Integrated Renewable Resource Management for U.S. Insular Areas

June 1987

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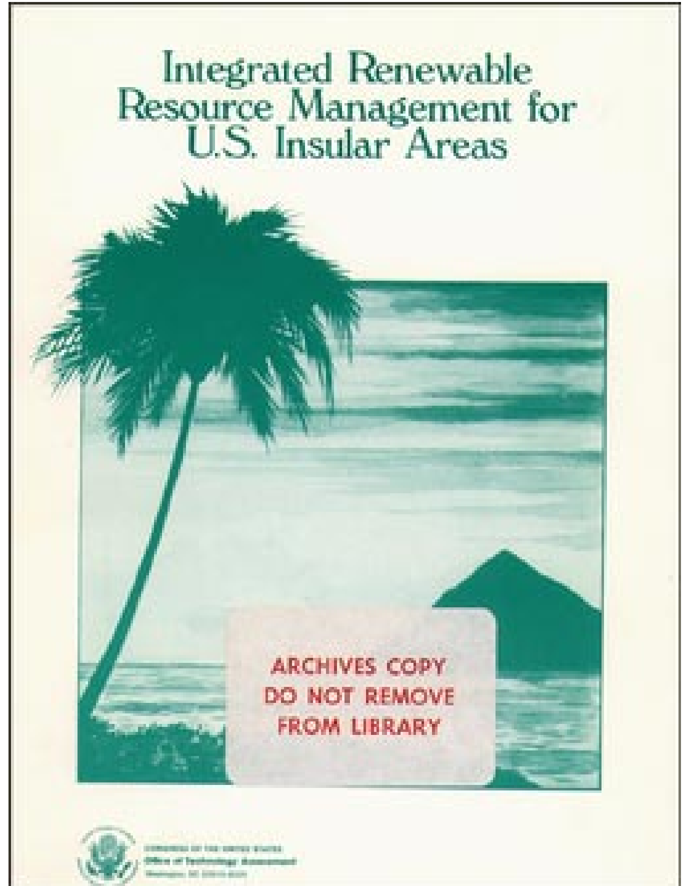

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Foreword

The United States has political, economic, humanitarian, and strategic interests in sustained economic development of U.S.-affiliated Caribbean and Pacific islands. Despite a U.S. commitment to support the economic vitality of these islands, most have become less self-reliant in food and fiber production, and now depend increasingly on Federal funding for jobs, public welfare, and food and other goods and services to the islands.

Interest in the development of increased self-reliance in U.S.-affiliated islands has grown significantly in the last two decades. After 16 years of negotiation, the Congress, the United Nations and three governments emerging from the former Trust Territory of the Pacific Islands —the Republic of the Marshall Islands, the Federated States of Micronesia, and the Commonwealth of the Northern Mariana Islands—approved agreements redefining their relationships with the United States. The remaining agreement, with the Republic of Palau, is expected soon, thus terminating the only remaining trusteeship created by the United Nations after World War II. Concomitant with the interest in development of island self-government has been concern over development of self-reliance. Similarly, the economic well-being of the U.S.-affiliated Caribbean islands has come under increasing scrutiny due to the growing strategic importance of the Caribbean Basin, and the implementation of the Caribbean Basin Initiative,

Several factors contributing to the growing dependence of U.S.-affiliated islands include: scant natural resources and long distances between islands and sources of inputs, products, or markets; rapidly growing populations; tropical resource characteristics with generally high natural productivity but extreme vulnerability to disruption; and common histories of significant resource degradation. Despite the latter, the economic constraints posed by size and isolation of many of these islands dictate that much of the productive sector be based on renewable resources—agriculture, aquiculture, fisheries, and tourism.

Renewable resource development can help foster self-sufficiency, but certain approaches are not compatible with sustained development (e. g., harvesting resources until long-term productivity is lost, resources are depleted, or the environment is degraded). Similarly, policies, programs, and projects that seriously conflict with local cultures and customs are likely to be counterproductive.

The Senate Committee on Energy and Natural Resources, in 1984, requested the Office of Technology Assessment to conduct an assessment of the constraints to development of insular resource-based enterprises, and the opportunities to improve sustainable renewable resource development and management on the U.S.-affiliated islands. The House Committee on Interior and Insular Affairs endorsed the request. The assessment identifies and discusses in-depth some constraints and opportunities to integrated management of renewable resources on these islands.

OTA greatly appreciates the contributions of its advisory panel and workshop participants assembled for the study, and the authors of the commissioned papers. We are especially grateful for the time and effort donated by the numerous contributors who served as reviewers and as liaisons from the insular governments and other government agencies. In addition, we would like to thank those from within OTA who provided assistance, particularly Dr. Gordon Law of the International Security and Commerce Program. As with all OTA studies the content of the report is the sole responsibility of OTA.

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NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the reviewers. The reviewers do not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

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7From November 1986.

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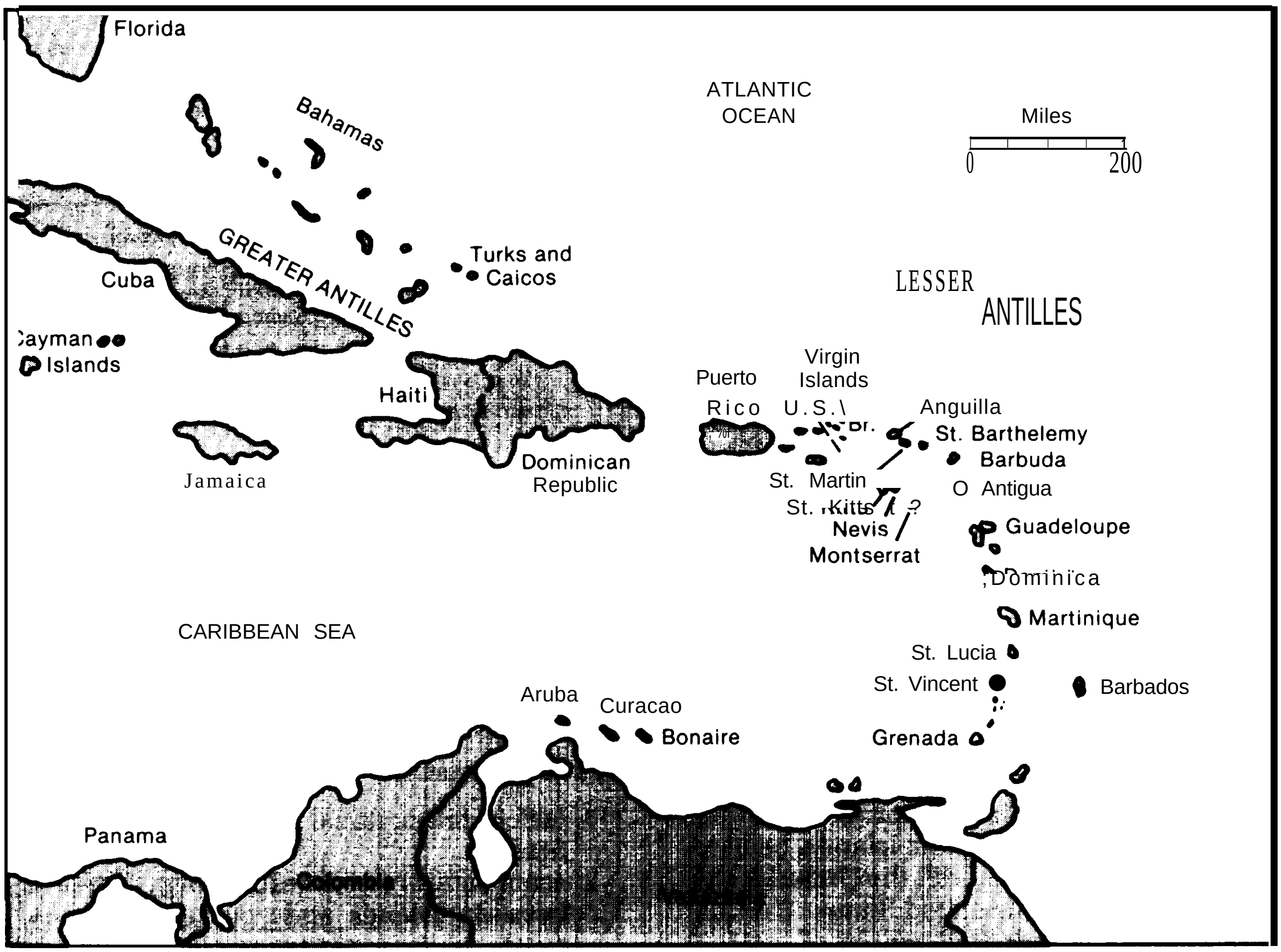
INTRODUCTION

