadows

Seagrass meadows and mud bottoms within lagoons and between the shore and reef crest serve many crucial ecological functions of direct and indirect economic importance to insular peoples. Although the seagrass itself is of little intrinsic economic value (except perhaps as soil amendments on some islands), the associated sand, coral rubble, fish, and invertebrates commonly are harvested for materials and food throughout the U.S. tropical islands (168).

The sand and mud bottoms on which seagrass beds form create habitat for many burrowing and benthic organisms. The leaves and interwoven roots provide extensive shelter for small organisms and grazing surfaces for a variety of species. Many species migrate to and from seagrasses either daily or at a fixed stage during their lifecycle. For example, although many food fish live and are harvested in the coral reef areas as adults, they pass the critical larval and juvenile phases in the protection of seagrass meadows (168). Seagrass beds provide additional feeding areas for species on nearby reefs, and the variety of fish tends to be higher on reefs close to these habitats (61).

Seagrasses promote settlement and consolidation of sandy sediments, thus helping to prevent coastal erosion. They accumulate sand on which mangroves further consolidate the land (168). To some extent they can absorb organic wastes and sediment. However, heavy sedimentation can cut off light to bottom communities and eventually smother them. Seagrasses are

Photo credit: Office of Technology Assessment

Seagrass meadows are an integral part of the island nearshore ecosystem. Like mangroves, seagrasses may enhance nearshore fishery potential by providing habitat and organic matter, and contributing to stabilization of bottom sediments.

particularly vulnerable to dredging and to anchor and propeller damage; holes cut in the bed may take years to regenerate (35,153). Under natural conditions, it takes from 6 to 100 years for a seagrass bed to recover from a stress once impact has ceased (153).

The mangrove, seagrass meadow, and coral reef ecosystems commonly are adjacent and mutually interactive. Mangroves, for example, trap sediment from terrestrial runoff that can be highly detrimental to coral reefs and seagrass beds. Similarly, coral reefs function as breakwaters, protecting seagrass beds and mangroves from the full impact of sea waves. Moreover, a number of animals of subsistence and commercial importance migrate among these ecosystems during their lifecycles (35).

History and Present Status of Resource Use

Pacific

Despite low nutrient levels common to tropical oceans, the nearshore marine ecosystems of Micronesia are among the most productive in the world (119). Since the arrival of the first inhabitants of the Pacific islands some 3,000 years ago, the marine environment has supplied most of the food of the islanders as well as many material needs. (See Lal (97) for an extensive list of nonfood products.) Subsistence harvests continue to make a major contribution to the standard of living even in the most urbanized islands. Given the limited land mass of the islands, the oceans will continue to play a significant role in economic development.

Pacific islanders have traditionally relied on the resources of nearshore waters; fishing and gleaning of shallow water benthic invertebrates from the reef have been the primary means of obtaining food from the sea. Traditional fishermen of all islands possessed precise knowledge of fish behavior, food preferences, spawning patterns, predator-prey relationships, and climatic and oceanographic influences (82,84,85). Rich vocabularies for describing fishing and maritime activities exist within the many languages spoken by Micronesians in the Carolines, Marshalls, Marianas, and by Polynesians in American Samoa (20).

Seldom in traditional island economies was fishing practiced for its recreational value alone, although sport and competition was sometimes involved, Skilled fishermen enjoyed social prestige; fishing knowledge was handed down through generations and was a form of highly valued property not lightly shared. The market system did not exist nor did monetary profit motivate fishermen. Fish were distributed by complex systems of exchange and barter between and among extended families (76). Today, most fish caught by Pacific island fishermen do not reach monetary markets (96,85,113),

Although the elaborate and diverse tradition of fish cultivation reported to have existed in the Hawaiian Islands (93,150) and Nauru (131) apparently did not develop in this region, evidence of stone structures and fish pens suggest some fish culture was practiced in the mangrove areas of Yap, in the lagoon at Pingelap, and possibly near a mangrove area in Guam.

Natural coral reef productivity appears to be more than sufficient in the aggregate to meet the subsistence needs of island populations. Regionwide generalization maybe inappropriate, however, because it fails to consider the diversity of reef organisms and their dispersion among widely scattered islands, as well as human population densities on certain islands.

On high volcanic islands, which normally have abundant freshwater and other land-based resources, fishing is usually combined with agriculture. On low coral islands, which have a paucity of freshwater and arable land, fishing may be the primary source of animal protein. Villages commonly are located on the lee side of islands at sites with suitable access to the sea, lagoon, and reef resources. A variety of village activities may be based on the fishery, including boat building, repair, net and trap making, processing, and distributing.

Despite great differences in language and culture among island populations, each group evolved a distinctive set of traditions which reflect a keen awareness of local ecological relationships. Harvest, distribution patterns, and customs differed, but often were designed with resource conservation as one objective and functioned as effective resource management systems (81). The islanders traditionally practiced principles of property and use rights, resource ownership, and limited entry. Exploitation rights were carefully controlled by taboos to ensure a sustained yield (87).

On Yap, for example, the right to fish nearshore waters was subdivided, with particular families controlling reef flat areas and tracts inside the reef. The Yapese considered these sea resources along with associated land resources (i.e., taro patches, gardens, forests) as a single unit. The highest ranked "Chief of the Village" exercised ultimate control over nearshore waters. The second ranked "Chief of Fishing" led communal fishing in the open sea, while the "Overseer of Fishing" directed communal fishing inside the lagoon (149). Some areas were closed to fishing until fish populations returned to preharvest levels, and permitted fishing methods were carefully defined for different social classes. For example, the lowest ranked Yapese class owned no fishing grounds, were allowed only the most primitive fishing gear and were allowed to gather seafood only in streams and estuaries.

Magellan's landfall at Guam in the 16th century marked the beginning of an era of European exploration and exploitation in the Pacific. From the 17th through the 19th centuries, Spain, England, and Germany exerted varying degrees of influence on Micronesia. Iron was introduced and quickly replaced natural products as the raw material for everything from fishhooks to adzes. Traditional tenure systems were modified or outlawed in favor of ownership, which frequently resulted in uncontrolled abuse of resources (44,135). For the most part, these nations were primarily concerned with land-based resources, agriculture, and trade. These colonial powers paid little commercial attention to fisheries.

Important nonfood marine products in early trade, however, were found in pearls and mother-of-pearl from shells of the Pteriidae family. Small-scale, hand harvest of pearl shell began in Palau during the German administration. As merchants eagerly sought pearl and mother-of-pearl for the European market, harvests were unmanaged and stocks were overexploited. By the 20th century, natural populations of pearl oysters were depleted throughout their Pacific range (123). Exhaustion of pearl oyster stocks led to a search for methods of improving productivity and for new nacre sources.

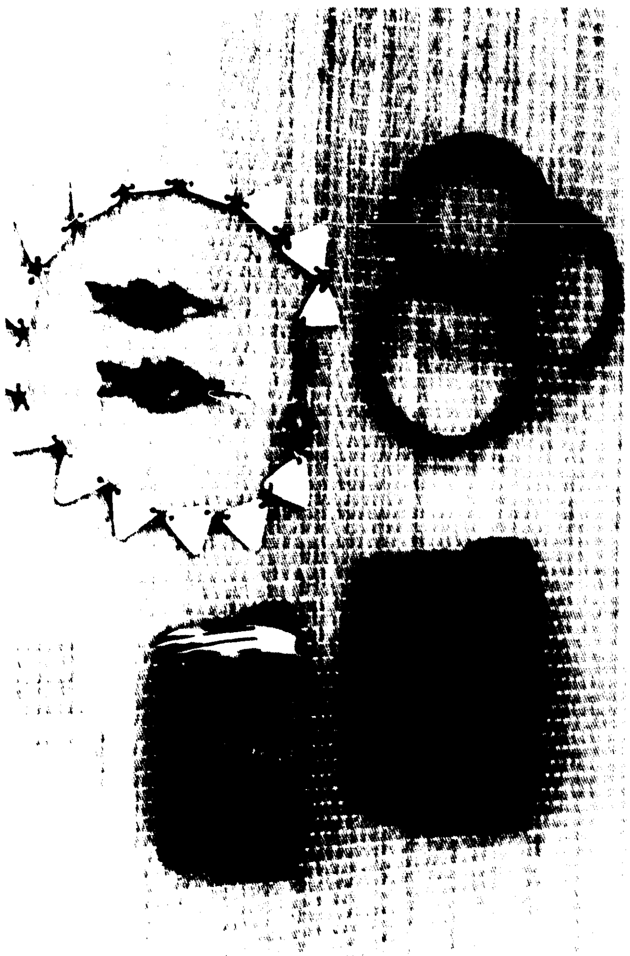
The commercial topshell *Trochus niloticus* was found to produce nacre suitable for button material. Japanese scientists successfully transplanted topshells in the Caroline and Mariana Islands in the 1930s (6,7,8). Truk was the only area that produced commercial harvest before World War II suspended the fishery (108),

During the Japanese mandate, four Japanese companies cultured pearl oysters in Palau, In 1938, these companies produced more of the introduced gold-lipped pearl oyster, *Pinctada maxima,* than any region in which natural populations of the species were exploited (115). However, pearl oyster culture operations ended as World War II moved into the Pacific.

Disrupted by war, harvest of pearls and mother-of-pearl never regained its place of importance in island economies. The culture methods developed by Japanese scientists in Palau before the war were regarded as proprietary information. Without transfer of this technology to local inhabitants, natural stocks of pearl shell were not sufficient to support the industry.

In the more urbanized district centers and ports, commercial exploitation of topshell resumed under U.S. Administration. Because the war prevented commercial harvest, overexploited populations had recovered to some extent, and harvests were greater in the years following the war than they were just prior to its outbreak (108). However, populations began to decline again by the mid-1950s, leading to establishment of reef sanctuaries in which no harvest was permitted (109).

The topshell continues to be a major item of export for several island groups (72). For example, Yap has an ongoing trochus seeding project for the outer islands (162). Steady in-



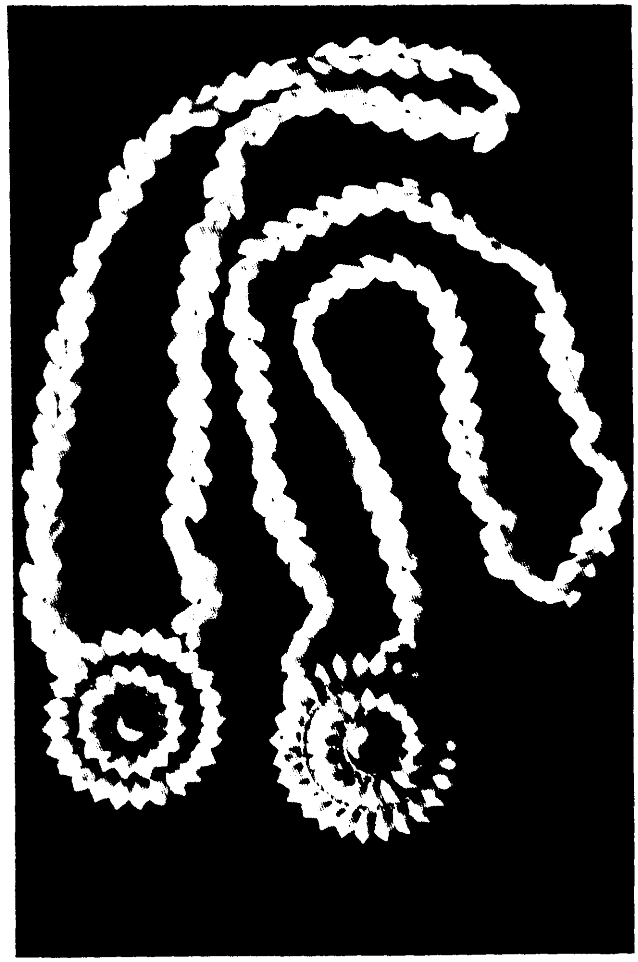


Photo credit: M Vitarelli

Nonfood resources gathered from the islands' nearshore waters continue to be important in island cultures and economies. Shown here are Marshall Islands shell necklaces and tortoise shell and mother-of-pearl jewelry from Palau.

creases in market prices in the last decade have resulted in the trochus harvest becoming an important sector of island economy. It is a principal source of subsistence income, especially in remote areas, and as one of the few natural product exports, it is an important source of foreign exchange for island governments.

Good quality *Corallium* reportedly was harvested off the southern coast of Peleliu in Palau and north of Pagan in the Marianas before World War II (145). A temporary glut of precious corals depressed world markets after extensive new grounds were discovered near Midway in 1980 (63), However, the continued decline of other stocks and the rapid depletion of the Midway beds combined to raise world trade in precious corals to at least $50 million (U.S. dollars] in 1982.

Excluding whaling, fishing in a commercial sense began only in the 20th century with the arrival of the Japanese and Americans. Most fishermen today are part-time, and almost all contribute heavily to the nonmarket sector (84,113,126). Semicommercial fishing is, however, developing. Problems of overcapitalization and habitat and resource degradation are apparent and become more complex as populations grow and a market economy penetrates into the lives and cultures of traditionally subsistence people.

Urban development generally has concentrated in coastal areas of the Pacific islands. Urban centers grow as rural, or outer island dwellers migrate to them for better education and employment opportunities. Commercial fish markets, commonly cooperatives, are established to serve the centers emerging cash economies. Increased subsistence and commercial fishing, along with habitat degradation, stress urban center nearshore resources. As marine products become scarce locally, on a seasonal and annual basis, market prices are driven upward encouraging even more intensive harvest efforts.

As urbanization continues, reef resources are overharvested in an ever-widening area emanating from the urban center (118). The radius of depletion depends in part on the relative prices of fish in the district center markets and on costs of harvest and transport from rural and outer island areas. When urban fish prices rise (with depletion of resources), less expensive foreign imports begin to flow into island fish markets. Urban consumers benefit from cheap imports, but fishermen are trapped between a fixed price for their product and ever-increasing costs of exploitation. Their only solutions are to turn to other occupations or to harvest more fish more efficiently. If governments subsidize such efforts, the circle of resource depletion widens. If the numbers of full-time fishermen decrease, part-time fishermen begin to take over the fishing sector, joined eventually by recreational fishermen.

In attempts to establish more equitable income distribution, island governments sometimes subsidize shipment of resources from outer islands to the urban center. The full-time subsistence fisherman becomes a part-time commercial fisherman whose efforts are tuned to rising market prices rather than to traditional reef tenure systems and subsistence needs. Old resource management systems are circumvented. With government subsidies for gear, ice, freezing, and transport, and the lure of participation in a cash economy, the fisherman may now harvest far more of the resource than he needs and otherwise would have. Modern, but often less selective equipment aids this effort. In the quest for those species most preferred by the urban dwellers, less commercially valuable resources may be unintentionally overharvested (23].

The above scenario is in various stages of realization throughout the U.S.-affiliated Pacific islands. Guam (2), American Samoa (173), and the Commonwealth of the Northern Marianas (CNMI) (126) find themselves in the later stages of the scenario. Palau, the Federated States of Micronesia (FSM), and the Republic of the Marshall Islands (RMI) seem to be in the earlier stages (23). Legislation has been passed to conserve and manage remaining nearshore resources, and national policies have attempted to redirect resource use away from the more heavily exploited nearshore areas toward comparatively underexploited outer reef and pelagic resources (151).

The number of disputes over access to fishing grounds in the U.S.-affiliated Pacific islands also is growing as populations increase and pressures on resources push yield potentials to the limit. Unprecedented levels and kinds of waste discharge (104) pose still more problems. Although some reports exist that population densities of specimen shell species have decreased where tourism has developed in the Trust Territory of the Pacific Islands (TTPI), it is not clear if the reduction is caused by over-exploitation or by increased runoff and pollution associated with urban development (70).