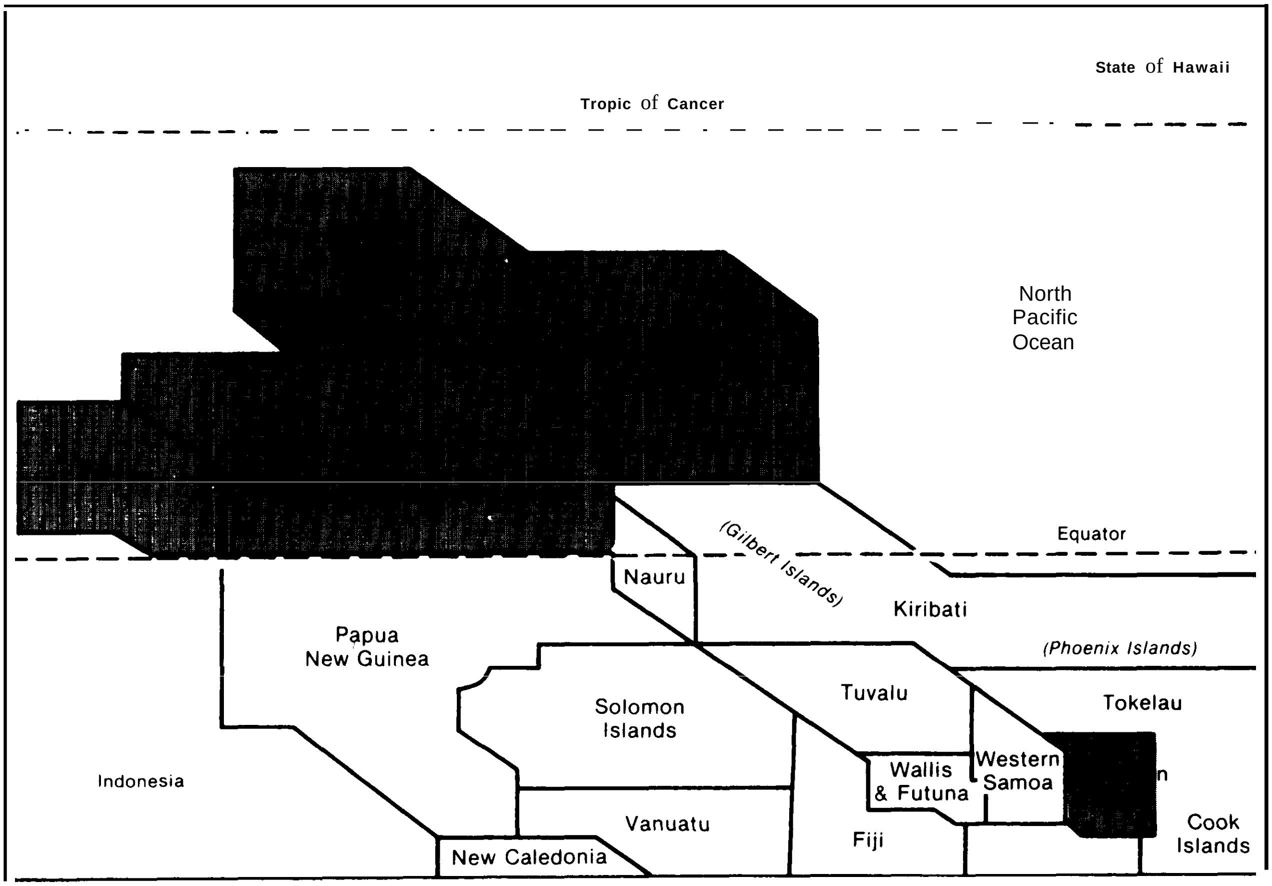
The U.S.-affiliated tropical islands include Puerto Rico and the U.S. Virgin Islands (USVI) in the Caribbean (figure l-l) and American Samea, Guam, the Commonwealth of the Northern Marianas Islands (CNMI), the Republic of the Marshall Islands (RMI), the Federated States of Micronesia (FSM), and the Republic of Palau in the Pacific (figure 1-2). All of these islands, except Puerto Rico, are very small (table *l-l);* the Micronesia island groups are distributed over an area as large as the conterminous United States (figure I-3) but have an aggregate

Figure 1-1.—U.S.-Affiliated Caribbean Islands and Neighboring States



SOURCE Office of Technology Assessment, 1986

Figure 1-2.—U.S.-Affiliated Pacific Islands and Neighboring States



SOURCE Adapted from a map prepared by the State of Hawaii Department of Planning and Economic Development, 1984

land area less than that of Rhode Island. The U.S.-affiliated Pacific islands also are distant from major foreign population centers.

As commonwealths, Puerto Rico and the CNMI have autonomous governments, but are voluntarily associated with the United States. The USVI, American Samoa, and Guam are unincorporated territories with semi-autonomous governments. The FSM and RMI, which (along with the CNMI and Palau) comprised the former Trust Territory of the Pacific Islands, have recently signed compacts with the United States to become Freely Associated States. This status allows the islands free control of internal affairs, assures them fiscal aid, and makes them eligible for some international aid; the United States retains responsibility for national defense.

The majority of the U.S.-affiliated islands have developed dependence on Federal funding to provide jobs, to support public welfare, and to import food and other goods and services to the islands. Several factors common to the U.S.-affiliated islands have contributed to this dependence:

1. lack of full political status and benefits of States;
2. scant natural resources and large distances between islands and sources of inputs, products, or markets;
3. rapidly growing populations;

Table 1-1.— Population, Land Areas, and Estimated U.S. Federal Expenditures in U.S.-Affiliated Islands