Because the tropical environment is near the upper tolerance limits of temperature for many reef organisms, thermal effluent from powerplants has disrupted reef communities in some areas (88,120). Chlorine, used to control biofouling in powerplants, is also very destructive in tropical ecosystems (14). Toxic chemicals such as pesticides and herbicides used in agriculture also enter coastal ecosystems via storm runoff.

Nearshore resources are the social security reserve and unemployment insurance fund of many island people. Further damage to these resources, and/or resource depletion through overcapitalization of fisheries, may have an extremely high opportunity cost in terms of public assistance and food imports. Social costs include diminished self-esteem, which accompanies reduced self-sufficiency.

Caribbean

Caribbean waters have supported continuous subsistence-level exploitation since prehistoric times (64). There is ample evidence that fishing played a significant part in the lives of Amerindians who inhabited the Caribbean islands prior to European settlers, though fishing was never a major occupation during the colonial period (148). Fish was, however, an important food for plantation populations in the Danish West Indies. Planters and slaves dined on locally caught fish and shellfish, as well as on salt fish imported from Denmark and the United States in exchange for plantation produce (157).

Commercial fishery development in Puerto Rico began in 1941 under the Department of Agriculture. Local demand for fish increased with the influx of military personnel and has been perpetuated by tourist hotels. After World War II, the program was transferred to the Puerto Rican Agricultural Development Corp. Fisheries Division which emphasized offshore fisheries; the program was terminated in 1947. Since then, the Puerto Rico Corp. for the Development of Marine Resources (CODREMAR) and the U.S. Virgin Islands Division of Fish and Wildlife have established fishing gear distribution centers, a fishery credit scheme, and constructed facilities for gear storage and landing of boats (94).

Historically, coastal resources have shown a consistent pattern of use: exploration, discovery, exploitation, and finally, depletion (64,102). Between 1974 and 1976 some 30 modern fiberglass boats were introduced to the Puerto Rican fishing fleet. Between 1976 and 1982 the number of fishermen on the island rose from 1,230 to 1,872; the number of vessels rose from 865 to 1,449 (25,90).

The multimillion-dollar nearshore fishing industry of Puerto Rico and the U.S. Virgin Islands (USVI) produced some 7 million pounds of seafood in 1982 (25), Harvest of nearshore marine resources takes place primarily near coral reefs and seagrass beds where it is relatively easy to deplete many stocks. Traditional fishery resources typically are harvested without true knowledge of resource levels so harvests in excess of maximum sustainable yield may occur (94).

Combined technology transfer and increased market demand have accelerated harvesting pressure and pose potentially serious ecological consequences for tropical coastal ecosystems. Fiberglass boats, outboard motors, scuba apparatus, and (to a lesser extent) deep-diving submersibles not only have significantly increased harvesting within previously exploited habitats, but also have led to exploitation of entirely new habitats and organisms. Recent efforts directed toward deep reef resources in Puerto Rico and the Virgin Islands may have significantly depleted these stocks.

In 1974, the waters of Puerto Rico were characterized as “very nearly overfished” and “heavily exploited” (90,92). Between 1975 and 1980, catch per unit effort declined at least by 50 percent: a classic indication of overfishing (25).

Fisheries development efforts have been much less intensive in the USVI. But even modest increases in fishing effort coupled with technological innovations may have exceeded natural productive capacity, The growth of the fishing fleets in Puerto Rico and the USVI coupled with a small resource base has had a predictably negative impact on target stocks.

While information is not adequate to permit definitive evaluation, spiny lobster and shallow reef fisheries [and possibly conch and some deepwater fisheries) in Puerto Rico and the USVI seem to be fully or overexploited. Important Eastern Caribbean fishery species such as the spiny lobster *(Panularis argus)* and queen conch *(Strombus gigas)* are highly vulnerable to overfishing. Stocks of spiny lobster in the USVI and Puerto Rico may depend on production in other locales.

Major habitats, including coral reefs, mangroves, and seagrass beds are threatened by development as well as exploitation patterns not consistent with sustained use. The Puerto Rico Coastal Management Program states that three-quarters of the island's original mangroves have been destroyed (160). Water contamination and dredging and shoreline modification associated with tourist development are also a major threat to nearshore resources in Puerto Rico and the USVI.

Levels of harvesting and exploitation of non-food resources still are relatively low among the U.S.-affiliated Caribbean islands as compared to the U.S.-affiliated Pacific islands primarily because of the development pressures accompanying tourism, particularly on the Virgin Islands. However, the future of the habitats is by no means assured. Poaching in federally protected parks and recreation areas and small-scale personal collecting continue and ultimately may pose a serious threat to the sustainability of some aquatic populations.

Traditional methods of extracting medicinal substances from shallow water organisms (mainly by boiling hand-picked algae) are giving way to large-scale harvesting using snorkeling, scuba, and remote or manned submersibles (168). Although laboratory synthesis of useful compounds has generally proved more cost-effective than continued large-scale harvesting, residuals are a problem in synthesized compounds, and organically grown compounds are desired at premium prices. Future economic conditions or biomedical demands could easily lead to large-scale harvesting of benthic organisms in the Caribbean.

Finally, the tropical western Atlantic Ocean is only about one-tenth the size of the tropical western Pacific ocean, and so the Caribbean has a more regionally integrated marine species pool. The biota of the western Pacific shows a decrease in species diversity along a gradient between Indonesia and French Polynesia. Thus, ecological processes in the Caribbean, such as population blooms or die-offs, will have regional influence on marine resource management. For example, a recent mass mortality of the sea urchin *Diadema* antillarum had a widespread effect on benthic communities throughout the Caribbean. In contrast, mass mortality of the urchin *Echinothrix* in the Pacific remained confined to the Hawaiian Islands (15).

COMMON CONSTRAINTS TO FISHERIES AND AQUACULTURE DEVELOPMENT

Constraints to Nearshore Fisheries Development

The major constraints to nearshore tropical fisheries development include: inadequate knowledge of complex ecosystems, the inherently limited productivity of waters around tropical islands, and the vulnerability of tropical fisheries to a variety of natural and human disturbances. Equipment maintenance and servicing, and problems of transporting inputs and exports also hinder development.

Inadequate Knowledge of Coastal Ecosystems and Species

Although there has been intense interest in subtidal tropical marine communities for centuries, it has only been in the last three decades–since the advent of scuba gear–that rigorous field research was possible. As a consequence, less is known about these ecosystems than about any other of comparable extent and importance.

Capture fisheries are based on resources which are ultimately finite, and no development strategy can result in an open-ended stream of benefits. Typically, greater pressure exists to "develop" than to obtain information on actual development potential.

The complexity of coastal ecosystems, and our scant knowledge of the most basic ecological characteristics of their components, virtually preclude successful community manipulations. Before communities or even single populations of benthic organisms can be manipulated predictably toward some desired end, further basic research on abundances, distributions, life history characteristics, diseases, and ecological interactions must be conducted. Progress in the comprehensive management of corals and other sedentary or sessile animals, for example, will depend ultimately on the acquisition of basic biological information on longevity, reproductive capacity, larval and population dynamics, and environmental stability.

Scientific information on the current status of nearshore marine resources is fragmented and inconclusive, and generalizations about such a vast and diverse geographic area can lead to faulty conclusions. Concise information on resource distribution and abundance also is lacking. In the absence of such data, the concept of optimum sustainable yield is mere technical jargon.

Most research and classical models of marine biological systems have been based on continental shelf areas of the Northern Hemisphere. The physical differences between reef slopes of oceanic islands and continental shelves, and the diversity and complexity of tropical fisheries reduce the applicability of these biological and bioeconomic models in tropical areas. The effects of selectively harvesting certain species, of fishing the same species at different depths, and the relationships between nearshore and offshore stocks, and the fish population dynamics, are less well understood in tropical than in temperate waters (95).

Inherent Restrictions to Productivity

The nearshore waters of many islands have high nutrient levels and are highly productive compared to the surrounding oceanic waters. The primary productivity of island nearshore waters is a function of several interacting factors including: island size, island height (influencing rainfall *and* terrestrial runoff), area of submerged bank, coastline complexity (e.g., embayments supporting mangrove forest growth) (111,118), and nearshore bottom communities (e.g., seagrass meadows). Barring disturbances (see below), the productivity of potential fisheries is assumed to follow a gradient related to the factors influencing primary productivity y of nearshore waters (118).

Harvest in the nearshore marine environments of the U.S.-affiliated islands is also constrained by the limited physical size of productive nearshore areas. Puerto Rico and the USVI have a continental shelf of less than *3,000* square miles and less than half of this area is highly productive *(116).* The U.S.-affiliated Pacific islands are based on steeply sloping submerged mountains and reef slopes and have no continental shelves or substantial ledges. Potential harvest is correspondingly small.

Lack of Economies of Scale

The nonuniform distribution of highly productive habitats, the immense diversity and seasonality of reef ecosystems, and the mixture of high-value and less desirable species in most fishery stocks require great versatility of capital and labor for harvest and precludes the development of single-species fisheries. The rugged topography and potential for extensive degradation of coral reefs precludes use of nonselective, towed gear in many commercial fisheries. The need for versatility, coupled with geographic remoteness and small island size, results in high production, preservation, and distribution costs which are not easily reduced through economies of scale *(23).* Size and isolation are even more constraining in the Pacific than in the Caribbean. With a combined land mass less than one-half that of the State of Rhode Island, the FAS are analogous to oases in an oceanic desert.

Vulnerability to Disruption

Tropical ecosystems are vulnerable to a number of natural and manmade disruptions, and this vulnerability represents an impediment to resource management and development efforts. Natural disturbances result from both physical and biological processes. Physical disturbance agents include: hurricanes, earthquakes, extreme low tides, extreme water temperatures (e.g., El Niño), extremes of freshwater runoff and terrigenous sedimentation. Biological disturbance agents include predator outbreaks (e.g., crown-of-thorns starfish), pathogen epidemics (e.g., black band disease in corals), fish poisoning (ciguatoxins), introduced competitors, and unusual drastic population pulses of ecologically important species (e. g., the recent Caribbean-wide die-off of sea urchins and the resultant destructive bloom of their algal prey).

Coral reef communities are disturbed by natural events, such as the tropical cyclones common in the CNMI and Caroline Islands, so often that few develop a climax community (32). Episodic catastrophes have also been related to tidal phenomena (177). Rainstorms coinciding with spring low tides killed up to 92 percent of reef invertebrates at Enewetok Atoll, RMI (loo).

Large-scale biological disturbances have been generated on coral reefs by population explosions of the coral predator *Acanthaster planci,* or crown-of-thorns starfish. Initial outbreaks of *Acanthaster* are associated with high islands and are probably related to increased terrestrial runoff (16). Recovery of the coral communities requires a decade or more, but may be interrupted by secondary outbreaks (30,31).

Sources of human-induced disturbance include: increased sediment runoff from agriculture and construction; thermal and chemical effluents from industry; oil spills; ship damage (grounding and anchors); dredging and blasting during channel construction; nutrients and toxins from sewage and solid waste disposal; direct removal of exploited species; and indiscriminately destructive fishing methods (chlorine, dynamite, grenades, etc.) (168).

Manmade disturbances, including cutting, clearing, and filling of the mangrove swamps, can be even more devastating than natural ones. Regeneration of mangroves in clear-felled areas of Southeast Asia has not been successful (146). (Sustained yield mangrove forestry, on the other hand has been quite successful, for example, in Malaysia.) The destruction of important fishing grounds and traditional fish pens has resulted from dredging and filling for airport extension in the absence of thorough environmental assessments (86).

Similar patterns and similar potential for problems affect the Caribbean islands because of their small size and the small "buffer" capacity of ecosystems like reefs. Few or no adjacent areas exist to which fishermen or tourists can move when nearshore environments are seriously damaged.

Although most major disturbances—natural and human—are relatively rare, virtually any program of resource exploitation and management will eventually experience their effects *(86).* Knowledge is still being collected about rates or sequences of recovery processes, and will be essential to management plans dealing with disturbance.

Constraints to Aquaculture Development

Despite potential for aquiculture in the U. S.-affiliated islands, progress in aquiculture development has been slow. Because of the physical and biological characteristics of the small islands, only certain kinds of aquiculture are practical, and some of these require a better base of scientific knowledge and more practical experience than exists today (58). The development of aquiculture in the U.S.-affiliated Pacific and Caribbean islands faces other common constraints, including:

- dearth of suitable land for pond construction;
- small freshwater supply;
- high energy costs for pumping seawater;
- low levels of nutrients in the sea (and consequent lack of food for filter-feeding species);
- scarcity of protected bays and estuaries for pen, raft, or rack culture systems;
- logistical problems and generally high costs of supplying inputs (feed, equipment, supplies, and technical assistance) and distributing the products to distant markets;
- potential for serious conflicts between aquaculturalists and other users of publicly owned areas (155).
- high cost of culture (materials, land, labor) relative to value of production *(43,122),* creating difficulty in competing with artisanal fisheries *(162).*

- lack of appropriate tested technology for many species;
- lack of security of cultured stock from poaching;
- lack of social and traditional context for aquacultural practices; and
- lack of trained personnel capable of operating sophisticated systems,

These constraints are particularly severe on the smaller islands. American Samoa, for example, comprises an area of less than 100 square miles on three mountainous islands. Freshwater is scarce and lagoon/reef areas are communally held. Culture systems beyond the scale of small family or subsistence farms thus are ruled out in such settings.

In areas like the CNMI, Yap, Pohnpei, Truk, Kosrae, and the RMI (all small volcanic islands or atolls with limited land and freshwater, low populations, and undeveloped infrastructure), aquiculture potential probably is limited to species which obtain their own food or can be fed on locally available feeds. The culture of dolphinfish, groupers, or snappers would be technically feasible in those islands with protected waters, but the cost of importing feeds and of transporting the product to distant markets could be prohibitive. (In some cases, fish not used for human consumption and fish scraps might be available for economical culture of these species.) Similarly, aquiculture in the USVI probably will be limited to marine species raised in the sea (e. g., marine plants, queen conch, dolphinfish, groupers, or snappers), or in coastal ponds (e. g., marine shrimp). Since none of these species have been grown in the USVI, a period of adaptive research and pilot-scale testing would be needed in order to determine applicability of culture methodology used elsewhere.

Other impediments to sustainable development of aquiculture include technical difficulties in applying the culture system to the selected site, lack of local sources of juveniles and post-larvae, prohibitive shipping costs, lack of aquiculture extension programs and marine advisory services, lack of regional planning and coordination, and lack of sustained aquiculture and mariculture research programs and funding. Cultural settings and levels of technological development, moreover, ‘vary greatly among island groups.

Increased activities in mariculture may cause degradation of the reef and lagoon environments from increased boat traffic, physical impacts on adjacent areas, impacts from placing structures on reefs, and intensive grazing by fish penned in shallow reef areas. Heavy supplemental feeding required by some intensive cage or pen culture programs also may increase the nutrient load in lagoon waters. The increase of suspended organic matter may have adverse impacts on adjacent reef areas (118). Further, there exists the potential for introduction of disease.

Other Constraints to Marine Resource Development

Risk

Capture fisheries, based on multispecies resources, are inherently more flexible than aquiculture, which focuses on a particular product. Aquiculture, however, permits more control of production and harvest of a particular species, whereas capture fisheries generally depend on natural abundance. Risk is inherent in both activities, posing a common constraint to credit and insurance, and both activities are vulnerable to competition from imports.