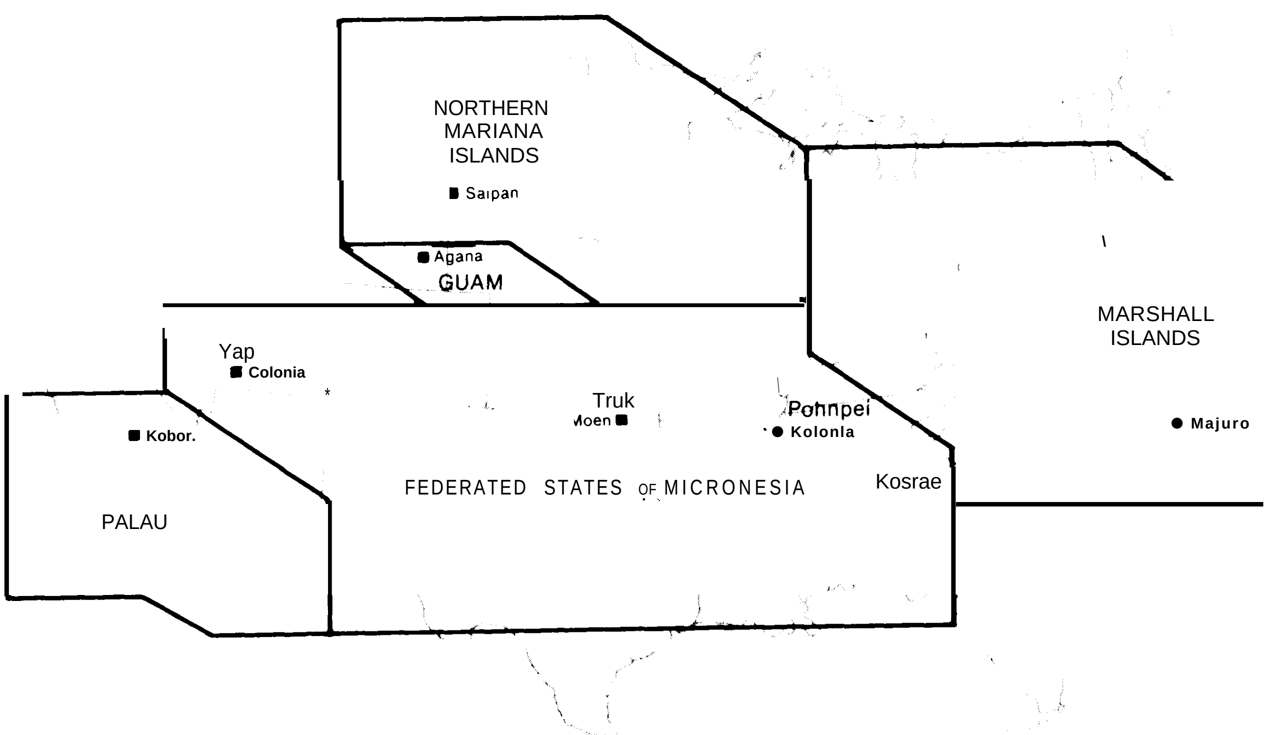
Insular area	1984 Population[a]	Land area (sq. mi.)[b]	Approximate number of islands[b]	Estimated U.S. Federal expenditures, 1984[c]
Puerto Rico	3,270,000	3,425	4	$5,420 million
U.S. Virgin Islands	107,500	132	66	$ 387 million
Guam	119,800	209	1	$ 768 million
American Samoa	35,300	77	7	$ 61 million
Northern Mariana Islands	18,600	182	21	$ 103 million
Marshall Islands	34,900	70	1,225	
Federated States of Micronesia	88,400	279	607	$ 163 million
Palau	13,000	179	350	

SOURCES: [a]*Land Use Planning Report,* 13(46):365, November 25, 1965; U S. Department of State, 1984 Trust Territory of the Pacific *Islands,* report to the United Nations on administration of the Trust Territory of the Pacific Islands, 1965

[b]U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Puerto Rico Coastal *Management Program and Final* Environmental Impact Statement (Washington, DC: U.S. Department of Commerce, 1976); U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *The Virgin Islands Coastal Management Program and Final Environmental Impact Statement* (Washington, DC: U.S. Department of Commerce, 1979); US Department of State, *Annual Reports* for American Samoa, Guam, and the Trust Territory of the Pacific Islands, 1980.

[c]U.S. Department of Commerce, Bureau of the Census, Federal *Expenditures by State, FY 1985 (Washington, DC: U.S.* Government printing Office, 1986) Includes: 1) Grants to State and local governments, 2) Federal salaries, 3) payments to individuals, 4) procurement, and 5) other

Figure 1-3.—Micronesia and the Contiguous United States: A Comparison of Size



SOURCE Adapted from H F Nufer, *Micronesia Under American* Rule: *An Evaluation of the Strategic Trusteeship (1947-1977)* (Hicksville, NY Exposition Press, 1978)

4. tropical resource characteristics with generally high natural productivity but extreme vulnerability to disruption; and
5. common histories of resource degradation.

Despite the United States' past and present commitment to the economic vitality of the U.S.-affiliated islands, most have become less self-sufficient in food production over the past several decades. This dependence amounts to a complete reversal of precontact tradition. Before European discovery, the inhabited Pacific and Caribbean islands were self-supporting. People subsisted on the available marine and terrestrial natural resources and extended family systems provided for members unable to provide for themselves.

Changes occurred with colonization and the increasing influence of foreign cultures. Colonial policies and practices over several centuries, the introduction of new fishery and agricultural technologies and cash economies, military occupation and use, and the advent of tourism, all have affected island resource systems and uses. Growing populations on many islands represent an added stress on an already limited resource base.

High levels of financial aid from the United States during the last two decades have not fulfilled the intention of fostering modern, self-sufficient island economies. Largely directed toward social support programs, generous aid packages may have reduced local incentives to pursue that goal.

A self-sufficient economy meets as many domestic needs as possible, and generates export revenue to pay for the imports required for a desired or acceptable standard of living. Development of an active productive sector on the islands may foster increased self-sufficiency. The economic constraints posed by size and isolation of many of these islands dictate that much of the productive sector be based on natural resources—e.g., agriculture, fisheries, and tourism.

Renewable resource development can help foster self-sufficiency, but sustainable development precludes certain approaches. For example, harvesting resources to the point where long-term productivity is lost, resources are depleted, or the environment is degraded is ultimately counterproductive. Similarly, policies, programs, and projects that seriously conflict with local cultures and customs are likely to be counterproductive.

Insular Resource History and Trends

Although the histories of the peoples and settlement of the U.S.-affiliated island areas are diverse, certain common factors exist:

1. on most islands, relatively large indigenous populations were sustained by island resources before western contact and remnants of traditional agriculture and fishery practices still exist on many islands;
2. all of these islands were colonized or administered by foreign nations whose activities primarily were designed to exploit island resources; and
3. all of the islands have been of some strategic importance to the United States and most remain so.

The islands share common renewable resource problems, including both natural (e.g., flooding, landslides, and other natural hazards) and manmade resource degradation. Deforestation and soil-moving for agriculture and construction have caused heavy soil erosion on many islands and adversely affected the surrounding coral reefs. Numerous island species are near extinction, and others have already gone extinct, due partly to habitat loss (e.g., removal of mangroves), to overexploitation (e.g., hunting of fruit bats), and to introduction of exotic competitive or predatory species (e.g., brown tree snake, mongoose). Increasing human population density, combined with inadequate sewage treatment, and introduction of agricultural and industrial chemicals has reduced freshwater and nearshore water quality on many islands. Oil spills have damaged nearshore environments in both the Pacific and the Caribbean.

Turtles, nearshore fish and shellfish, and certain tree species have been overexploited in many island areas. Despite attempts to recover declining populations, poaching by local inhabitants and foreign nationals continues. Dynamite and chlorine bleach used by Pacific fishermen to "fish" have long-term destructive effects on the reef and lagoon areas. Dredging and mining in nearshore areas has resulted in the loss of many mangrove areas and coral reefs, which in turn may adversely affect nearshore fishery potential. Shipwrecks, heavy sedimentation, and anchor gouges have caused significant degradation of coral reefs and seagrass beds near many islands.

Puerto Rico's nearshore waters have been heavily exploited and very nearly overfished. Similarly, even modest increases in fishing effort could surpass the natural capacity of waters around the USVI. While good data on harvest levels and production capacities in the Pacific are lacking, there is evidence of depletion in the nearshore environment, particularly around urban centers.

More exotic resource problems remain in the Pacific islands, American and Japanese military ordnance from World War II still litter some of the islands, presenting a hazard to humans and inhibiting the use of some lands. Chemical repositories on Johnston Island have leaked military chemicals into the groundwater. Nuclear testing in the Marshalls has rendered several islands virtually uninhabitable. Efforts are being made to restore these islands to habitable conditions. Although surface nuclear tests have been banned; other islands still are used as nonnuclear practice bombardment targets.