Many small-scale fishermen are unwilling to engage in capital risk-taking in order to achieve higher profits, preferring the comparative security and familiarity of simple, inexpensive methods even if they yield only subsistence levels of income. Those few fishermen who are willing and can afford to use improved technology may come to dominate the fishery, while the standard of living for the rest may stagnate or decline (81; app. F). Others may seek more lucrative or less stressful employment in nonproductive sectors.

Equipment Maintenance and Servicing

Fisheries and aquiculture development commonly are hindered by inadequate supplies and high cost of replacement parts (i.e., for freezers, motors, and other gear). Metal structures deteriorate rapidly in the tropics due to internal sweating, poor ventilation, corrosion, and electrolytic action (137), In addition, equipment maintenance sometimes is beyond the operators' skills.

Transportation

Transportation in general is a problem in the Pacific islands (see ch. 8). Even routine mail deliveries are jeopardized at times by the lack of airline service. The costs of air freight within the region together with the general lack of airline services greatly hinders development of export fisheries and aquiculture in this region. In Guam, for example, export operations in the aquarium trade have been relatively short lived, primarily because of problems related to the airlines. Neglect and flight delays have resulted in losses of entire shipments, and shipping expenses are extremely high.

Small Size or Lack of Formal Markets

No formal market structure exists for the nonfood products of the Pacific islands. Collection, analysis, and dissemination of market information and trends are absent. Usually this means the islands receive less than market value for their resources (146).

Although ornamental shell industries already exist in some U.S.-affiliated islands, most of the handicrafts sold in tourism centers are imported from the Philippines, where greater varieties of products are available at lower prices. Carleton (26,27,28) noted poor organization of handicraft industries in the Pacific. The major constraints identified were intermittent production and lack of business and financial expertise.

Resource Use and Ownership Customs

Fishing customs and rights are intimately enmeshed in local social and religious practices on some U.S.-affiliated Pacific islands. This creates management impediments as well as opportunities that have often been overlooked by western-trained fishery managers (81). It is difficult for researchers and decisionmakers to predict and assess social impacts of development activities and projects objectively, since these may involve changes in the way of community life, perceptions, and values that are partly products of history and group culture. It is particularly difficult to assess the social impacts of changes in marine resource uses, It is difficult to observe fishing activities at sea, data on marine resources are scarce, and relationships between socioeconomic and marine resource systems are complex.

In areas where traditional ownership and use systems have lapsed or never existed, it is very difficult to maintain exclusive rights to production from certain ventures (e.g., sea ranching and habitat enhancement) because these activities involve resources which are traditionally considered common property,

Absence of Federal Agency Representatives

Most Federal agencies with oversight responsibility for development of marine resources in the Pacific are not actually present. Federal representatives, usually based in Hawaii, make occasional visits to the islands, but may have little understanding of the islands' needs. The lack of Federal officials to enforce Federal laws poses a severe problem for renewable resource management in many island areas (155). Budget constraints are cited as the rationale for this situation.

Progress in tropical coastal management is handicapped by jurisdictional ambiguities created by incomplete and nonspecific laws and regulatory statutes (50,64,65,159), low levels of enforcement of current practices leading to overexploitation, insufficient recognition of the regional nature of ecological issues, and lack of scientific cooperation among Caribbean polities, Due to these limitations, many current or potential levels of exploitation already exceed the capacity to either analyze, regulate, or enforce resource management programs.

COMMON OPPORTUNITIES

Significant opportunities exist for aquatic resource development in the U.S.-affiliated islands of the Pacific and Caribbean including: enhancement of artisanal fisheries, development of pelagic fisheries, development of small-scale collecting and gathering, and aquiculture. These opportunities result from substantial natural stocks, growing markets for fisheries products, the favorable climate which permits year-round growth of tropical species, and the availability of clean seawater. As with agriculture, opportunities include the three main categories of import substitution, increased production of domestically consumed products, and export promotion.

Although clearly significant as a million-dollar industry, the fishing industry of Puerto Rico and the USVI falls far short of meeting local demand for fresh seafood. Demand has increased markedly with expanding tourism in the region. Nearly 60 million pounds of seafood valued at $48 million are imported annually to the islands (25). Some island products, besides serving a burgeoning domestic market, would likely find ready acceptance in mainland markets, Because Puerto Rico and the USVI import more from the mainland than they export, favorable haul-back rates are possible for island products.

American Samoa, the Commonwealth of the Northern Marianas, and Guam also have been net importers of protein for some time. Guam annually imports at least 390 tons of fresh and frozen whole fish (23). The successful Japanese fisheries in Micronesia during the mandate period suggests that a great deal of potential for economic development of marine resources is currently unrealized.

Expanded Use of Underexploited and Migratory Species

Because nearshore fisheries of many U, S,-affiliated islands seem to be near or beyond maximum sustainable yield, and nearshore marine ecosystems are vulnerable to and already adversely affected by inappropriate land and sea uses, developing these fisheries is likely to have a long-term negative impact. However, potential exists to maintain or enhance nearshore fishery productivity through such mechanisms as preservation of mangrove, seagrass bed, and coral reef ecosystems, placement of artificial reefs, restocking and reseeding programs, and development of markets for underused marine species. Species that currently seem underexploited include sharks, some outer-reef fish, deepwater shrimp and crabs, and migratory pelagic species. The latter form the basis for large commercial fisheries in both regions, but the islands are little involved in these industries.[1]

Collecting and Gathering

The islands of Micronesia and American Samoa lie within the Indo-West Pacific region which is characterized by having the most diverse fauna and flora in the world (46). For this reason the Pacific islands are also in a position to supply an expanding specimen market with species of shell and corals that are not available from other sources. However, extreme vulnerability to overexploitation requires harvest on a small-scale, selective basis. Long-term sustainable exports may not be justified, but coral and shells have some economic potential for small-scale, tourist-oriented sales.

Bans on exports of coral and shells, some of which play a vital role in the health of coral reef communities (84,86), have resulted from reef destruction caused by overexploitation in some areas (27,28,110,172). However, the value of unprocessed deepwater precious corals ranged from $33 to $2,200/lb (U.S. dollars) in 1981 (63); thus even small beds of precious coral could provide important revenues when harvested on a sustainable yield basis.

An examination of historical catch data indicates that the Micronesia reefs are capable of sustaining far greater numbers of topshell

[1] An assessment of commercial fisheries development for migratory pelagic species is beyond the scope of this report.

than presently are harvested. Parkinson (130) estimated that Palau's reefs should yield sustainable harvests of some 200 tons/year. However, the few records available for recent years indicate an average harvest of about 100 tons/year (146).

Current supply does not satisfy demand in the aquarium fish trade, particularly in the United States. Demand worldwide is expected to increase 10 to 15 percent per year in the future (26). The Caribbean islands and those Pacific islands with direct flights to Hawaii or Japan are suitably located to establish small aquarium fish businesses to take advantage of this situation. When nondestructive methods of collecting are used, small-scale fisheries of this kind can be developed without upsetting the ecological balance on the reef. Aquiculture of high-value aquarium species may offer an alternative to capture techniques; however, the general constraints to aquiculture would still apply.

Sea cucumbers offer some export potential today, as they did under the Japanese administration, although several past attempts to develop export industries have failed. Asian markets require a consistent high-quality product of a particular species, dryness, size, shape, and color. It has not proved possible to provide the required volume of that product; natural abundances may have to be supplemented with mariculture to provide long-term economic viability, but not enough is known of the biology of commercially valuable species to begin culture.

Aquaculture

While fishing is an important source of jobs and food protein in the pacific, the supply of fish is variable and sometimes small (163). Increases in population have resulted in a higher demand for marine resources than local waters often can supply on a sustained basis. Under these circumstances, opportunities to increase marine harvest become increasingly important in the Pacific and Caribbean regions. Aquiculture operations have been examined as an opportunity to remove some pressure from nearshore fisheries, reduce unemployment, and decrease dependence on imported seafoods. However, many aquiculture projects have been unsuccessful.

Species that have been identified as having particular potential for aquiculture development in the U.S.-affiliated islands include sponges, freshwater prawns, marine shrimp, giant clams, pearl oysters, rabbitfish, milkfish, tilapia, and macroalgae (seaweeds). Much aquaculture research has been done on species such as bait fish which can be more profitably produced by capture fisheries. Attention also has been given to species, such as marine shrimp, that command high prices in foreign markets. However, the expense and logistical difficulties of transporting the product to markets may preclude culture of these species. Other factors that adversely impact on aquaculture include the high cost of imported inputs, difficulty in procuring juveniles, and lack of marketing and technological assistance.

The potential for development of viable aquaculture also varies with the physical characteristics of the island groups, their location in relation to sources of inputs and markets, availability of suitable sites, cost of production, investment capital, and quality of project management.

The phycocolloid seaweed industry is rapidly growing and, for the most part, is still limited by the supply of raw materials (the seaweeds) (39,40). The economic situation and the growth of the phycocolloid industry have resulted in a worldwide interest in seaweed cultivation, particularly those containing agar or carageenan. Such cultivation maybe well suited to remote islands, since the thalli can be sun-dried and stored for many months (119). The value of the world phycocolloid industry was reported to be about $1 billion (U. S.) in 1978, and gel extracts were estimated to be essential to some $22 billion (U. S.) in the U.S. gross national product.

Pearl oyster cultivation and edible seaweed mariculture offer some export potential. The Japanese administration pursued both of these endeavors in Micronesia. Japanese technology and marketing participation would likely be required for success in export markets today. Joint ventures may warrant investigation.

The challenge is to select species and culture systems appropriate for subsistence or commercial use in a given area by: evaluating the local environment, analyzing the labor and energy requirements and the cost of production and transport to market (in comparison with the costs to competitors), considering the cost of alternative uses of the resource, and evaluating the social acceptability of this activity in view of land and water requirements, It also is important to evaluate the environmental impacts of aquiculture projects.

POTENTIAL STRATEGIES FOR NEARSHORE FISHERIES DEVELOPMENT IN U.S.-AFFILIATED ISLANDS

Introduction

An increase in fishery production in the U. S.-affiliated tropical islands can be realized in several different ways, including:

- increased efficiency or intensity of nearshore fisheries;
- development of subsistence and small-scale commercial fisheries aimed at underutilized stocks;
- development of large-scale fisheries aimed at migratory pelagics;
- management of nearshore fisheries for sustained yields (fish aggregation devices, artificial reefs, restocking, conservation); and
- farming (aquiculture) of selected species (95).

The technical capabilities of fishing communities are major determinants of the appropriateness of technologies. Sociological factors, such as the nature and strength of extended family systems, also play major roles in identification of technologies appropriate for development within the region.

Increasing exploitation of marine resources may be seen by administrators as a method to alleviate some economic and social problems, through improvement of exports and balance of payments, increased local food supply, provision of employment, stemming of rural drift, increased profits for local entrepreneurs, and improved welfare of coastal communities. Thus, the identification and implementation of fishery technologies may be determined by the direction and priorities of local government policy objectives. The extent to which the needs and values of coastal communities are considered depends on the degree of interaction between administrators and coastal communities on such policy considerations (95).

Potential Strategy: Increase Fishery Exploitation Efficiency

To increase the efficiency or intensity of fishing efforts in the U.S.-affiliated islands, further improvements are needed in technology related to boat and gear design and construction, credit availability, subsidies for or reduced taxes and duties on fuel and supplies, landing and storage facilities, and local and foreign distribution and marketing capacity (151), However, care should be taken not to oversubsidize the commercialization of nearshore fisheries. An overcapitalized nearshore fishery will encourage depletion—adding to the income of market participants while reducing the lifestyle of subsistence participants. Such income redistribution may not lead to desirable long-run results (174,175).

Given the susceptibility of nearshore marine resources to overexploitation, technologies that would materially increase nearshore harvesting efficiency can be expected to have a negative long-term impact in the Caribbean and Pacific island areas. In most Pacific island areas, little potential exists for expansion of nearshore fisheries beyond that which may occur naturally as island populations increase (127), Increased pressure on the resource will occur if an increase in harvest efficiency is not met with a corresponding decrease in harvest effort (95).

If currently harvested resources are being harvested at or beyond maximum sustainable yield (as seems to be the case in many localities), effort within the fishing fleet must either be reduced or diverted to other stocks.

Evidence from Puerto Rico and the USVI strongly suggests that availability of harvest technology is not a problem. Rather the need is to apply appropriate technology at a level suited to the productive capabilities of natural systems. Continuation of a development style directed solely toward capitalization and harvest efficiency without regard for sustainable yields can only result in resource depletion and adverse socioeconomic impacts.

A large proportion of total fishery production is lost to wastage in many tropical areas. Thus, methods to reduce waste of current harvest levels can offer an alternative to increased exploitation levels in boosting fisheries' production. Avenues to reduce waste include improving storage and processing techniques, increasing efficiency in transportation to markets, and developing markets for bycatch (see ch. 8).

Potential Strategy: Increase Support for Subsistence and Small-Scale Commercial Fisheries Aimed at Underutilized Stocks

The importance of small-scale fisheries lies in their income- and employment-creating potential and their use of appropriate forms of technology. As nearshore resources come under greater pressure, however, fishermen are increasingly moving offshore and/or making more use of migratory pelagic fish sometimes found in nearshore environments. Pelagic resources probably offer an opportunity in the U.S. Caribbean and Pacific for the expansion of small-scale island fisheries—commercial, recreational, or subsistence. Proper management of these resources can also provide opportunities for economies of scale.

A relatively small number of marine organisms comprise the preferred fishery target in most countries. Commonly this occurs because the species are plentiful and easy to catch (e.g., a schooling fish which is easy to net), or because a social preference exists for a particular species (95). The identification and development of alternative underused stocks may be expected to increase economic benefits from the nearshore fishery.

Current Puerto Rico and USVI fisheries development policy emphasizes underutilized offshore resources (e.g., swordfish) (24) and recreational fishing *(61).* Although the status of stocks is not known, it is expected that considerable amounts of pelagic swordfish can be harvested (45). This approach has considerable merit, and might help divert some fishing effort from stocks that currently are overexploited, thus increasing economic benefits from the nearshore fishery. However, while an increase in the harvest of underutilized species is possible, these species can support relatively few fishermen (94), and there is no reason to suppose that these stocks are less vulnerable to overexploitation than others if reliable estimates of sustainable yields are lacking *(61).*

Similarly, Pacific island government agencies have encouraged commercial harvest of identified offshore resources as it has become clear that there are relatively few, if any, nearshore resources remaining underutilized in the U. S.-affiliated Pacific islands (23). Further, nearshore schools of fish provide a food reserve for local populations in the event of natural calamities, making underexploitation preferable to commercial overexploitation.

Sharks represent a potentially important and virtually underutilized resource in the tropical Pacific. In spite of the seeming abundance of sharks, Pacific islands supply only a small proportion of the market. Sharks are harvested primarily as a bycatch of Taiwanese tuna long-liners landing at Pago Pago, and the fins are the only product currently retained *(26).*

Markets for shark products are expected to continue a recent trend of gradual expansion **(26,244).** Market growth, particularly for shark leather, appears to be limited by the supply of hides *(27,135).* Novelty products such as jaws and teeth have a ready market in tourism, while new products such as artificial skin for burn victims are still in the development stages (3). Shark resources also are generally underutilized in the Lesser Antilles, but are particularly vulnerable to overexploitation because of low reproductive potential, slow growth rates, and greater age at maturity than other fishery stocks. They can quickly be depleted if commercially developed *(61).*

Deepwater species beyond coral reefs may be suitable for development of new fisheries. The exact magnitude of the resource is not clear, and large-scale harvest and marketing problems have not yet been solved *(23).* Two species of deepwater shrimp *(Heterocarpus ensifer* and *Heterocarpus laevigatus)* are fairly abundant at depths of nearly *700* feet on the seaward faces of fringing reefs and probably barrier reefs and atolls throughout the U. S.-affiliated Pacific islands. Rough terrain and the potential for habitat destruction make trawling unacceptable, and trapping has not yet proven economically viable. Pacific island fishermen recently have been encouraged to exploit forereef deepwater snapper (family Lutjanidae). The distance of these fish from ciguatoxin sources make them less likely to be contaminated with ciguatera (95).