Concerns have increased over adverse trends in resource use resulting in efforts to maintain or enhance resources on many of the U. S.-affiliated islands. These concerns have been expressed in a variety of ways, including:

- efforts to maintain the resource base (e. g., coastal resource management);
- efforts to restore the renewable resource base (e.g., reforestation, captive breeding of endangered populations);
- efforts to redirect use to underused resources (e.g., outer reef fisheries);
- efforts to culture species (e.g., aquiculture, culture of crops currently gathered from the wild); and
- efforts to enhance existing renewable resources (e.g., artificial reefs, enrichment planting of forests).

Sustainable renewable resource management depends not only on the capability of the ecological resources, but also on the availability of skilled labor and willingness to engage in resource management and development activities. Many young adults seek education and employment opportunities in the U.S. mainland. Despite substantial outward migration, remaining populations are rapidly growing.

Many of those who remain depend on extended family relationships and social support programs to supply their needs. Most formal labor is captured by local governments and services for the public sector and its employees. Wages, security, and prestige are higher in government employment. Skilled labor, training, and interest in the agriculture and fisheries sectors are low on all the islands.

Insular Renewable Resources

Characteristics of island resources—soil, water, vegetation, and wildlife—determine the uses and technologies that may be implemented productively and sustainably. U.S.-affiliated islands may be categorized into four groups with common resource characteristics:

1. high volcanic islands: peaks of undersea volcanoes (both active and dormant), often surrounded by fringing reefs;
2. low-lying atolls: composed entirely of coralline reef limestone enclosing a lagoon;
3. raised limestone islands: primarily limestone, originally formed in waters surrounding older volcanic islands and now above sea level; and
4. continental islands: geologic extensions of continents or parts of certain undersea mountain ranges.

All of the islands are within the tropical climatic region characterized by warm, relatively stable temperatures and commonly high humid-

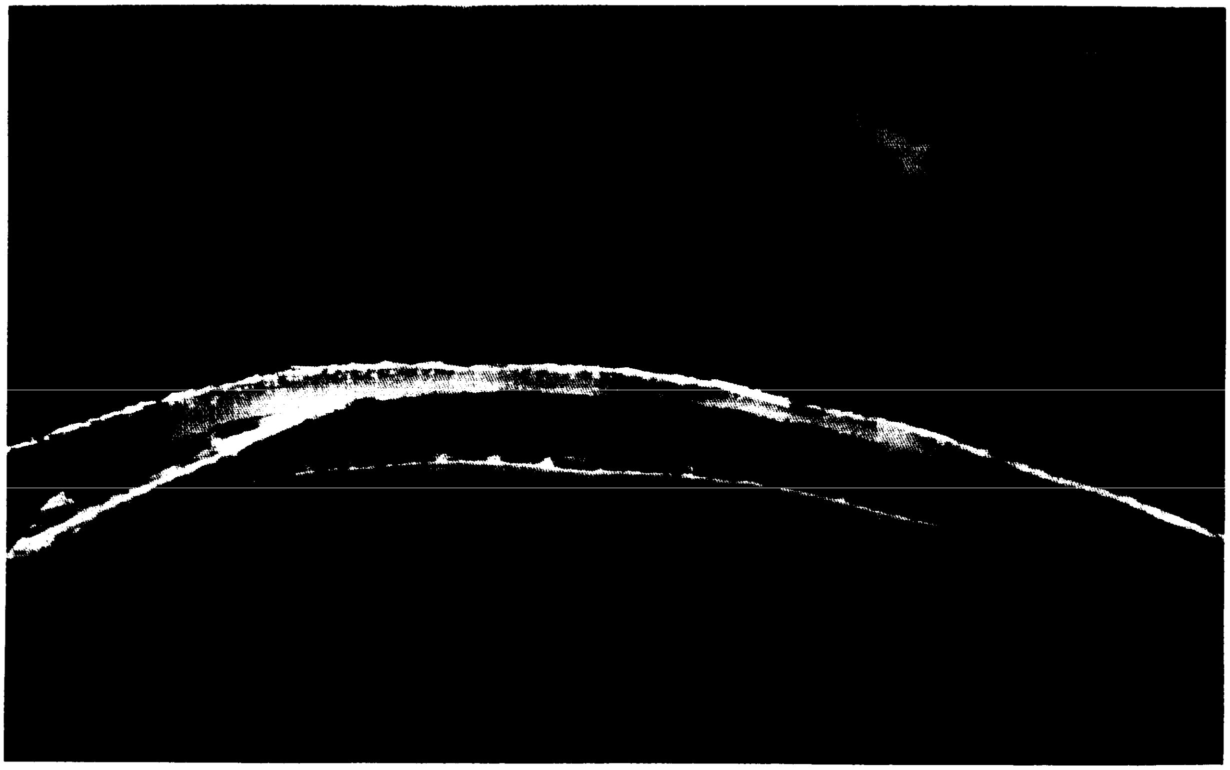


Photo credit: Office of Technology Assessment

A low-lying atoll island in the Marshall Islands, built on the inside edge of an encircling coral reef.

ity. Precipitation levels vary widely among the islands. Rainfall has high kinetic energy and, thus, greater ability to erode soils than in temperate regions. Further, the islands are vulnerable to major disturbances—hurricanes and typhoons (e.g., the western north Pacific receives an average of 26.3 typhoons per year), which can have devastating effects on resources, infrastructure, and populations.

Freshwater availability is determined largely by island structure. Atolls have no natural surface water and retain little groundwater due to highly permeable soils. On the other hand, flash flooding and heavy erosion is common on high islands where slopes are steep. Hydrologic systems are much more complex on continental islands, corresponding to their more complex geology.

Chemical weathering of soils predominates on tropical islands causing accelerated leaching of soil nutrients. Resultant soils generally are nutrient-poor regardless of parent rock type. Further, the chemical composition of the resulting soils often is imbalance so that many food or tree crops will exhibit stunted growth or will not survive.

Because of differing histories of formation and geology, the nature and extent of renewable resources on the islands vary. However, their insular ecology leads to certain commonalities among resource systems:

- richness in endemic species,
- species-richness of forests,
- value to science disproportionate to their size,

g G m
are infertile, barren, and actively eroding.