The development of new fisheries may require the introduction of new fishing technologies as well as the surmounting of social prejudices. It may be possible to develop export fisheries for species that have little local value but constitute a desirable export commodity, or to develop export fisheries for highly valued products. For example, holothurians (sea cucumber or beche-de-mer) are gathered in several Pacific island areas; a particular species *(Microthele nobilis)* of this family commands a high price in Southeast Asian markets. Fisheries based on tropical lobsters also have been developed on some Pacific islands (95). Squid and deepwater crab may be underexploited in the Caribbean (124).

Potential Strategy: Develop Large-Scale Fisheries Aimed at Migrating Pelagics

The Japanese have been lauded for achieving a sound degree of economic progress based on indigenous island resources in many of the Pacific islands during the mandate period (121). After more than 2% decades of Japanese fisheries development in Micronesia, exports from nearshore fisheries were relatively small. In fact, during the Japanese administration nearshore production was only sufficient for subsistence needs and supply of local markets for Japanese immigrants; at least 90 percent of the exports by weight and value were composed of pelagic species, primarily tuna (161). Any significant commercial fishery resource potential rests with offshore pelagic resources, not nearshore resources.

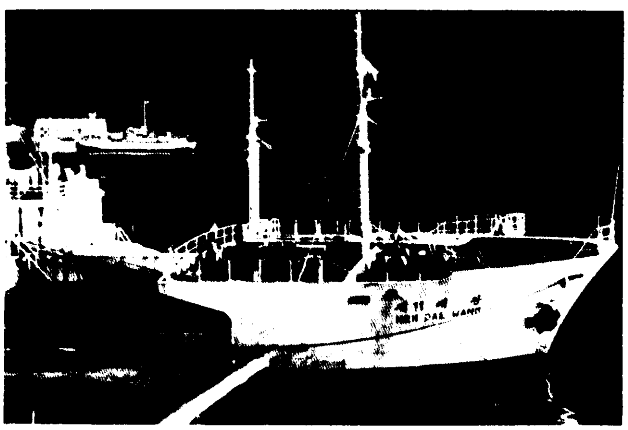


Photo credit: A. Vargo

Pelagic resources around the U.S.-affiliated islands form the bases of many foreign commercial fisheries and could offer an opportunity for increased food production for the U.S.-affiliated islands. Except for a few tuna processing facilities in the U.S.-affiliated Pacific islands, the industry remains largely in the hands of foreign operators. Shown here, a Korean tuna boat in Pago Pago Harbor, American Samoa.

Highly migratory species—tuna, dolphinfish (mahimahi), and billfish–are the major commercial offshore resources in the U.S.-affiliated islands. Most of the world's tuna stocks probably already are exploited close to maximum sustainable yields (61). An important exception are the huge Pacific skipjack tuna stocks which still apparently are not exploited at levels close to those they could sustain (80).

Potential Strategy: Manage Nearshore Fisheries for Sustained Yields

Although attempts at marine resource management were made as long ago as the Middle Ages (64), serious scientific concern for the consequences of uncontrolled and unplanned exploitation is a relatively recent development. Primitive efforts to manage coral and mollusk fisheries involved rotation of harvesting beds to allow recovery (64,65). Rigorous scientific efforts to manage these resources have emerged only recently.

Management of marine fishery resources commonly involves regulatory measures to conserve individual fishery stocks and critical habitats. More recently, attempts have been made to increase harvestable stock through fish aggregation devices (FADs), artificial reefs, habitat restoration, and restocking programs,

Opportunity: Develop Fish Aggregation Systems

One promising technology for augmenting small-scale, nearshore pelagic harvests is the FAD; usually an anchored buoy placed a mile or more outside the reef. Buoys may be constructed of metal, wood, or even bamboo, and sometimes nets or short ropes are attached to the buoy and anchor line.

It is well known that pelagic fish are attracted to and congregate around floating debris in the ocean (23). Tuna purse seiners commonly search out floating logs and other debris and may stay with a particular log for some time, setting the net around the log. Floating debris clearly provide a reference point for excursions of highly mobile pelagic predators, Hundreds or thousands of fish may aggregate around a single log or other floating object,

A variety of mid-water FADs are being used experimentally in the Lesser Antilles (61). Studies by the USVI Division of Fish and Wildlife have shown that catch rates are significantly increased by deployment of FADs. Units installed close to the edge of the coastal shelf are reported to attract many migratory pelagic species, but the impact of this technology on fish stocks, and sustainability of high catch rates have not been evaluated. Because of the limited nature of nearshore marine resources, the long-term impact of most innovations is likely to be negative unless implementation is consistent with the productive capacity of the stocks to be harvested (61), and unless there is adequate regulation of exploitation (12).

Manufactured FADs can be costly, which may preclude their use in some areas. Materials and placement costs for a raft can be as high as $8,000; most FADs to date have been installed through government subsidy. Life expectancy currently is between 12 to 24 months and FADs frequently break loose and are lost. Many fishing communities are reluctant to replace those initially provided under aid. Research efforts could be undertaken to increase longevity and lower the fabrication costs, allowing standardization and mass production of FADs (147).

Other problems with FADs include: difficulties establishing ownership of FADs or of the fish attracted by FADs, conflicts between competing fishermen, presentation of navigational hazards, possible interruption of normal pelagic migration patterns, and attraction of fish away from customarily entitled nearshore fisheries (151). As knowledge is gained on the "catchment areas" of FADs, deployment methods that minimize their adverse impacts on nearshore fisheries will develop. For example, subsurface FADs, which do not hinder navigation, maybe as effective as surface FADs (78).

Opportunity: Construct Artificial Reefs

In recent years, efforts have been made to enhance the productivity of reef flats through the introduction of artificial habitats. It seems that natural production may be enhanced by the provision of suitable substrates for colonizing sessile species that provide food for nearshore fish, resulting in greater harvests than would be possible without artificial enhancement (23). Whether artificial reefs in fact enhance overall production or merely increase local populations by attracting fish from other areas is not yet known, although evidence exists supporting both theories.

Old automobiles, ship salvage, and other scrap structures have been placed on Pacific island reefs over the years in an attempt to increase fish abundance. Wave action and siltation due to steep reef slopes limits the application of this technology beyond natural reefs (23). Prototype artificial reef projects in Montserrat, British Virgin Islands, and the USVI suggest that increased production of shallow-water fish is possible using scrap automobiles and tires. Another approach involves the use of structures designed specifically to increase production of selected species. A recent study in Florida indicates that fish biomass on Japanese "designed reefs" was two to six times greater than on scrap metal "reefs" (141).

Opportunity: Restore Mangroves and Seagrass Beds

Mangroves and seagrasses constitute important fish habitats and contribute to sediment stabilization in nearshore ecosystems. In many areas, including the U.S.-affiliated islands, natural and human perturbations have altered the species compositions of mangroves and seagrass beds, or seriously damaged and even denuded these habitats, Depending on the extent of degradation, natural or induced recovery may or may not be possible.

Mangrove plantings to restore degraded mangrove habitats or to stabilize unvegetated areas is a management option. Planting large tracts is expensive; however, natural recovery of partially degraded areas can be accelerated at more modest costs by planting in bald spots. Stresses to the ecosystem must be removed for successful restoration.

An acid sulfate condition may develop in degraded mangrove area soils that have been exposed to air and disturbed for agriculture or aquiculture. This condition further hinders reclamation of mangrove areas (68).

Nearly three-quarters of Puerto Rico's mangroves have been destroyed (179), and little attempt currently is being made to restore them, Replanting mangroves has been practiced in Florida, however, at costs equivalent to reforestation on land). Successful rehabilitation of a mangrove area damaged by an oil spill has been carried out on Guam.

Techniques for artificial seagrass restoration have been developed and used with some success in U.S. coastal zones. Recovery of seagrass beds may depend on such factors as cessation of stress, level of degradation, availability and quantity of seed or vegetative tissue, and turbulence level of site.

Restoration methods include plugging; seeding; sodding; and planting of seedlings, sprigs, or shoots. While replanting may be possible, it is technically difficult to stabilize the bottom sufficiently to prevent the loss of plantings (35). However, information necessary for the understanding and use of restoration procedures has been inadequately reported. Recovery rates, both natural and artificial (e.g., transplants of root plugs, shoots, and turf), are poorly documented as are return rates of animal populations. Lack of knowledge about the physical environmental factors affecting seagrasses may impede successful restoration efforts (153).

Costs of planting seagrass may vary depending on species selected, experience and source of labor, and type of equipment needed, as well as geographical factors. The cost of seagrass restoration may range from nearly $1,200 to $12,000/acre and, the success rate of past attempts has been less than 50 percent (153).

From an ecological viewpoint, the best strategy is to protect mangroves and seagrasses from adverse impacts. They are valuable resources that take up to 100 years to reestablish naturally in many locations and may be impossible to reestablish in others. Where possible, restoration can be costly and success is not guaranteed.

Opportunity: Restock Nearshore Habitats

Farming of marine organisms (mariculture) may become important not only to supplement food resources but to remove pressure from and replenish depleted stocks of fish and invertebrates. For example, although attempts to mass-culture pearl oysters in the laboratory have failed in French Polynesia, recent success with artificial spat collectors is expected to end the harvest of wild stocks, permitting recovery of natural populations (29).

As the nearshore resources of the Pacific and Caribbean regions are becoming overfished or degraded, the idea of regeneration and "reseeding" of these resources is gaining attention. Breakthroughs in the spawning and culture of trochus (Trochus *niloticus)* and giant clam (family Tridacnidae) offer the possibility of reef reseeding (see box 7-A) (71,73). Of course, without appropriate controls on subsequent harvests, a reestablished population may be exploited at a greater than optimal rate and possibly reextinguished (154).

Giant Clams.—Farming of giant clams for the purpose of restocking natural habitats has been compared to resource management in forestry (176). The meat and the large shells of the Tridacnidae family represent a potential export if reseeding and grow-out techniques can be perfected. In some of the Pacific islands, techniques and skills for limited husbandry of clams already exists and may have useful application for expanding clam mariculture (154). An Australian government-funded project to develop and transfer giant clam breeding to Pacific islands coordinated by the James Cook University of North Queensland is nearing completion (43).

Giant clams, sometimes reaching weights of 220 pounds, have been overharvested by both local inhabitants and poachers from Southeast Asian countries to the point of extinction near

Box 7-A.—Culture of Tridacnid Clams

Considerable interest exists in the Pacicultivregion in the clams (Tridacnidae family) in order to replenish and manage natural stocks (176)ovide a to density culture opportunity. Although most clams require adequate supplies of limiting culture in the tropical islands to certain areas with alde popul tridacnids derive most of their nutrients from symbiotic id@ cells within their mantle and can therefore survive and grow on coral reefs with low populations of algae. Research cinethat these are the fastest-growing bivalve mollusks; they provide large quantities of with e minimal input (74).

Technologies for spawning and larval rearing of these species have recently developed (67,74,75). A variety of studies are under way in Micronesia and nearby areas on larval biology (51), the status of natural stocks (77,109), their growth rates in natural habitats (18), and reproductive biology (19). Advances in clam breeding are likely to be made in the next few years which will reduce the costs of seed clams and improve the economics of culture.

Tridacnid culture currently is practiced on a pilot scale in Palau, Yap, and Pohnpei and is planned in Truk and Kosrae. At present only experimental hatcheries exist; development of local hatcheries is required for widespread application.

Methods for hatchery culture of four of the six species of Tridacnidae have been developed and transplants have been made to Guam, Hawaii, Marshalls, Pohnpei, Yap, and the U.S. mainland; requests have been received from government representatives in American Samoa, Mexico, and the Caribbean region (74). Outplanting of trial shipments of juveniles produced in a hatchery in Palau appear promising, but the technology for more intensive of Tridacnid clams has not yet been fully developed or tested.

Clams require a suitable substrate and most cannot be grown off-bottom culture systems. Therefore clam Tridacnidae or other of clams would require careful site selection. Nevertheless, clams might be grown in ventures in isolated island areas and contribute to local food supplies as well as income.

some islands (95). The two largest clams, *Tridacna gigas* and *Tridacna derasa*, have been placed on the International Union for the Conservation of Nature and Natural Resources (IUCN) endangered species list (154). *Tridacna gigas* still live in the RMI and Palau, but are no longer are found near Pohnpei or in the Marianas, although fossil shells have been seen in these areas (80).

Giant clams are unique among farmed animals in that they are autotrophic—they feed themselves—through symbiosis with algae embedded in their mantle. Exposure to sunlight allows the algae to synthesize food for the clam, thus they do not require artificial feeding as do other species (154). This capability also makes giant clams well-adapted to the sunlit waters of low nutrient coral reefs, especially near atolls. The annual production of edible meat per acre from giant clams exceeds that provided by tilapia and nearly reaches that of mussels (75).

The basic technologies for both intensive and extensive giant clam farming now exist. Hatchery techniques developed at the Micronesia Mariculture Demonstration Center (MMDC) in Palau employ natural spawning of clam broodstock and rear clams to the juvenile stages (0.4- to 0.8-inch shell size) in seawater raceways. By using plankton-rich lagoon water there is no need for feeding, but the success rate in breeding and rearing juveniles to the macroscopic stages varies. Little capital investment beyond the cost of juveniles and protective clam cages for the earliest stages is required for the ocean grow-out phase of giant clams, This phase seems technically simple and clams of "grow-out size" appear to have few predators. Tim-

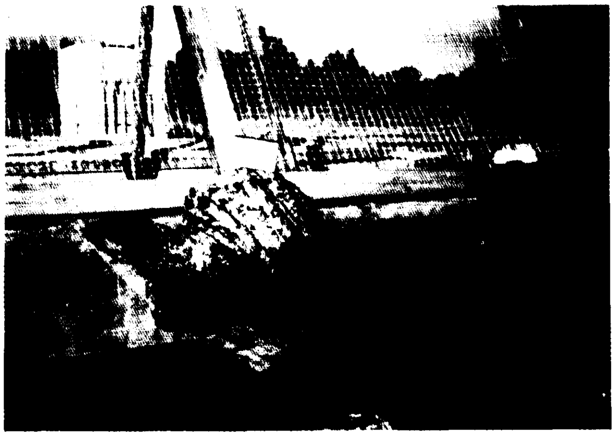


Photo *credit: Office of Technology Assessment*

Giant clams, immortalized incorrectly as “diver-trapping” denizens of the deep in children’s cartoons, have been overharvested throughout a significant part of their range. Research on culture techniques for giant clams are ongoing in a number of U.S.-affiliated Pacific islands.

ing of the outplanting of clams to maximize benefits of nonreproductive periods of major clam predators (e.g., the snail Cymatium muricinum) and, if required, manual removal of predators from nursery trays can ensure low predation mortality rates (145). Still, with a normal grow-out phase of 3 to 5 years, the effects of giant clam reseeding efforts will not be apparent for at least a decade (154).

Trochus.—Technology for mass culture of trochus also was developed at MMDC (72). It is being transferred to Pohnpei where it could be applied to reseed the regions depleted reefs through a program similar to trout fishing enhancement programs in the United States. However, reseeding trochus could conceivably lead to reductions in populations of herbivorous reef fish as a result of depletion of standing algal crops. Although trochus has been widely introduced without obvious disruptions, no data are available on interactions between populations of large herbivorous snails and herbivorous reef fish. Work to gather these data could be undertaken.