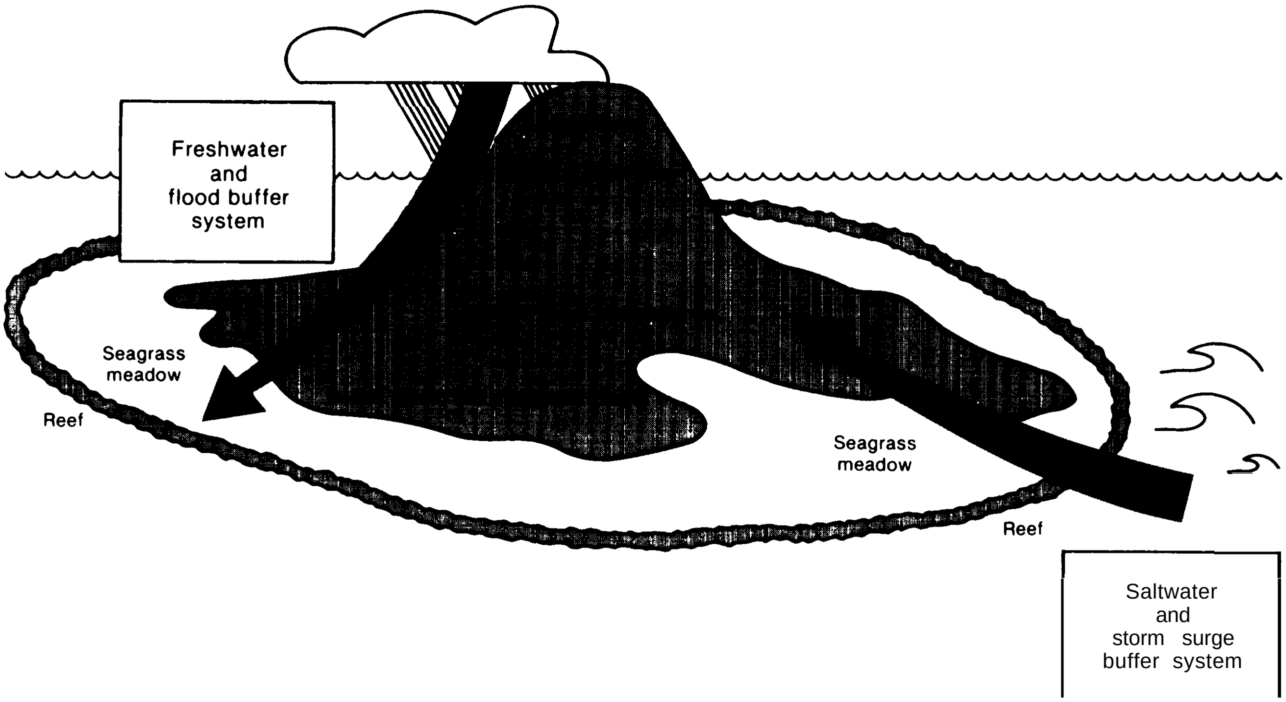
- vulnerability to disruption, and
- vulnerability to overexploitation.

Islands as Integrated Resource systems

Island ecosystems are closely interrelated. Island terrestrial ecosystems, structured topographically from highland forests to coastal vegetation, sequentially buffer the erosive forces of heavy tropical rainfall and rapid runoff and protect nearshore marine ecosystems from excessive freshwater intrusion and sedimentation (figure 1-4). Similarly, the combination of coral reefs, seagrass beds, and littoral vegetation serve to reduce the erosive energy of wave action, thereby protecting shorelines from erosion and providing the basic conditions for island expansion. Organic matter also is transported among these ecosystems via water flow and movement of animals, allowing recolonization and recovery of degraded areas. Thus, the value of individual ecosystems includes not only the particular resources they contain, but also their essential functions in the insular ecology.

Unmodified island ecosystems generally are at equilibrium. However, environmental manipulation or modification generally is necessary to accommodate human populations. If such modifications allow the natural flow of energy, freshwater, and nutrients through the system the natural equilibrium still may be maintained. Options exist in the methods and types of modifications to be enacted; selection of a development approach which mimics or acts in concert with the desired natural process will result in fewer impacts on associated ecosystems.

Figure 1-4.—Erosive Energy Buffer Systems on Islands



SOURCE Office of Technology Assessment, 1986

Traditional island societies demonstrated a keen sense of the interrelated nature of the island ecosystems: activities were designed to mimic natural ecosystems and preserve related environmental functions. Damaged areas were left fallow allowing natural recovery processes to restore productivity. Present population pressure coupled with human economic desires preclude most resource uses which rely on time for recovery. Alternative methods include abandoning degraded lands, or expending considerable money, energy, and effort to reclaim sites (e.g., reforestation).

The U.S.-affiliated islands' renewable resources still provide many goods and services, however, they have not become the basis of viable, modern economies. A variety of factors constrain efforts to achieve this goal.

Constraints to the Sustainable Development of Renwewable Resources

A number of physical, biological, geographical, and socioeconomic factors constrain sustainable renewable resource development and management on U.S.-affiliated islands. Physical constraints that particularly affect small island agriculture and land-based aquiculture are limited availability of land and water resources. Low fertility of tropical soils, occasional torrential rainfall, distinct dry seasons on some islands, and mountainous topography of high volcanic and continental islands may preclude some types of agricultural activity. Physical constraints to fisheries development include low productivity of offshore tropical waters and limited extent of productive nearshore areas. Many nearshore resources already are being exploited near or beyond sustainable levels. Marine ecosystems are extremely vulnerable to natural and human disturbance, often requiring long recovery periods.

Added to these constraints are the lack of reliable data on the status of island terrestrial and marine renewable resources, and incomplete understanding of the "mechanics" of tropical ecosystems. The development strategies and technologies designed for temperate fisheries and agriculture are not readily transferable to tropical settings. Failure to appreciate this may explain why many "western" attempts to manage and develop resources in tropical settings have not been successful.

Geographically, the Pacific islands are extremely isolated. Transportation in general is difficult and unreliable. These factors, combined with small size or lack of formal markets for export products, and proximity of major Asian competitors, make it difficult or impossible to achieve economies of scale. Such constraints are much less severe in the Caribbean.

Sustainable resource development is limited not only by the inherent nature of tropical resources, and island geographic settings, but also by several socioeconomic characteristics of the islands. In the Pacific, certain resource ownership and use traditions constrain access to resources by "outsiders," including other islanders, who may be interested in developing the resource. Commercial development of resources, in particular, is contrary to traditions of harvesting for immediate subsistence use only, and of sharing any harvesting excess with needy relatives or friends.

The skills and knowledge needed for sustainable resource development is also scarce on these islands. Environment and resources play a minor role in school curricula, or are entirely neglected. Education at all levels is primarily oriented toward liberal arts. A preference exists for government employment rather than in the fisheries and agriculture sectors which are perceived as "lower status. " Many who do not find government jobs, migrate to the mainland United States, and many who leave the islands to pursue higher education never return. Outmigration and reluctance of the islanders to work in some types of employment creates a demand for alien immigrant workers, whose presence may create social tensions.

Opportunities for the Sustainable Development and Use of Renewable Resources

Opportunities exist for expanding the role of renewable resources in the economic development of the islands, and for reducing the islands' heavy dependence on imports and U.S. aid.

Warm temperatures and generally favorable climates characterize most of the U.S.-affiliated islands in both the Pacific and Caribbean regions. The islands are capable of sustaining high agricultural and aquatic productivity. The mangrove, seagrass, and coral reef ecosystems of these islands are highly productive and rich, and interactively support populations of economically valuable marine organisms.

Nearshore marine resources show signs of stress in both regions. However, the success of the Japanese in Micronesia during the mandate period suggests there is unrealized potential in the Pacific for marine resource development, particularly through expanded use of underexploited and migratory species. Aquaculture may have some potential in the U. S.-affiliated islands to supply both local and export markets. Both regions have appropriate sites for pond, estuarine, or offshore culture systems. However, significant constraints to aquiculture development exist, including high cost of inputs, difficulty in obtaining juveniles, and lack of aquiculture extension services. Thus, aquiculture has not been developed to any great degree in the U.S.-affiliated islands.

The high islands of the Pacific and Puerto Rico also have significant terrestrial resources. There is potential for making traditional agricultural methods more productive and for introducing new crops and technologies to the U.S.-affiliated islands. Agroforestry, a landuse system that integrates or rotates growth of woody perennials and nonwoody crops or ani-

Photo credit: Off/cc of Technology Assessment

Growing numbers of tourists visit the U.S.-affiliated tropical islands to enjoy their natural beauty and explore cultural and historic sites. (Pictured here: Truk Lagoon.)

reals was traditionally practiced on many U. S.-affiliated islands. Incorporating trees into more productive agricultural systems can optimize landuse while retaining the advantages of a forest (watershed protection, erosion control, wildlife habitat).

Commercial agriculture still is considered desirable for the U.S.-affiliated islands. Even small islands may become successful producers of specialty crops attractive to world markets. Pohnpei black pepper, for example, has penetrated U.S. gourmet markets. Coffee, nuts, spices, essential and perfume oils, cacao, and certain ornamental plants, fruits, and vegetables are all high-value crops which have market potential.

The natural resources of tropical islands also may contribute to economic development through tourism. Tourists are attracted to the islands because of their warm climates, coral reefs, beaches, flora and fauna, and spectacular scenery. Tourism and related industries currently comprise the major economic sector of the USVI, and tourist presence in the Pacific region is growing rapidly. Tourists provide revenue by purchasing food, services, and island handicrafts. Although tourism has created environmental and social problems in the past, it has the potential to contribute significantly to the economic self-sufficiency of the U. S.-affiliated islands. Ideally, the tourism industry would be planned and developed to maximize economic benefits to the islanders and minimize negative environmental and social impacts.

Successful and sustainable renewable resource development may assist in increasing the self-sufficiency of the U.S.-affiliated islands. There are many other potential benefits, including reduced unemployment and outmigration, improved lifestyles for islanders, and maintenance of biological diversity. If development is sensitive to island traditions and practices, it can also contribute to the retention of rich cultural heritages.

DEVELOPMENT GOALS AND STRATEGIES

Introduction

Imports constitute the bulk of island consumption, thus, to increase self-sufficiency territories must either produce enough to satisfy local consumption, or generate export earnings to balance imports, or both. In view of the constraints to agricultural development and increasing depletion of nearshore marine resources on many islands, total self-sufficiency is probably not attainable. A more attainable goal may be to improve the islands' long-term productive capacities through optimal use of land available for food production (taking into account other land use requirements), redirecting marine harvest to include certain underexploited species and offshore areas, and further development of culture techniques. Strategies for agriculture or fisheries development could be tailored to nonmarket, semicommercial or full commercial production as appropriate. What is appropriate may vary among islands and will depend on many geographical, ecological, and socioeconomic factors.

The integrated management of renewable resources for sustained yields requires a blend of strategies for resource development as well as for resource conservation, recovery, and replenishment. Strategies simply to increase harvests of already overexploited resources may raise yields initially, but will ultimately lead to depletion that may be irreversible.

Agriculture, Agroforestry, and Forestry

Traditional forms of agriculture remain on many islands, especially in the Pacific. These forms evolved to be productive while retaining many natural ecosystem functions. Common Pacific island systems are:

- culture of wetland tare,
- atoll pit taro culture,
- mixed "tree gardening, "
- intermittent tree gardening,
- "lanchos" (weekend farms) and backyard gardening, and
- traditional open canopy culture.

In the U.S. Caribbean, little indigenous agriculture remains, but traditional agriculture systems have been brought into Puerto Rico and the USVI by "down-island" migrants such as the French herb farmers from neighboring St. Barthelemy who practice a specialized form of polyculture of herb and tree crops.

Despite the success of traditional systems, most modern attempts to develop agriculture on the islands largely have followed the U.S. example of consolidated, capital-intensive monoculture requiring imported fertilizers, pesticides, irrigation or drainage systems, and mechanization. Although efforts to develop agriculture in the U.S.-affiliated Pacific islands have been introduced as small-scale projects for limited-resource farmers, many have been unsuccessful for reasons including:

- lack of markets,
- low market prices,
- technologies dependent on imported inputs,
- lack of management skills among farmers,
- diseases and pests, and
- a general lack of commitment by the U.S. and local governments.

Agriculture in the U.S.-affiliated Caribbean islands historically centered around major

Photo credit: C Hodges

Eighty percent of American Samoan households engage in small-scale agriculture, commonly an indigenous polyculture as pictured here.

export crops including such commodities as sugar, tobacco, and coffee. Most of this type of agriculture was abandoned as markets declined and soils became degraded. Development of modern agriculture in the U.S. Caribbean has seen some success, especially in dairy and beef production, and vegetables and fruits. Still, Puerto Rico annually imports about 1.2 billion dollars' worth of food. Most farm operators in the USVI and Puerto Rico also engage in off-farm wage-earning activities. Many lands have been abandoned, and agriculture has adapted to resource loss by reducing farm size and effort, replacing capital-intensive inputs, and changing the composition of output from export crops to domestically consumed products.

Major constraints to agricultural development which apply to all of the U.S.-affiliated islands generally fall into the following categories: biophysical, economic, infrastructural, and sociocultural. Major biophysical constraints are low soil fertility, limited or irregular water resources, and limited arable land of suitable soil types and level topography. Land tenure systems, characterized by fragmented landholdings and clan influence over use rights, are primary cultural constraints. Economic constraints include the small size of domestic markets for agricultural products, availability of high-paying alternate employment, low social esteem of farming, high cost of imported livestock feed and other inputs, and in tourism-dominated islands, the relatively low value of agricultural lands compared to other uses (i.e., commercial real estate). Undeveloped infrastructure on some islands (i.e., lack of rural farm roads, scarcity of transportation to markets) also pose constraints.

Successful tropical island agricultural systems generally exhibit characteristics which mimic and extend natural ecosystem processes by providing for water and nutrient flow, and maintaining a canopy to protect and enhance soil quality at critical periods. An agricultural system which incorporates a diversity of crop species and varieties strengthens the system's resilience to disruption from pests and disease outbreaks and, further, provides a variety of products throughout the year despite erratic weather patterns. For such systems to be readily adopted, they should be based on traditionally used systems and require minimal exotic, nonrenewable inputs such as fossil fuel energy or derived chemicals.

Major characteristics of ecologically and economically sustainable systems include:

- mimicking natural systems through polycultures that incorporate perennial species,
- optimization of agroecosystem components (e.g., maximizing recycling of locally available plant nutrients and natural maintenance of soil moisture) rather than maximization of total yield,
- provision of farmer and consumer security in areas prone to natural disaster and in areas with small and erratic markets, and
- emphasizing incremental changes from traditional agricultural systems to ease and speed adoption.

Although farm size, type of technologies applied, and farming goals are not directly related, agriculture in the U.S.-affiliated islands can be classified into four general types that comprise a continuum of farming systems:

1. Subsistence smallholder: Family (or clan) member(s) producing solely for family consumption, although "surplus" commodities may be sold. Traditional cropping or gathering techniques commonly are used, and the number of crops produced usually is greater than in commercial smallholder systems.
2. Semicommercial smallholder: Individual or family members regularly producing commodities for the market, but only on a part-time basis. Farming mayor may not be regularly directed to home consumption (the farmer may have a full-time wage job in the money economy). Commodities sometimes are produced using modern technology,
3. Commercial smallholder: Individual or family member(s) producing solely or substantially for the market. Commercial smallholders typically are full-time producers who derive their principal livelihood from farming. Commodities are normally produced using modern technology. The range of crops is much narrower than for the subsistence smallholder, The commercial smallholder may have a few wage employees, but most would rely solely on unpaid family labor.
4. Large-scale commercial farming: Usually characterized by significant investment in operation, and use of paid wage and salary workers. Ownership commonly would be corporate in form, with production using modern, high-input technology. Output per unit of land or labor would tend to be much higher than for smallholder agriculture.

"Large-scale" commercial farming on the islands is not large by continental U.S. standards. Commonly, field farming of over 20 acres or annual gross sales over $20,000 is considered a large-scale operation for the U.S.-affiliated islands. Most farming in the U.S. Pacific is subsistence and semicommercial; in the U.S. Caribbean islands, small-scale commercial and semicommercial farming is prevalent. In Puerto Rico, several large-scale enterprises exist, but the most recent of these (a large rice project on the north coast and one Israeli-sponsored vegetable and fruit development on the south coast) have failed. For the most part, island ecologies and economies are not conducive to large-scale farming.

Strategy: Support and Protect Nonmarket Agriculture

Nonmarket (subsistence and part-time) agriculture provides the basis for good nutrition and a cadre of people who will retain the interests and skills allowing future upgrading to semicommercial and commercial systems.