Sea Turtle.—All four species of sea turtle found in the U.S.-Affiliated islands are listed as threatened or endangered species; thus, exploitation is prohibited or regulated. At selected sites during the turtle nesting season, hatchlings could be captured and retained in mesh pens or tanks, maintained until they pass the stage of high vulnerability, and then released to the ocean. Turtles are raised for release at the MMDC. While wild turtles take between 20 and 50 years to reach sexual maturity, turtles in artificial culture systems may reach sexual maturity in 10 to 12 years *(33)*. The ecological impact of releasing large numbers of young, sexually mature turtles to the ocean has yet to be studied.

Queen Conch.–Most reseeding efforts in the Caribbean have focused on the queen conch. Natural stocks have declined due to heavy fishing pressure throughout the region. Conch hatcheries have been established in the Turks and Caicos, Bonaire, Venezuela, Mexico, and at the University of Puerto Rico (Mayaguez). To date, the viability of restocking operations for queen conch has not been demonstrated, though it is technically possible to develop hatchery operations adequate to support a release program (143). Preliminary data indicate a possible positive impact of stocking, but only if the stocked cohort has adequate habitat and is protected from fishing pressure until after it reaches reproductive age (4,11,79).

Coconut Crab.—Populations of coconut crab (Birgus *latro)*, highly prized throughout the Pacific, have decreased considerably and may be extirpated on some islands. The adult crab spends most of its life ashore, while the larval stages are thought to be spent in lagoons or within reefs. Thus, changes in these environments may affect the coconut crab. The mature animal possesses a large claw which it uses to open coconuts and extract the coconut meat. An on-going research program funded by the Australian Centre for International Agriculture Research (ACIAR), is investigating the potentials of farming this species and reintroducing it regionally (95).

Opportunity: Conserve Nearshore Resources

Ultimately, maximum economic yield cannot be attained in an open access fishery (129). Development efforts directed toward increasing the catch without regard for sustainable yield in the Caribbean appear to have resulted in overfishing of shallow-water reef fish stocks, and probably of conch and spiny lobster as well, Black coral fisheries are currently under study and/or management in the USVI and Puerto Rico, and harvesting of corals and other sessile or sedentary animals is restricted in these islands by various Federal and commonwealth statutes. All four species of sea turtle commonly occurring in the islands are protected by living within Federal waters, or by their status as threatened or endangered species. Other methods of restricting harvest of particular species include:

- restricting access to fisheries;
- restricting efficiency of harvest efforts;
- restricting harvest seasons, sexes, or sizes; and
- restricting markets for products derived from certain species.

In addition, many critical marine habitats fall within protected parks and recreation areas and, thus, certain populations are protected from overexploitation (168). Identification and protection of habitats critical to maintenance of important fishery stocks is a method of conserving nearshore resources to ensure a sustainable yield.

Restrict Access.—Action to prohibit a portion of current fishermen from further participation in local fisheries politically is not realistic; freezing participation at current levels might be more acceptable. More rigorous constraints such as fishing licenses could be applied to resources not heavily utilized now. Such restrictions could obviously be modified from time to time as better information became available on resource abundance,

Common objections to limited entry measures are reduction in available jobs and possibly reduced supply of seafood due to decreased numbers of fishermen. These objections do not apply to the activities proposed here because:

1. the number of fishermen would be stabilized, not decreased; and
2. the supply of seafood should be expected to increase due to improved management of overexploited resources and identification of underexploited stocks.

Restrict Efficiency of Harvest Efforts.-The Caribbean Fishery Management Council has jurisdiction over Puerto Rico and the USVI, and has prepared management plans for spiny lobster and shallow-water reef fish fisheries. These plans place restrictions on types of gear that may be used for harvest, and establish minimum permissible sizes for harvested individuals of particular species, (Other restrictions, e.g., closure of seasons or fishing areas, are also possible, but have not been enacted.) These plans provide an excellent starting point for sustained development of nearshore marine resources in Puerto Rico and the USVI. Their primary shortcomings have been that they are intended to focus on single species or groups of species rather than entire systems, and must address currently exploited species before consideration can be given to underexploited resources. Also, these plans must be adopted and enforced by the respective island governments (94).

Harvest Restrictions.—Experience with overexploitation has also led to measures to conserve marine resources in Micronesia. For example, a few years after discovery of topshell as a source of nacre, harvests began to decline in a pattern similar to that of pearl oyster. Island governments attempted to sustain populations at fairly constant levels by imposing regulations that controlled the length of the harvest season and the minimum size of shells that could be harvested (107,108).

Although most island governments have regulations on the harvest of edible or other commercially valuable shells, few have enacted protective measures for species involved in the ornamental shell trade. Monitoring of this trade among FAS is nonexistent, Additionally, there is essentially no management of the aquarium fish trade,

Restrict Market for Certain Species.—Overexploitation of corals and shells in some areas have adversely affected the associated coral reefs and resulted in bans on exports of corals and shells (27,110,172), Most island governments have legislatively restricted harvest of coral for commercial purposes, and only a few small-scale coral specimen enterprises cater to the tourist industry (70). There is now no commercial export of specimen corals from the U.S.-affiliated pacific islands.

Harvest of precious corals in American Samoa and Guam is regulated by a fishery management plan under the Magnuson Fishery Conservation and Management Act of 1976. However, enforcement of regulations is rare. The Guam Division of Aquatic and Wildlife Resources has established permit requirements for coral harvesting and harvest site restrictions. Harvesting is monitored as closely as possible under current manpower restrictions (155).

Protect Critical Habitats.—Ultimately, some extremely sensitive areas and critical habitats may have to be given special status as marine parks and reserves. Coral reefs, which are highly vulnerable to degradation, are prime candidates for such protection. Mangroves, seagrass meadows, and other important fish spawning and nursery areas are also excellent site candidates.

The establishment of protected areas for ecosystem preservation has long been applied to land areas. In recent years, interest in the establishment of marine parks and sanctuaries has grown. However, definition and protection of marine parks can be difficult because of the interrelated nature of island ecosystems. Marine park definition must consider not only the nearshore habitats (coral reefs, seagrass meadows, shallow bottoms, and mangrove and estuarine environments) but also the terrestrial habitats that are inextricably linked to and ultimately affect the reserve's quality. Thus, watershed management becomes highly important to the integrity of the marine park (140).

Additionally, sociocultural factors, including traditional use rights and subsistence gathering, may further complicate successful siting of marine reserves for some islands. Opportunities exist for developing flexible reserves that may ameliorate these constraints. For example, a rotating marine reserve has been established in New Caledonia. Parts of the barrier reef are closed sequentially for 3-year intervals, thereby allowing each area a 3-year regeneration period and continually maintaining an accessible reef area (36).

Ideally, the marine park core area should be large enough to be self-replenishing for all species the reserve is designed to protect; the implication then is to establish a core area with the highest degree of diversity (140). If successfully sited, established, and managed, marine parks and reserves may not only protect critical habitats but also provide a source of recruitment for restocking exploited surroundings.

As yet few such areas exist in the U.S.-affiliated islands. A wildlife preserve in Palau (Ngerukewid Wildlife Preserve or the Seventy Islands Park) contains considerable marine areas in addition to the Limestone Islands, and a federally designated marine sanctuary has recently been established in American Samoa (Fagatele Bay). Trunk Bay (St. John) and Buck Island (St. Croix) and the Virgin Islands National Park (St. John) have protected marine areas in the USVI, and several sites are proposed as Federal or State marine sanctuaries in Puerto Rico (e.g., Mona Island).

Marine parks can serve numerous purposes. National marine sanctuaries are designated to serve the multiple purposes of research, public education, recreation, and preservation of ecological or esthetic values. Sanctuaries are designed to provide protection and beneficial use of distinctive marine resources that require comprehensive, geographically oriented planning and management (158). The Fagatele Marine Sanctuary in American Samoa may have considerable potential for environmental education and visitor recreation (9).

However, the needs for nearshore ecosystem protection, public education, and research must be carefully balanced. Overuse, for whatever purpose, can degrade nearshore ecosystems. For example, tourism impacts in Trunk Bay, USVI, have resulted in severe degradation of corals. Regulations to control access and activities are extremely important. In the Pacific, such regulations may be patterned after traditional customs that effectively conserved the environment prior to westernization (81).

While fishing efforts might be limited by any or all of the above methods, effective policing of domestic or foreign fishermen is extremely difficult (151), particularly in tropical areas where there is an abundance of species, large numbers of fishermen and boats per unit of catch (relative to western commercial fisheries), and a paucity of catch and market data. Biologists also know much less about tropical species than they do about temperate marine food fish and are thus poorly equipped to make useful decisions concerning their conservation.

Government enforcement of environmental laws is lax in some U.S.-affiliated Pacific islands and may be further impeded by fishermen who may resent the loss of their traditional fishing rights and the imposition of strange new laws. In many cases regulatory regimes do exist, but control of fishing effort may require a more coherent arrangement than the existing pattern of fishing agreements (151). Establishment of the Forum Fisheries Agency Regional Register represents a major advance insofar as it has provided a regional sanction ensuring compliance by foreign vessels with the fisheries laws of island governments (151).

Opportunity: Learn From Traditional Conservation and Management Systems

Fisheries science is a relatively modern discipline in western societies; however, management measures have been traditional village activities in many Pacific islands (95). Fisheries regulations in developed countries usually are directed simply towards protecting the target species, whereas many traditional measures were designed to manage the species' habitat and ecological relationships (95). Despite attempts to protect overexploited resources, western culture techniques may be inappropriate for management of multispecies tropical reef fisheries. Traditional use rights in fisheries (TURFS) is effectively the principle of limited entry traditionally practiced by the Pacific islanders. This developed almost certainly because they depended on the sea for most of their animal protein and because the marine resources around small, isolated islands are so vulnerable to overexploitation (81).

Basic marine conservation measures associated with TURFS include closed seasons and areas, and gear size and catch restrictions (85). TURFS continue to play a major role in some island cultures (e.g., Yap, Palau, the outer Caroline Islands); a diminished but significant role in others (e.g., Truk, Samoa); and have lapsed entirely in others (e.g., Marianas, Pohnpei, Kosrae). Knowledge of these reef and sea tenure systems is fragmentary and studies performed as little as 10 years ago may not reflect adequately the state of affairs today because of the rapidly changing island economies.

Traditional management and conservation systems have been seriously disrupted by the introduction of modern fabrication, harvest, preservation, and transport technologies. New materials and technologies have obviated the traditional long apprenticeship period. Consequently, the social status of fishermen has diminished and traditional teachings on the interdependence of men and the environment may no longer be passed on. This disruption has been accelerated by the economic pressures of commercialization which accompany fast-growing urbanization. The public property, open-access philosophy embodied in U.S. marine law directly conflicts with traditional island conservation mechanisms; thus, the effectiveness of modern conservation legislation has been constrained from the outset and probably has been diminished in effectiveness (81).

Regulations recognizing traditional marine tenure in the islands could be established. To be successful, management schemes must be socially acceptable. Furthermore, any legislation that weakens marine tenure laws also reduces the ability of the owners to police these resources—something they do voluntarily at no cost to the government if their rights are secure. Such legislation therefore would increase the government's regulatory responsibilities and place serious new burdens on already understaffed and underfunded fisheries departments (81).

Management schemes could formally recognize traditional marine tenure in the islands. Sea tenure and exclusive reef ownership underlie traditional island fisheries management, and private enterprises, such as seaweed and giant clam farming, pearl culture, and trochus fishing, probably would respond appropriately to exclusive ownership. Further, families, clans, and communities might be more willing to invest in the protection and acquisition of marine resources and might engage in more innovative resource development efforts due to a greater confidence in their chances for a return on investment (23).

Where they currently exist, formal recognition of TURFS may contribute to fisheries conservation in the FAS, but they cannot guarantee it. Systems of traditional fishing rights are very diverse, and some are more useful in fisheries management than others. While TURFS work against maximizing employment in the short term, in their absence, employment might be affected much more severely in the long term. Where TURFS impede full exploitation of marine resources, but have strong community support (a characteristic of subsistence economies), it probably would be politically unacceptable to abolish them. Where weakly held TURFS impede full exploitation, they might be modified to facilitate greater harvests, but hastening their demise would rarely be justified.

TURFS do pose an impediment to commercial tuna fishermen who obtain bait fish from TURFS. The formalities of requesting and granting permission take considerable time and some tuna fishermen have become so frustrated they have left valuable resources unharvested (83). TURFS also may impede nearshore harvest of migratory pelagic species. A fisheries "progress report" for Truk (133) reported that fishermen did not buy nets to catch abundant mackerel that traveled in schools in the lagoon because the ownership of fishing grounds prevented their pursuing the schools. One possible solution to this is to interest representatives of different TURFS in cooperative arrangements—for example, in the joint purchase of a single net to be used cooperatively to harvest the migrating fish.

Opportunity: Emphasize Local Management of Marine Resources

Even in places where traditional authority does not exist, is faltering, or has disappeared, local management initiatives, if instituted, could have a positive impact not only on fisheries, but also on recreational and tourism sectors. Enforcement responsibilities probably would be assumed by villages and other local organizations if the groups firmly believe that the management strategy was beneficial. For example, village councils in American Samoa could take a more active role in conservation and management (170).

Fisheries cooperatives are another possible means of using nontraditional but still local authority to pursue management objectives. The Japanese took this route, gradually transferring TURFS from traditional village leaders to village-based cooperatives. However considerable expertise—cultural, biological, and economic—is required to adapt cooperative forms of enterprises to island social settings (23).

Of particular relevance are the activities of the Virgin Islands Resource Management Cooperative (cf:139), which is currently involved with developing management strategies for the Virgin Islands Biosphere Reserve. A variety of potential benefits to nearshore fisheries are associated with this activity including improved information on major stocks and ecosystem processes, establishment of breeding reserves for heavily exploited or threatened species, and provision of information needed for rational development of underutilized species. Because of the commonality of marine resources, these benefits may also be significant to other Lesser Antillean countries, and prospects for a multisite regional Biosphere Reserve are being investigated.

Summary

Considering the limited extent of nearshore resources in the U.S.-affiliated islands and indications of probable" overfishing, credit, and incentive programs for purchase of vessels and gear (e.g., the program for Fishery Credit conducted by the Puerto Rican Agricultural Credit Corp.) probably are not conducive to sustainable development of fisheries unless the fishing effort being capitalized is directed toward underexploited resources or areas (e.g., offshore banks or seamounts).

The approach to nearshore fisheries development in the Pacific islands also has been shortsighted. Development has been viewed as being synonymous with the commercialization of the subsistence fisherman. Little attention has been paid to either the long- or short-run opportunity costs of this "development." Management and conservation regulations have usually pursued a species-specific, gear specific, or seasonal format. Enforcement costs have been high and results negligible,

POTENTIAL STRATEGIES FOR AQUACULTURE DEVELOPMENT

Introduction

Aquiculture, the cultivation of aquatic organisms in fresh, brackish, or marine waters, began at least 2,000 years ago in China and developed into a widely accepted procedure for producing food in India, Malaysia, Indonesia, the Philippines, and elsewhere in tropical and subtropical Southeast Asia (58). A primitive form of aquiculture—holding juvenile fish in coastal impoundments, sometimes with supplemental feeds—was practiced traditionally in various island groups, including Hawaii. The remnants of early fish traps and impoundments can be found on many islands, but few are currently in use (58),

Aquiculture can range from the culture of simple (e. g., single-cell algae) to complex organisms (e. g., sea turtles). Similarly, systems range from nearly self-sustaining extensive ponds to high energy-, capital-, and labor-intensive hatcheries and raceways. Markets are as diverse as products: species may be maintained in ponds as a means of storing protein for subsistence consumption, or cultured to supply local demand (e.g., tilapia) or distant specialty markets (e.g., phycocolloids). Aquiculture's history and range of potential uses, however, conceal a considerable number of modern failures; it should not be viewed as a ready solution for social and economic problems faced in the islands today (163).