Most subsistence agricultural systems are characterized by high crop diversity, are well adapted to natural conditions, are strongly rooted in local culture, and make maximum use of local resources. These systems generally are stable, sustainable, and ecologically benign. They often provide beneficial environmental services, such as soil stabilization and habitat protection.

Without a conscious effort to preserve such food production systems, even relatively stable systems may become rare or disappear along with the rich genetic heritage they represent. Most traditional systems already are declining. Potential mechanisms to support nonmarket agriculture include:

- consideration of the impacts of development on traditional agriculture (e.g., as a component of environmental impact statements);
- provision of research and extension services for backyard gardeners; and
- enhanced game management to protect traditional agriculture and provide an alternate source of protein for low-income families.

Development projects that might have adverse impacts on traditional agricultural systems could be redesigned.

Strategy: Develop Smallholder Agriculture

Development of smallholder agriculture could generate cash income for subsistence farmers in the pacific, and increase income for small-scale or semicommercial farmers in both the Pacific and Caribbean areas. Modest acreage is required for smallholder operations, which rely heavily on family labor. Policies and technologies which would raise subsistence sector productivity and strengthen urban markets for local farm products could assist in gradually expanding nonmarket production to semicommercial production.

Several common characteristics of traditional systems might be integrated with modern practices to achieve more productive agricultural systems with commercial potential. Improved cultivars of traditional crops, as well as the introduction of new crops and technologies may be appropriate for development efforts. Trees could be incorporated with crops in new, more productive versions of traditional agroforests, space would be used as efficiently as possible, and crop combinations designed to maximize overall productivity on a sustainable basis. Similarly, livestock could be penned and fed agricultural wastes, thus providing a supplementary protein or income source and a supply of organic matter to re-apply to fields.

Commercial small-scale operations may be handicapped by small and unstable markets or inadequate transportation services. Moreover, small producers commonly are not able to produce uniform quality products, do not have access to adequate capital, and lack marketing skills. Thus, development of small-scale farming systems probably would require strong government and private sector support for credit, identification and extension of appropriate technologies and crops, and identification and creation of market outlets.

Development of smallholder agriculture is likely to benefit the large number of subsistence farmers (Freely Associated States), semicommercial, and part-time farmers (American Samoa, Guam, the CNMI, Puerto Rico, and the USVI) in the U.S.-affiliated islands. Further, it is likely to be more compatible with the present land tenure systems than would large-scale farming. Smallholders tend to produce a large range of commodities which may alleviate marketing constraints in small size markets.

Photo credit" Office of Technology Assessment

This semicommercial mixed polyculture on St. Thomas, USVI, provides more than 30 crops, including tree crops, for the farmer's subsistence and for sale in a roadside stand.

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Strategy: Develop Intensive Commercial Farming

Although subsistence and semicommercial farms may satisfy many local food needs, additional commercial and competitive operations are needed to generate cash to pay for imports. The high input requirements of large-scale commercial agriculture limit its applicability on most of the U.S.-affiliated islands. Large parcels of land with uniform soil types are scarce in the Pacific territories; where they occur in the Caribbean, they are expensive. Local markets to absorb large product volumes are also lacking, export potential is difficult to achieve, and transportation is poor. Although these factors all constrain the development of large-scale commercial farming, particularly in the Pacific, selective opportunities for such development exist. On Puerto Rico some large-scale farming is possible. New technologies, including drip irrigation and improved pasture technologies, may be needed to increase productivity and raise the quality of crops and livestock with large-scale commercial potential. In some cases, improvements in management alone may increase yields.

Highly productive, commercial agriculture could be developed on a smaller scale in other island areas. Certain carefully selected crops and modern technologies could be adapted to tropical island ecology. Where appropriate, increased mechanization for tillage, seeding, spraying, and harvesting could be made available as agriculture develops.

An alternative to improved pasturage and more intensive field farming is cultivation in controlled environments. Various types of container and site-controlled agriculture, ranging from small containers to permanent greenhouses, offer potential for development of intensive agriculture in the smallest U.S.-affiliated islands. Controlled-environment cultivation may overcome some constraints posed by land and freshwater availability, high land prices, unproductive and highly erodible soils, and pest and disease outbreaks. Such technologies (hydroponics, greenhouses, and shadehouses) already have been implemented on some islands with varying degrees of success. Yields from container agriculture commonly are very high although labor and water requirements also are high.

Tropical greenhouses permit growth of crops that cannot withstand heavy rainfalls typical of the tropics. Shadehouses are used throughout the islands for tree and perennial crop propagation and may also be used to grow cool-season crops sensitive to high temperatures and long day lengths. Hydroponics—a totally controlled system with artificial growth media, and high capital requirements—is probably feasible only for certain high-value herbs and vegetables. Such systems have been successful in the U.S.-affiliated Caribbean islands and on Guam, and are technically suitable for other islands where water supplies are adequate.

Very high-value specialty crops offer another possible commercial agricultural opportunity for many islands: spices, essential oils, specialty fruits and vegetables all have development potential and some (e.g., Pohnpei black pepper) have already penetrated world gourmet markets. High returns to labor and management are possible from small plantings. Strict quality control would be necessary which may initially require private joint ventures or government management.

Strategy: Develop Commercial Forestry

Commercial forestry development may be possible on some lands unsuitable for other uses. The forestry program in Puerto Rico, a cooperative operation with the U.S. Forest Service, has had considerable success in species enrichment of forests and in increasing total forest cover. The USVI Urban Forestry Program provides mahogany culled from roadside plantings to small-scale furniture and crafts producers. Forests in the Pacific islands commonly are used for construction materials, charcoal, and fuelwood, but little forest maintenance, enrichment, or reforestation is practiced. Reforestation or afforestation of severely degraded lands may renew soil productivity to allow profitable use of these lands.

Strategy: Develop Research Programs Relevant to Island Needs

In order to accelerate agriculture development, research programs need to be directed to specific goals relevant to island development, Although the need for research is widely recognized, the research capacity of many U.S. island institutions is limited. Research is hindered further by inadequate or unavailable baseline data and skilled research staff. The U.S. Department of Agriculture (USDA) has designated research institutes for tropical agriculture (the Tropical Agriculture Research Station in Puerto Rico and the Tropical Fruit and Vegetable Research Laboratory in Hawaii) and for tropical forestry (the Institute of Tropical Forestry in Puerto Rico and the Institute of Pacific Islands Forestry in Hawaii). However, funding for these institutions has declined in recent years.

Research performed by local institutions could be supplemented by taking advantage of research performed by other regional institutions. Research performed by the University of the South Pacific, the South Pacific Commission, the Caribbean Agriculture Research and Development Institute, and other regional research institutions can provide useful information. It probably would be to the advantage of small island governments to establish cooperative relationships with appropriate international research institutions or major universities that can assist in basic research.

Nearshore Fisheries and Aquaculture

Islanders have harvested tropical aquatic organisms for a tremendous range of utilitarian, symbolic, and ornamental functions since prehistoric times. The sea was important as a food source in the Caribbean and supplied an estimated 90 percent of the Pacific islanders' animal protein. Fishing was an integral part of traditional high island socioeconomy and essential to life on atolls. Today, as in the past, marine resources still supply a large percentage of consumed protein.

Photo credit: C. Wahle

Nearshore fishing takes place primarily in the vicinity of coral reef ecosystems, a major feature of atolls and tropical nearshore waters.