Most U.S.-affiliated tropical islands have an active interest in the development of aquaculture. Goals commonly cited for aquiculture development include:

Photo credit: Office of Technology Assessment

This experimental giant clam hatchery in Pohnpei employs culture techniques developed at the Micronesia Mariculture Demonstration Center in Palau. Success of this experimental hatchery may lead to expanded operations in Pohnpei.

1. to increase the availability of animal protein to improve nutrition;
2. to increase job opportunities and income generation in rural areas;
3. to create an additional tax base to generate government revenues;
4. to generate export dollars; and
5. to supplement marine resources by providing seed stock for reseeding nearshore areas that have been depleted by overexploitation *(163),* and to compensate for decreasing fish catches,

Although benefits in total dollar value would be greatest on large islands like Puerto Rico and Guam, and least on the small islands and atolls, on a percentage basis a small increase in employment or food supply on the small islands might be of greater relative importance (58).

A large number of tropical and temperate species have potential for aquiculture in the U. S.-affiliated Pacific islands. A Pacific islands mariculture conference (69) was convened some years ago to advise in the development of aquaculture in this region. Notably, aquiculture has been proposed for food production, phycocolloid production, water treatment, and bait fish production. A number of Federal and local agencies and educational institutions have funded aquiculture research in each of these areas. Guam has even completed an Aquaculture Development Plan (52) and funded feasibility studies for the operation of a multispecies hatchery (cf:5,154).

Neither Puerto Rico nor the USVI has an extensive history of aquiculture development, although both seem to have good potential for aquatic farming. Aquiculture development in Puerto Rico began around 1970 when research was initiated with tilapia, catfish *(Ictalarus punctatus),* and freshwater prawns *(Macrobrachium rosenbergii).* The island has excellent potential for development of viable aquaculture projects involving a variety of species (59,128). In general, it has a stable, well-developed infrastructure. Materials and services, including research, extension, and skilled and unskilled labor are available.

Overall, Puerto Rico has a number of suitable sites for pond, pen, and raft production units for freshwater and especially marine species. The USVI seem to have much lower potential for land-based aquiculture development, being much smaller. In the USVI, research and development have largely focused on a project in St. Croix to evaluate the potential of using nutrient-rich deep ocean waters pumped to shore to grow algae for feeding to various species of shellfish (138). While technically feasible, the economics of the system and species were not promising. There does not appear to be any other significant aquiculture development in the USVI. However, the potential for development of saltwater hatcheries and cage/pen culture of fish in coastal waters has not been adequately researched.

In spite of the long-term interest and previous work, few commercially viable aquiculture ventures exist in the U.S.-Affiliated Pacific islands at present. A few have developed in Guam, which has a relatively large local market and sophisticated technological base. Significant research efforts are under way to develop cultivation of phycocolloid-bearing seaweeds (Guam, Kosrae, and Pohnpei), freshwater prawns (Guam), giant clams (Palau), and rabbitfish (Guam and Palau) (119). Other species identified as having particular potential for aquiculture development in the region include marine shrimp, pearl oysters, milkfish, mullets, tilapia, and bath sponges.

Many aquiculture projects have failed in the U.S.-affiliated islands. Many efforts were designed as research and development or demonstration projects and, as such, were not designed to show a positive cash flow, Others, although workable, were poorly executed and some projects have been supported even when impractical or when they exhibited a suboptimal use of available resources (33). Most resulting ventures have been unable to market products profitably, eventually develop cash flow problems and subsequently fold. Aquaculture projects supported by international assistance agencies commonly are developed by temporarily assigned, outside consultants. On their departure, projects may fold due to lack of follow-on assistance, or lack of local technical and business management skills (163). Components such as training, economic analysis, commercial development, and technology transfer often were missing in the failed aquiculture projects (163).

Local residents who want to grow food or increase their income by raising fish or shellfish need ambition and a real interest in aquaculture, as well as a simple, thoroughly proven low capital cost system for growing the selected species, readily available low cost inputs (feed and labor) and a local market. Commercial-scale farms require a thorough feasibility study, sound business and financial management, adequate financing, enough land at an acceptable cost, identified markets, and adequate technical staff with culture expertise.

The primary adverse impact of past aquaculture activities has been the introduction of exotic species, such as tilapia and the Malaysian freshwater prawn into the wild in Puerto Rico. The introduced *Oreochromis mossambicus* is now considered a pest because its inferior qualit y as human food has created consumer resistance to the cultured species *(Tilapia nilotica).* There may also be ecological consequences from introduction of exotics, such as the displacement and extinction of endemic species, particularly since island species generally evolved under less severe competitive pressures than continental species.

Such scenarios are even more likely in the relatively fragile and little understood inland aquatic habitats of the islands. Pests or diseases also can be introduced along with the desired exotics, which can have significant effects on local related species. Therefore native species are preferred to introduced species for aquaculture whenever possible (119).

Aquiculture activities require a source of juveniles for stocking. Juveniles can be supplied from broodstock matured and spawned in captivity or collected from the wild. Because most locally available species already are exploited to some degree by the local populace, hatchery production of young rather than collection from the wild is desirable for most aquiculture in the U.S.-affiliated islands. While hatchery, nursery, and grow out can be integrated for large operations, commonly hatcheries are centralized to provide juveniles for a variety of grow-out situations and farms (33),

Potential Strategy: Develop Sea Ranching

One form of sea ranching involves taking juveniles or other stock from the wild and growing them under managed conditions (154), Most species potentially suitable for restocking also are considered for sea ranching. Tropical invertebrates, mainly mollusks, are candidates for tropical island sea ranching, in contrast to the temperate zone where migratory fish (salmon) are the primary target (12). For example, in Manus (Papua New Guinea), giant clams are collected and held in walled reef areas until fishing is bad, providing a secure food source and a limited form of conservation. This form of culture does not promote growth, but it does establish property rights, which may result in the mollusks being held longer before harvest than if they were not in "ranches" (154). A 1982 review of recent conch mariculture efforts (13) indicated that commercial conch culture was not a viable proposition, but conch ranching may offer potential. However, success with this technology carries with it the risk that natural stocks will be collected at a rate faster than otherwise, leaving few for breeding in common areas (154).

The success of sea ranching depends on the availability of wild broodstock, accessibility of individuals to collect and ranch, property rights to the species within an area, incentives to conserve breeding populations, and enforcement measures to protect wild and ranched populations from poaching. To foster success, such programs could be accompanied by strong measures to control fishery pressure, possibly with habitat protection and/or enhancement,

Potential Strategy: Develop Extensive Culture in Natural Waters

Low technology extensive culture systems may be most appropriate where available natural nutrient abundance is adequate, and minimization of capital expenditures and production costs are major concerns. However, the reduced inputs and lower stocking densities of extensive culture systems generally is accompanied by reduced yields, In a true extensive culture system all of the species' nutritional requirements are derived from natural sources without human intervention. Thus, islands with greater terrestrial resources and therefore greater levels of available organic matter may

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have larger potential for extensive culture systems. A number of species have been identified as appropriate for extensive culture systems including oysters and seaweeds (58).

Opportunity: Bottom and Near-Bottom Culture of Sedentary Species

Intertidal or subtidal culture of high densities of sedentary species on or off bottom is attractive, but practical only where natural supplies of phytoplankton provide adequate nutrition—both quantity and quality—for filter-feeding mollusks or substrates that are suitable for seaweed culture. This generally occurs only in areas receiving nutrients from the land (58). Aquiculture on coral reefs, or of reef-dwelling organisms, is in the early stages of development and few species of animals or plants are currently cultured on a commercial scale.

At present, a red algae *(Eucheuma* sp.) is cultivated commercially in the Philippines and a few other areas for the production of carrageenin (39,40). Techniques for cultivating Trochus have been developed (72), and hatcheries are planned or operating on a pilot scale in Palau, Australia, New Caledonia, and the Cook Islands. Members of the Tridacnidae family can now be cultivated in sufficient numbers for commercial purposes (75,117). In the Bahamas, a significant recent development has been the recognition that the giant Caribbean king crab *(Mithrax spinosissimus)* is herbivorous, feeding mostly on algal turfs, is easily reared, and grows to at least 2.2 pounds in its first year (134).

Oyster Culture.—The culture of edible oysters is a traditional form of aquiculture throughout Asia, and methods now in use could be readily applied anywhere that the aquatic environment is satisfactory. Inputs are relatively simple since oysters obtain their own feed from the water. In most cases native species can be used, although some are too small for the market. The introduction of acceptable species from similar tropical environments may also be possible, although care should be taken to avoid introduction of parasites, diseases, predators, pests, or competing species.

Oysters require substantial quantities of phytoplankton, and waters slightly less saline than those of the high seas. Thus the potential for their culture is higher in the temperate than the tropical zone. Nevertheless oysters occur in isolated tropical locations, especially near the large mountainous islands which provide substantial amounts of terrigenous nutrients and freshwater to nearshore areas. These areas may have considerable potential for development of family, collective, or commercial oyster farms.

The establishment of oyster farms requires careful site selection and preferably pilot-scale tests. Also the method of culture will depend on the suitability of the substrate, the exposure to storms, and other biological factors. In some places, off-bottom culture is used to avoid predators and to increase growth rate. In this case the oysters can be suspended below fixed racks or floating rafts (59). Parasite infestations have terminated most oyster culture projects in the Pacific islands (162).

Aquiculture in Puerto Rico includes a small oyster fishery and some low-technology efforts to develop oyster farming based on research in the 1970s (169). The limited suitable area, mainly in Boqueron Harbor, precludes the development of a large oyster industry.

Pearl Oyster Culture.—Potential exists for profitable farming of pearl oyster species at various places in the Pacific islands. These species have been important items of commerce in Oceania for centuries (123). This type of cultivation is especially suited to atoll lagoon environments. Spat are reared in polyethylene net baskets until they reach 3.5 inches in diameter. Then, they are affixed to strings suspended from underwater platforms where they are left to grow for 3 years (145).

Research was conducted over a period of approximately 3 years by scientists at CNEXO (now EFRIMER) in Tahiti to develop technologies for the mass production of pearl oyster spat. However, oyster hatchery technologies developed for other species apparently were not successful when applied to the pearl oysters, so the research was discontinued (119). Since hatchery techniques for pearl oysters have not been developed, seed stock is obtained from natural spatfall. One problem with this method is that spat of the desirable pearl oyster, P. *margaritifera,* is often mixed with and, at a small size indistinguishable from, spat of smaller, undesirable species (119).

Although some attempts have been made to develop this industry in Palau, no pearl culture activities are ongoing in the U.S.-affiliated Pacific islands today. The success of this industry in Polynesia, however, and the research under way there indicates that the culture of pearl oysters has potential to contribute to developmental efforts in other areas of the Pacific, including Micronesia and American Samoa. The development of this industry in Micronesia or Samoa would require training in the techniques of inducing the oysters to form pearls. The Tahitian Government is sponsoring experts to train culturists in these techniques so, presumably, the technology could be transferred to other areas (119).

Queen Conch.—The most important edible mollusk in the eastern Caribbean, the queen conch *(Strombus gigas),* is seldom found below 100 feet, and is highly vulnerable to overfishing. There have been several efforts to develop technologies for conch culture, but a review of progress in the field (13) concluded that commercialization does not seem economically feasible and a similar conclusion was reached at the November 1985 meeting of the Gulf and Caribbean Fisheries Institute (61).

Seaweed Cultivation.—Some 10 species of marine benthic algae reported from the U. S.-affiliated islands may have the potential to yield harvestable commercial products (156). Seaweed cultivation may be particularly well suited to remote islands, since the thalli can be sun-dried and stored for many months.

The red algae genus *Eucheuma* has been farmed successfully on a pilot scale *in* Pohnpei (41) and Kosrae (146), but no marketing has been conducted. *Eucheuma* is used as a source of carrageenin gel in the food, pharmaceutical, and cosmetic industries. As the phycocolloid industry is limited by the supply of seaweed, the market situation for seaweed cultivation seems promising. However, high freight costs restrain the financial return to growers, and Asian nations may have an insurmountable advantage over small Pacific islands in terms of scale economies and labor costs (95), that may affect the long-term economic viability of commercial seaweed mariculture. Some attention has been given to the cultivation of seaweed as food for other organisms (53) (i.e., rabbitfish grown in association with algal turfs), however, this is likely to remain only a peripheral activity.

The Smithsonian Institution's Marine Systems Laboratory (MSL) has been active in mariculture research in Caribbean reefs. Research efforts have led to development of techniques for algal turf farming on artificial surfaces. While the harvested algae has a variety of purposes a primary interest exists in using it as a food source for the Caribbean king crab *(Mythrax spinosissimus).*

The MSL and the Puerto Rico Corporation for Development of Marine Resources (CODREMAR) and the University of Puerto Rico (Mayaguez) will be cooperating in the Caribbean king crab mariculture demonstration project sited on Vieques. Puerto Rico's Secretary of Natural Resources has committed funding to the project. The U.S. Navy has given tentative approval despite the project's siting in a naval training area on Vieques. The techniques involved in Caribbean king crab mariculture also maybe applicable to culture of other marine species. Further, the demonstration project may provide information necessary for increased development of Puerto Rico's mariculture efforts (134).

Potential $trategy: Culture of Marine Fish in Enclosures

The culture of marine species in floating net pens or cages is applicable to any island where space can be obtained in estuaries or bays protected from storms. This system requires no pumping of seawater and has low initial costs (58). This culture method is used in many other coastal areas (i.e., Japan, Norway, Scotland, the United States, and Canada], and several tropical species might be grown in cages or enclosures in the Pacific or Caribbean islands. However, the potential for conflict between mariculture practitioners and other reef and lagoon users exists (155), and may require development of mechanisms to ameliorate or prevent such conflicts.

Dolphinfish, for example, could be grown at hundreds of sites on the islands of the Pacific and Caribbean, since it occurs throughout the tropical seas. Field trials indicate good potential for growing dolphinfish in large floating nets or cages. However, the viability of such culture has not been determined. The chief unknowns are the availability and costs of feeds, the feasibility of operating local hatcheries, and the logistics of supplying inputs and processing and marketing the products.

Several species of grouper (Serranidae family) are grown commercially or for home use in enclosures or cages in Southeast Asia. Groupers occur throughout tropical and subtropical seas and are well accepted as food. A need exists for research to determine if methods used in Southeast Asia are applicable and to evaluate markets, availability and cost of feed and other inputs, development of locally produced feed, and wild stock availability.

Puerto Rico has an extensive shoreline of nearly 300 miles with numerous inlets and small bays which provide protected waters that may be suitable for anchoring floating pens or cages. Guam, surrounded by a surf-swept fringing reef, has few such areas, precluding most forms of floating net pen cultures there. On the other hand, hundreds of narrow channels and bays exist between individual islands of Palau. There is potential there for floating net pen culture of several species; local experience with rabbitfish culture would provide a sound basis for culturing this species. Sites are available, but to a considerably lesser extent, in the USVI, the CNMI, FSM, and the RMI. Because of heavy reliance of some of these islands on fish imports, evaluation of this means of increasing domestic production could have merit.

Most investigations of cage culture potential for Caribbean finfish appear to have been done in Martinique where preliminary results indicate that yellowtail snapper (Ocyurus *chrysurus),* permit *(Trachinotus falcatus),* palmometta *(Trachinotus goodei],* and European sea bass *(Dicentrarchus* sp.) have commercial potential. Other species under investigation elsewhere and deserving attention for the U.S. Caribbean include redfish, epinephilid groupers, striped bass and its hybrids, tilapia, dolphinfish *(Coryphaena* sp.), and amberjack.

Potential Strategy: Pond Culture

Traditionally, freshwater fish and shellfish in Southeast Asia were grown in large shallow ponds supplied with fresh or brackish water. The modern version of this system is a series of ponds from less than 1 to as many as 50 acres each with a depth of 2 to 3 feet, supplied with freshwater at 10 to 50 gallons per minute per acre from wells (bore holes), streams, or irrigation canals *(58).*

Freshwater ponds are used for growing various fish and crustaceans including freshwater prawns, tilapia, catfish, carp, ornamental fish, crayfish, etc., in monoculture or polyculture systems. Freshwater pond culture of eels, carp, and freshwater prawns has been developed on Guam and could be expanded (58). Since water is scarce, several species might be cultured in the same pond and the water reconditioned or reused.

In Southeast Asia and in some of the Pacific islands such as Hawaii, marine or estuarine fish and some shellfish were grown in shallow coastal ponds which could be flooded at high tide. This technology has now been applied in many countries to provide low-cost ponds for aquiculture of marine shrimp and various marine or brackish water fish.

Coastal farms should be sited on clay or other relatively impermeable soil. Many ponds built earlier in mangrove swamps were found to be unusable. The swamps' acid sulfate soil made pond waters highly acid, which was detrimental to fish health and growth. To avoid this, ponds must be constructed inshore of mangrove forests, even though ponds must then be pumped full (58). Recent studies in the Philippines have developed methods of pond-building in acid soils (162).

Freshwater Prawn.—The culture of the giant freshwater prawn *Macrobrachium rosenbergii* on a small commercial scale has been accomplished in Guam, and pond production of the species has proven satisfactory (55). *M. rosenbergii* has also been cultured on an experimental scale on Palau. Areas especially suitable for *Macrobrachium* culture occur on Pohnpei and Palau as well as Guam, although freshwater is in severely limited supply during the dry season. In Pohnpei, freshwater might be adequate for small-scale prawn farming. Since the development of hatchery techniques for mass production of post-larval stages, interest in prawn culture has been considerable. However, no operating hatcheries exist in Guam or Palau at present, and pond operators have been dissatisfied with Hawaiian supplies of post-larvae. In addition, past trials have exhibited relatively poor performance and interest has waned (162).

Although *M. rosenbergii* occurs naturally in Micronesia only in streams of Palau (112), several endemic species of *Macrobrachium* occur in freshwater habitats of the region, including another large species, *M. lar*. Work has focused on this species with the idea that ponds could be stocked with post-larvae and juveniles from local streams. The simultaneous introduction of predators and competitors poses problems (166), but to date no other source of the post-larvae exists. This species requires higher salinities than *M. rosenbergii* and is more aggressive, but is worthy of attention for cultivation on a cottage scale basis in areas where *M. rosenbergii* cultivation is not feasible.

Because of rapidly increasing prawn culture within the Pacific region, prawn culture in Micronesia probably can be developed only to fulfill local demand. Prawn aquiculture in the Indo-Pacific area is predicted to triple by 1990, which may result in an oversupplied market. Only 100 tons of the total estimated 140,000 tons is expected to be produced on Pacific islands (95).

Two early prawn farms failed in Puerto Rico, following extensive flood damage in 1975 and 1979 (58); a third discontinued operations in 1982, but was reactivated by Sabana Grande Prawn Farms, Ltd., and is now in operation with 86 acres of ponds and a hatchery (57). There is considerable interest in expansion with export to the United States and other markets.

Marine Shrimp.—Potential exists in Puerto Rico for farming marine shrimp (*Penaeus* sp.), but few large coastal tracts are available. Farms would need to include hatcheries with facilities for maturation of brood stock, since no wild stocks occur in the area. Adaptive research and pilot-scale tests to determine the applicability of Latin American technology for marine shrimp culture would be advisable,

Technical potential also exists for marine shrimp culture in the Pacific; preliminary trials have been conducted in Guam and American Samoa (119). Juveniles are not available, however, and stocks of the shrimp in shallow nearshore waters are too small to supply a hatchery. There is some potential for growing marine shrimp on the island of Babelthaup (Palau). Although suitable land is limited, small-scale farms might be established for the local market and for air shipment to Guam,

The technology of broodstock maturation is developing slowly for marine shrimp. The development of this technology will stimulate expansion of marine shrimp farming in the Caribbean islands, and possibly in the Pacific islands. The MMDC in Palau has facilities for marine shrimp culture and could be activated with new broodstock maturation technology development (33).

Mangrove Crab.—Another crustacean with potential for cultivation in the Pacific region is the mangrove crab *Scylla serrata*. Potential for its culture has been examined in Guam, but no commercial development has been realized and little interest in the species exists elsewhere in the region (119). This species is successfully cultured in Taiwan and Japan (33).

Rabbitfish.—Several species of rabbitfish (Siganidae), a prized fish throughout the Pacific are attractive candidates for aquiculture (98, 103) in ponds, as well as in natural enclosures or cages, or in association with algal turfs. They are herbivorous, juveniles can be collected from reef-flats in large numbers (91), will readily accept and thrive on commercially available pelletized diets, and survive in brackish water as well as seawater. Research efforts currently are underway in Guam and elsewhere.

Since the abundance of juveniles is extremely variable from year to year, the availability of stable supplies will eventually depend on mass production in hatcheries; the development of hatchery technologies is under way and several species have already been spawned and reared in captivity (89,132,167). Juveniles were consistently produced on a small scale at a hatchery of the MMDC in Palau for several years. Further work on reducing hatchery mortalities, and on the development of grow-out technologies is warranted since siganids bring a higher price than most other reef fish.

Milkfish.—Milkfish (Chanos chanos) are hardy and tolerate a range of environmental conditions from freshwater to saltwater, although they are most often cultured in brackish ponds. Milkfish have been successfully cultivated in several adjacent regions and are being cultured in ponds in Guam. However, wild stocks are too small to support a fry fishing industry. Areas with sufficient wild stock (e.g., Palau) have not developed milkfish culture, and export of fry from the Philippines, where milkfish culture is an economically important industry, has been banned by the government. Recently, however, aquaculturists have been able to spawn pond-reared broodstock, hatchery techniques are being developed (42), and it seems the availability of fry will increase, removing a major constraint to culture.

Mullet.—Several species of mullet may have considerable potential for development and have received some attention in Guam. Growth rates are slower than those of milkfish, but techniques for induced spawning and grow-out of the larger species such as the grey mullet (Mugil *cephalus)* have been well developed (142). The culture of juvenile mullet to market size can be economical because mullet feed largely on pond biota, requiring only fertilization. Mullet culture in the region deserves further consideration. Sources of fry need to be identified as an initial step.

Redfish.—The redfish *(Sciaenops ocellata)* is attractive as an aquiculture species since it can tolerate salinities from nearly 0 to as much as 45 parts per thousand. It can be grown in shallow ponds similar to those used for marine shrimp and prefers temperatures of 68 to 92° C. Although predacious in nature, redfish can be conditioned to feed on formulated pellets with acceptable conversion ratios. The redfish is highly esteemed as a food fish. Juvenile redfish could be obtained from a commercial hatchery in Texas and raised to adults at the site selected for the culture operations to provide brood stock (58).

Tilapia.—Tilapia, a staple food in many developing countries, are perhaps the easiest fish to grow in tropical aquiculture systems. They are extremely resistant to disease; withstand high density; and tolerate low dissolved oxygen, a wide range of salinity levels, and other adverse environmental conditions (58).

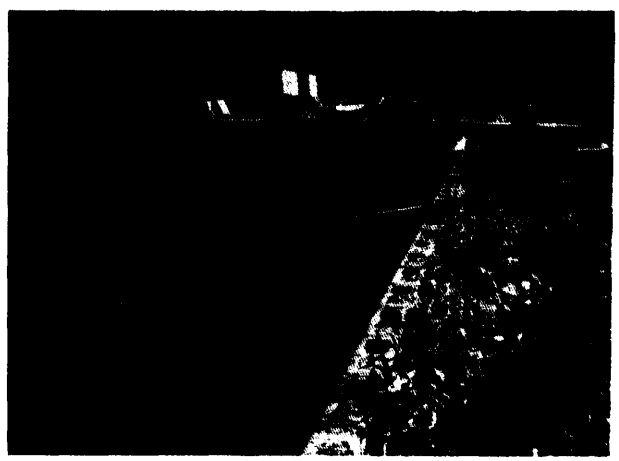

Photo credit: Office of Technology Assessment

Intensive aquiculture systems, employing supplemental feeding and high stocking density, may increase production significantly. Shown here is commercial tilapia aquiculture in Guam; peletized feed is discharged periodically from a homemade automatic feeder at the right edge of the pond.

Tilapia *(Oreochromis mossambicus)* are cultured fairly successfully on a small commercial scale in Guam and will probably continue to serve the local market. However, this species can readily establish itself in a variety of aquatic habitats, and the introduction of tilapia into islands where it does not already exist may have undesirable consequences (119). Tilapia eradication projects are underway in Kiribati and Nauru (162).

One commercial venture based on this species was started in Puerto Rico in about 1980 but was unsuccessful because of a poorly designed culture system. Research and development by the University of Puerto Rico has shown that tilapia culture with well-designed systems has much potential. Many areas in Latin America and the Caribbean islands are ideally located for large-scale culture of tilapia which might enter the world trade as frozen boneless fillets (58).

The efficiency of tilapia culture on a commercial scale depends on establishing the natural biota which provides part of the food and supplementing this with artificial feeds containing about 20 percent protein. Tilapia can be grown at lower density in family or subsistence farms without supplemental feeds or fertilization with animal manures. Production can be increased to at least 6,000 lbs/acre/year by stocking at high density and providing supplemental feed (58).

Ornamental Fish.—Potential for growing various species of freshwater and marine tropical fish for the aquarium trade exists in the Caribbean and Pacific regions. While freshwater tropical fish commonly are cultured, marine tropicals usually are collected from the wild. Species already are imported from Guam, American Samoa, the RMI, and Hawaii. To be competitive, such ventures would need to undercut production and shipping costs from other countries and production costs in Florida. In practice, most tropical aquarium farms raise several species and carefully select the best specimens for breeding purposes to maintain high quality of the product. This requires considerable expertise and strict procedures. However, this form of aquiculture is attractive because of the high value of the product, the short time required to reach market size and the small quantity of feed required (58).

Bait fish.—Extensive efforts to culture bait fish have taken place in American Samoa with monies, and in the RMI and Kiribati with milkfish (58). Results of the work in American Samoa and test fishing at sea show that mollies are acceptable as live bait for skipjack and yellowfin tuna but culture has been uneconomical under experimental conditions (22,165). Similar results were obtained from the Kiribati experimental farm. The milkfish were acceptable for pole and line fishing for tuna, however, an economic analysis of the project indicated little or no profit margin existed (163). There also is the possibility of growing native marine species such as the nehu or anchovy (Stole@ o-*rus purpureus),* the apagons *(Apogonidae),* and the white goby *(Glossogobius giurus)* or other species which are captured in the lagoons by tuna fishermen.

The emergence of purse seine fishing as the dominant technology for pelagic tuna harvest has reduced the importance of pole-and-line fishing, for which live bait is essential. If the technology for culture of native marine species could be developed, a stable aquaculture industry could be developed in many islands of the Pacific and the pole and line tuna fishery could be expanded. Again, this probably could expand only to fulfill local demands as the more efficient purse seiners are driving down international tuna prices (105). Alternatively, collecting fees for baitfish harvest may provide a source of income for bait ground owners and local governments, although this probably is hindered by difficult negotiations (95).

Summary

Freshwater and saltwater pond culture, culture in net pens, cages, and intertidal or subtidal culture (on or off the substrate) are all applicable to tropical environments and species of the U.S.-affiliated islands in the Pacific and the Caribbean. Adaptive research will be required to test the applicability of culture systems to local environments and species. Although seawater is plentiful, site availability is still a problem, and economic feasibility uncertain. Logistical constraints plague nearly all island groups (58).

Neither the U.S. Caribbean nor U.S. Pacific islands have the large expanses of low-cost coastal land and wild seed resources necessary to support significant "extensive" commercial pond aquafarms. Extensive aquiculture is characterized by low stocking density, little or no supplemental feeding, low yields per unit area, and high labor inputs. These systems are appropriate to Southeast Asia, where many developed, but are less suitable for the Pacific islands where marine farming is not a common traditional activity (95). Extensive aquiculture on a family scale may be possible, however, and could supplement family diets.

Both island areas; however, have sites suitable for "semi-intensive" commercial operations, which are characterized by smaller, more engineered and managed ponds, supplemental feeding and fertilization, higher stocking density, and heavy or complete reliance on a hatchery for supply of seed. Some aquafarm development of this type is already under way in Puerto Rico (e. g., Sabana Grande Prawn Farms, Ltd.), and semi-intensive pond culture of various species is likely to be a major area of commercial aquiculture development for the island in the future.

Intensive culture, involving a high degree of environmental control (i. e., tanks and raceways), high stocking densities, complete reliance on commercial feeds, high energy inputs, considerable technical expertise, and very high productivity per unit area remains in the experimental or pilot phases of development and probably is not yet feasible for most U.S. islands.

In Puerto Rico, the lower elevations of the coastal plains are generally considered primary locations for aquiculture. Coastal lands near urban areas commonly are unavailable or prohibitively expensive, but large areas of agricultural and rural lands could be used for aquaculture. For example, property abandoned from sugar cane production may be suitable for aquaculture. The south and southwest coasts provide the most protected areas for onshore and offshore culture. Areas below 700 feet generally have high enough temperatures to support year-round production of certain warm-water species. More cold-tolerant species such as channel catfish *(Ictalurus punctatus)* could be reared at somewhat higher altitudes (58).

In the Pacific islands, aquiculture operations which employ simple methods to culture highly desired species for local businesses (hotels and tourist facilities) or species to restock depleted areas may have the greatest potential. Production costs most likely would raise the price of products above the financial reach of many local islanders participating in market economies (95). However, aquiculture as a supplement to subsistence activities and contributor to nonmarket economies may be practible (33).

It is apparent that the availability of technology itself is inadequate to stimulate development. The technology must be economically feasible and socially acceptable. Most aquaculture projects that have been initiated in the islands attempted to prove the technology–a risky proposition—and many did not address economic or social issues. Thus, even if technical difficulties were overcome, the project had little chance of developing into a sustainable operation (163). Unfortunately project failures have had an unfavorable impact on the development of aquiculture: in the long-run, failures discourage governments and agencies from going into aquiculture.

SUMMARY OF MARINE RESOURCE STATUS AND POTENTIAL RESOURCE MANAGEMENT GOALS

Few, if any, nearshore resources remain underused in the U. S.- affiliated tropical islands. Based on past trends of fisheries development, future development of nearshore fisheries in the U.S.-affiliated Pacific islands might be guided by several underlying concepts:

- that growth embody the idea of smallness and technical appropriateness,
- that import substitution and long-run self-sufficiency be the foremost development goals, and
- that export of nearshore marine products be fostered only when it does not have negative impacts on present or anticipated future subsistence activities and only when such exports result in a significant local retention of revenue (175).

Management and conservation concerns are critical. An overcapitalized nearshore fishery will encourage depletion—adding to the income of market participants while reducing the lifestyle of subsistence participants. Such income redistribution may not lead to desirable long-run results (174,175).

A number of stocks appear to be overexploited in the U.S. Caribbean (61). Little empirical evidence exists of the present status of marine resources in the U.S.-affiliated Pacific islands, but circumstantial evidence leads to the strong suspicion of an ever-growing sphere of resource stress surrounding population centers (17,127).

Fisheries development and management could be carried out more in harmony with traditional social institutions. Cooperative organizations present a potential mechanism for accomplishing this. However, considerable expertise—cultural, biologic, and economic—is required to adopt the western cooperative form of enterprise to the island social setting.

Optimum use of nearshore marine resources in the U.S.-affiliated islands probably requires attention to both aquiculture and capture fisheries. The climate and traditions of the tropical Pacific islands are well-suited to many types of aquacultural development. Although the potential for such development remains largely unrealized, a high level of interest exists in aquiculture and mariculture within the region. This method of food production is appealing as a result of the traditional reliance of the islands on the resources of the nearshore waters. Most island groups have operated experimental or pilot-scale culture operations of one form or another.

Aquiculture ventures have had mixed success in the U.S. Caribbean, but with increasing domestic (including tourist) demand for seafood, opportunities exist for aquiculture development. While the USVI has little potential for land-based aquiculture, some sites might be available for culture of marine fish in offshore enclosures. Puerto Rico has much greater potential for both land-based and offshore aquaculture.

Wild stocks are needed to supply seed or brood stock for many aquiculture operations; some aquiculture operations (sea ranching) are essentially manipulations of natural processes in the wild, Aquiculture can provide adjunct or alternative opportunities to fishing enterprises which currently are marginal, and may have the potential to rehabilitate overexploited stocks.

While future development of nearshore fisheries is likely to continue to emphasize small operations, aquiculture may be developed as individual or commercial enterprises depending on the species being cultured. Certain economies of scale, for example, make small prawn farms less desirable than larger ones. Aquaculture projects have had a disappointing history in part because of the lack of site-specific pilot evaluations and logistic difficulties characteristic of small islands. Aquiculture development largely has focused on proving the technology, and paying little attention to financial, market, and socioeconomic aspects. Lack of attention to these aspects may result in failure of a technologically successful pilot project as it attempts to transform into a commercial operation (162). Adequate planning with thorough feasibility studies are needed to select appropriate species and sites and to reduce risks in new public programs or private ventures. Such planning studies should include sociocultural and institutional factors which often have a major effect on the success or failure of aquaculture projects.

Positive impacts of aquiculture development include increased employment opportunities, strengthening of traditional subsistence economies, reduction of imports, development of export products, improved use of marginal agricultural land, and potential increases in standing stocks of certain commercial fishery species. The most probable negative impacts are possible removal of a few coastal areas from general public access, and introduction or inadvertent release of exotic species. Negative impacts may result from small or even unsuccessful ventures, while the magnitude of benefits will depend largely on the eventual scale of successful aquiculture operations. Introductions are best undertaken with caution and only after thorough studies of the potential impact on the native fauna have been completed. Local species are preferable to introduced species whenever possible.

Research

Resource management problems in the U. S.-affiliated tropical islands are not only very complex at any one place or time, they also vary greatly with space and time. Resource managers are simply not in a position to solve them unilaterally; the biological and socioeconomic knowledge bases are too slim. There are two general responses to this problem, neither novel: 1) obtain additional information, and 2) encourage and support increased local involvement in marine resource management.

Baseline Biological, Ecological, and Technical Research

More baseline research on important marine resources and on ecological processes in tropical marine habitats is needed, particularly for resource management in the Pacific islands. Research projects that may not lead directly to commercial development still are valuable in that they may identify constraints to developments or indicate which fisheries or aquaculture activities are not feasible. Consideration of such information in project design may determine and will increase the likelihood of project success.

Marine biological research in the U.S.-affiliated Pacific islands is centered at the University of Guam Marine Laboratory (UGML). This laboratory has a faculty of seven full-time researchers working in various fields within the discipline. Environmental impact studies, studies in aquiculture techniques and species potential, and resource assessment surveys have been performed by UGML personnel at various islands throughout the region. Cooperative research programs have been developed with Taiwan, Indonesia, and French Polynesia, and visiting scientists from around the world have conducted research at the facility. The Guam Division of Aquatic and Wildlife Resources (DAWR) is active in marine resource management and to that end performs pertinent research related to Guam's marine resources. The DAWR uses annual fishery statistics to assess pressure on nearshore to offshore bank aquatic resources resulting from recreational, subsistence and commercial fisheries (66).

Additional marine research has been performed at the MMDC in Palau. Although there are no resident scientists at MMDC, a number of important advances in mass culture of trochus and giant clams have been made by researchers visiting this lab. Most islands of the Federated States of Micronesia have plans for small giant clam and trochus mariculture laboratories which eventually will supply their reseeding programs.

Fisheries biologists of the U.S. National Marine Fisheries Service, Southwest Fisheries Center, Honolulu Laboratory conduct occasional island resource surveys. However, their work has focused primarily on commercial food species.

Fisheries officers employed by local governments also have been involved in marine research. Generally these studies have been related to resource assessments of edible marine organisms and technologies such as artificial reefs.

Local institutions in Puerto Rico and the U.S. Virgin Islands have demonstrated capabilities for undertaking much of the work needed to realize opportunities related to the sustainable development of marine resources. The College of the Virgin Islands through its Ecological Research Station and the U.S. Virgin Islands Department of Conservation and Cultural Affairs and the Fisheries Research Laboratory in Puerto Rico have undertaken a number of studies of local fisheries potential (cf:21,37,125, 152). Several activities of the Caribbean Fisheries Management Council (CFMC), comprised of the University of Puerto Rico and the Virgin Islands Marine Resource Management Cooperative are relevant to development and management of nearshore marine fisheries, and these institutions have the ability to gather information needed for preparation of development and management plans for nearshore marine systems (61).

However, further research is needed. For example, the University of Puerto Rico and Medical University of South Carolina, in collaboration with other agencies and institutions in Puerto Rico and the USVI could expand the current research programs directed toward developing a field test for ciguatoxic fish (61). Based on the recommendations of the CFMC, local government, academic, and nonprofit institutions could prepare proposals to support relevant research activities under applicable funding programs, and could undertake these activities in coordination with the CFMC.

Several general areas of biological research are relevant to decisions involving marine resources in both the Pacific and Caribbean regions:

- life history characteristics of important organisms,
- larval ecology,
- ecological interactions among species, and
- role of disturbance in community structure and development (168).

For planning, even more detailed information is required. For example, in order to determine the potential for development of relevant aquiculture in each island territory or nation, sufficient information must be collected to establish a database, including:

- identification of land or site availability and land use regulations;
- assessment of water availability and quality;
- recommendations for appropriate species;
- identification of current aquiculture projects;
- existing tax structures and financial incentives;
- availability and cost of transportation;
- inventory of local energy supplies and current costs;
- identification of legal or institutional constraints;
- identification of construction and operating costs;
- social, cultural, and environmental impact considerations;
- assessment of potential markets for relevant species;
- assessment of local technical capability and available institutional support; and
- consideration of the prospects for manpower training (164).

Collection, assembly, and management of this information probably will require substantial external assistance (55).

The research priorities of individual islands rarely correspond to U.S. national priorities.

For example, research funds for aquiculture have been difficult to obtain on a sustained basis. Further, it requires several years to develop a project from the experimental stage to a commercially viable operation. Many Federal granting agencies restrict research proposals to short timeframes that are unrealistic for establishing a database, developing management models, and transferring technology to industry. Facilities are needed that could maintain a long-term financial commitment to an activity and focus on transformation from pilot to commercial scale (33).

Academic institutions in Hawaii could assist aquiculture development in the U.S.-affiliated Pacific islands by conducting adaptive research to determine the applicability of culture technology used in other areas and by conducting research to solve problems during production. The logical roles of academic institutions are to provide such information and to train aquaculture scientists and operators of aquatic farms. Centralization of Federal support into regional approaches and regional research and development centers would lead to more cost-effective expenditures.

In many cases it would be helpful for governments to support pilot-scale tests and demonstrations of aquiculture systems conducted by local academic institutions. A program of adaptive research is, for example, needed to determine the applicability of culture methods for snappers, sea perch, breams, rabbitfish, and milkfish developed in Southeast Asia to the islands of the Pacific and Caribbean. If successful, this could facilitate the development of family, cooperative, and commercial aquiculture in many islands which lack adequate supplies of freshwater.

Social, Cultural, and Economic Research

The management of biological resources demands the expertise of social scientists and biologists, however, there has been almost no direct input from social scientists concerning the role of social and cultural factors in marine resource management in the U.S.-affiliated Pacific. More needs to be known about the current status of TURFS in the Pacific islands, especially American Samoa, Truk, and the outer Caroline Islands. Biologists, geographers, or anthropologists could carry out such studies. However, because resources within island fishing grounds are becoming increasingly valuable as human populations increase and transportation to export markets improves, the value of TURFS is increasing. Under the circumstances it is not surprising to find that villagers will invent "traditional" fishing rights. Information obtained from villages on their fishing rights and customs is thus likely to be more reliable if it is elicited prior to the introduction of plans for commercial fisheries development in their waters.

Needed, along with improved information on the contemporary status of traditional sea rights practices, is more detailed local knowledge of the relevant aspects of marine resource use (locations, species, quantities harvested, methods used, distribution of the catch, the relation between the size of the fishery and of the resource base, the effects of adjacent or overlapping commercial fisheries, etc.). No substitute exists for detailed, locale-specific studies of current traditional sea rights and how they fit into the complex and varied sets of biological, political, economic, cultural, and geographic factors relevant to marine resource management.

Assessment also is needed of the implications of TURFS for island aquiculture development. It should involve a review of the literature pertaining to other areas (Southeast Asia in particular) and field research in the islands. One main objective of field research could be to determine whether past failures or successes in aquiculture efforts were associated with traditional tenure systems. A thorough examination of TURFS and their implications for management also could form a part of the training for resource managers in the Pacific islands.

A number of writers have called for studies of the causes for the failure of many artisanal fisheries development and management programs. Today, our understanding of those general causes has increased. More valuable might be the identification and evaluation of programs that have succeeded. Factors supporting success would be directly relevant to management and extension efforts. For example, it may be that charisma, empathy, and patience count for as much as or more than scientific expertise.

Extension

The ultimate value of information depends largely on the degree to which the affected public, legislators, and enforcement personnel appreciate the major ecological, social, and economic issues involved in management and development of coastal resources, and on extension of technical and managerial information to potential practitioners. Given the financial constraints on local enforcement (159), it is likely that public awareness and cooperation will prove as important as regulation in preventing overexploitation.

The transfer of technology, often as part of fisheries aid projects, sometimes has not been successful or appropriate. The term “appropriate” could mean using materials that are locally available, with a retention of local ways; or it could mean using the most efficient methods available and adapting local conditions to these. Truly appropriate technology transfer may lie between these extremes.

Introduced technologies should fulfill the requirements of the territory or country and should not greatly exceed the general technological level of the area (95). Additionally, training of personnel in the use and maintenance of equipment is integral in technology transfer. Imported technologies generally are more successful when they can be adopted by artisanal fishermen with a minimum of training. This is particularly so when the project is of real interest to the participants and where infrastructure levels are sufficient to allow the maintenance of imported equipment without creating an economic burden on the fishermen (95),

While the technologies developed in Southeast Asia may be more appropriate for the Pacific islands than technologies developed in Western temperate countries, the Southeast Asian experience may not provide a good model for the Pacific islands with respect to markets and factors of production, Asia has large populations and markets that are easily accessible by reliable transportation networks. In the Pacific islands, small populations mean small markets with unreliable and expensive transport links. In Asia, the subsistence-level market is large, with people facing a real protein shortage. In the Pacific islands, the diet is nowhere near the crisis level of Asia; there are few starving Pacific islanders. In addition, land, labor, and water are abundant and cheap in Asia. In the Pacific islands, labor and land are limited and freshwater supplies may be critical (163).

The typical fisheries manager in the U. S.-affiliated islands, whether indigenous or expatriate, generally has responsibilities too numerous to allow much time to be spent on extension activities. Carefully chosen individuals whose sole responsibility is to serve as liaison between fishing communities and the government are needed. Often such work would require living in fishing communities for weeks or months at a time (cf:83 for a discussion of some of the practical aspects of such involvements).

Many initially enthusiastic aquaculturists become discouraged as a result of management problems or inflated expectations. This problem could be alleviated through proper counsel from knowledgeable extension agents and marine advisory agents. Such services generally are lacking in most of the Pacific region.

The only formal marine extension programs in the U.S.-affiliated islands are the Sea Grant Extension Service, at the University of Puerto Rico and the University of Guam Marine Laboratory (a cooperative project of the University of Hawaii Sea Grant College Program and the University of Guam). Staffed by a single agent, the latter program has concentrated on fisheries development, marine conservation, and public information and awareness.

Local fisheries officers have been involved in extension efforts from time to time. A number of fishermen’s training programs have been conducted through marine resources offices. If significant development of nonfood marine resources is to occur, especially in the more remote islands, marine extension and advisory programs throughout the region will need to be strengthened.

Marine extension agents could be established in major population centers, and could travel regularly to more remote fishing communities. Working closely with the islanders, the agents would transfer new and proven technical information from researchers to the harvest sector and facilitate research by relating problems encountered in the resource management sector to the appropriate researchers. It would be useful to educate extension agents as well as administrators, scientists, and resource managers from outside the area on local customs and cultures. To perform more efficiently, the extension agents could receive annual updates and training programs in technology and market developments. This effort could be coordinated on a regional basis through Sea Grant programs. The coordinator would be responsible for collection, analysis, and dissemination of this information through the extension network.

Regional Coordination and Cooperation

Clear advantages exist in establishing a mechanism to promote active cooperation between the U.S.-affiliated islands in the Pacific and the Caribbean, and among islands within each area. Since both areas rely on assistance from the United States, especially in technical areas, joint programs could be helpful.

Regional coordination in the planning and development of aquiculture within the Pacific and the Caribbean regions might be highly desirable. Regional technical conferences could be convened for these purposes. Many island groups have common interests in aquiculture development which enhances the value of such conferences. These islands are under-represented at most international meetings dealing with aquiculture and other marine resources. One setting where the regional representation could be strengthened is the Coral Reef Symposium which is held every 4 years; another is the Pacific Science Congress. The contacts made and the information gathered at such international meetings could facilitate the development of aquiculture within the regions. Representatives could be sponsored to attend regional technical conferences and appropriate international meetings whenever possible.

Collaboration with other Lesser Antillean countries on management and development activities is also of great potential use to Puerto Rico and the U.S. Virgin Islands. Such collaboration could provide for improved access to developments in other areas and to regional markets and sources of supply; and help to improve economic, social, and political ties between the United States and the strategically important countries of the Eastern Caribbean.

Many of the potentials and constraints to development of capture fisheries and aquiculture in the U.S. Caribbean also apply to most of the other Lesser Antilles. As a result, important opportunities exist for joint marine resource development ventures between the U.S. islands and the Eastern Caribbean countries.

The U.S. territories might assist and benefit from efforts in other Caribbean countries to manage common nearshore marine species. Some fishery stocks (e.g., spiny lobster), for example, have long larval lives which makes it difficult to determine the origin of adult populations. Consequently, stocks in Puerto Rico and the U.S. Virgin Islands may depend on production in other locales. As is the case with dolphinfish fisheries, this potential interdependence offers substantial justification for collaboration with other Lesser Antilles countries in developing marine resource management strategies.

Further, a regional approach to training for maritime industries would mitigate costs for developing territories which lack investment capital for expensive training facilities and equipment, and expedite reciprocal recognition of regional standards. However, difficulties may arise with this approach because of the varying levels of development within the region (101).

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