Tropical nearshore environments are biologically complex and variable. Ecologic structure and composition vary widely within and among islands, even over short distances. Nevertheless, nearshore ecosystems in the islands generally comprise three distinct, but intimately interrelated habitats: 1) mangrove forests, 2) seagrass meadows, and 3) coral reefs. Many animals migrate among the habitats during different times in their life cycle, and nutrients are efficiently captured, retained, and recycled. However, these systems are highly susceptible to disruption and degradation by natural or manmade stresses. Natural recovery processes can take decades once the source of stress is removed.

Nearshore resources effectively are the social security reserve and unemployment insurance 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, food imports, and social costs of diminished self-esteem.

The major constraints to nearshore tropical fisheries development include inadequate knowledge of complex ecosystems, inherently limited productivity of offshore waters, and vulnerability of tropical fisheries to natural and human disturbances. Equipment maintenance and servicing, and problems of transporting inputs and exports also hinder development. Scientific information on the current status of nearshore marine resources is fragmented and inconclusive. Without concise data on resource distribution and abundance, 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 sea fisheries reduce the value of these biological and bioeconomic models. The effects of selectively fishing certain species, fishing the same species at different depths, the relationships between nearshore and offshore stocks, and fish population dynamics, are less well understood in tropical than in temperate waters.

Strategy: Support Subsistance and Small=Scale Commercial Fisheries

Nearshore marine resources are susceptible to overexploitation, thus, technologies that simply increase nearshore harvests probably will have long-term negative impacts on fisheries' potential. The productive capabilities of nearshore systems have already been exceeded in many areas and are being approached rapidly in others. Therefore, little potential exists for significant, sustainable expansion of these fisheries.

Subsistence and small-scale fisheries are nonetheless important for their food-, income-, and employment-generating potential. As nearshore resources have come under greater pressure, fishermen have increasingly moved offshore and/or made more use of migrating pelagic species sometimes found in lagoons and at reef edges. Such resources, as well as other underexploited species (possibly shark, deepwater shrimp, and other species beyond reefs) probably offer opportunities in the U.S. Caribbean and Pacific for expansion of small-scale fisheries—commercial, recreational, or subsistence. Development policies in both areas emphasize underused marine resources. In some cases, it might be possible to develop fisheries for species not desired locally, but valuable as export commodities. However, even underexploited resources can become quickly depleted without careful management.

Strategy: Develop Aquaculture

Aquiculture, the cultivation of aquatic organisms in fresh, brackish, or marine waters, began over 2000 years ago in China. Interest in aquiculture is apparent in the U.S.-affiliated tropical islands. Aquiculture offers a potential mechanism to supply fishery products to local markets, increase job opportunities and income in rural areas, generate export dollars, and supplement marine resources through reseeding programs.

Systems range from low maintenance marine enclosures to intensively managed hatcheries and raceways, and from subsistence production to production for commercial markets. Applicability of these techniques may depend on many factors: including availability of appropriate sites; technology, capital, and labor requirements; and market potential.

Sea ranching involves collecting and growing wild or cultured stock—usually sessile or sedentary species—under managed natural conditions. This carries the benefit of a secure food source, but also the risk that natural stocks will be collected too rapidly, reducing natural productivity. Control and conservation measures may mitigate this problem,

Culture in natural waters includes bottom and near-bottom intertidal and subtidal culture of sedentary species (clams, oysters, conch, seaweed). This is practical only where natural supplies of phytoplankton are sufficient to serve the food needs of cultured species–generally these areas are restricted to larger islands. Seaweed cultivation, on the other hand, may be well suited to small, remote islands, since the thalli can be sun-dried and stored for many months.

Culture of marine fish in floating net pens or cages is possible where space is available in protected estuaries and bays. Several species of finfish could form the basis for mariculture in the Pacific and Caribbean.

A variety of crustaceans (prawns and shrimp) and fish (rabbitfish, milkfish, mullet, redfish, tilapia) are suitable candidates for fresh or saltwater pond culture on U.S. islands. Commer-

Photo credit: Office of Technology Assessment

Techniques have been developed at the Micronesia Mariculture Demonstration Center in Palau for culture of giant clams—unique among farmed animals in that they derive their nutrition from symbiotic algae embedded in their mantles and thus require no supplemental feeding.

cial ventures based on pond aquiculture have been developed on Guam and Puerto Rico. These have had mixed success, but interest in this form of aquiculture remains high. There is potential for expansion of pond farming in both regions not only to raise food species, but also high-value species for the aquarium trade, and bait fishes to supply tuna fisheries.

All of these forms of aquiculture are possible in tropical environments, however, adaptive research is required to test the applicability of specific culture systems to local environments and species. Technologies must be socially acceptable and economically feasible. Logistical constraints such as difficulties in supplying inputs and delivering products should be considered.

Land availability constrains the development of extensive pond aquiculture on most islands. However, semi-intensive commercial operations may have some potential. Such operations, which are already being developed in Puerto Rico, are characterized by smaller, more engineered and managed ponds, more supplemental feeding, and higher stocking densities than extensive systems. Intensive culture involving even higher degrees of environmental control and technical expertise probably is not yet feasible for most U.S. islands. Aquiculture development in many island locales may be most successful where simple methods are used to produce high-value species to supply hotel and tourist facilities.

TECHNOLOGIES TO SUPPORT RESOURCE DEVELOPMENT

Several constraints to resource development might be addressed through appropriate technologies for food storage, processing, distribution, and marketing. In general, reduction of crop losses and maintenance of product quality is easier than expanding and intensifying sustainable production. Tropical diseases, pests, and spoilage all take a toll on crops and livestock before and after harvest. Nearly 30 to 40 percent of island crops may be lost to a combination of these factors.

Preharvest Control Technologies

Appropriate pest, disease, and weed control can contribute to reduction of losses and damage, and thereby, effectively increase yields and marketability of crops and livestock. Use of pest- and disease-resistant crops is a traditional strategy that might be more widely applied on the islands following development and field trials. Certain traditional cropping systems also serve to control pests, i.e., polyculture (with some plants serving as pest barriers), field and crop rotation, and careful timing of plantings.

Chemical controls are easily applied and immediately effective, but may destroy the natural balance between pests and their natural predators, leading to more severe problems in the future. The effectiveness of chemical controls generally is short-lived and environmental contamination poses a serious risk.

Biological control employs the use and manipulation of natural predators to control pests, and may be preferable to chemical controls.

However, considerable research, experimentation, and field trials will be necessary to identify appropriate control agents. A balance of biological and chemical controls, and polyculture may offer the best long-term pest/disease control strategy. Highly skilled and motivated agricultural extension services will be integral to the success of this strategy. Strong quarantine programs to prevent reinfestation could complement such efforts.

Food Preservation and Processing

Improved storage and transportation could greatly reduce postharvest loss of agriculture and fishery products to spoilage, insects, rats, and other pests. Refrigeration can achieve these results, but generally it is constrained by lacking or irregular power supplies. Newly developed solar-powered refrigeration systems offer some promise for cold storage at remote localities; however, development costs would be high initially.

Other methods of food preservation and processing range from traditional sun-drying and smoking of fish and coconut meat to modern freeze drying and canning technologies. Some processing and preservation methods are practiced on the islands, and others which are not yet practiced might be applicable. However, most modern processing technologies are energy-intensive and therefore expensive. Establishment of regional or local cooperative food processing centers may make processing more affordable.

Market Development

Steps to develop local markets for island products could include gradual increases in the use of locally produced commodities for federally funded programs, for U.S. military personnel, and for tourists. Currently, only limited amounts of island products enter into these markets. Several factors hinder greater reliance on local products by these sectors, including irregular and limited supplies, and irregular product quality.

There is potential for development of regional markets in the Pacific, but this will depend on strengthened transportation services, and establishment and/or revision of quarantine regulations. In the Pacific, Guam and the CNMI have better export potential because of air transport links with Japan. Currently, Japanese markets remain closed to Micronesia exports because of strict quarantine regulations.

Removal of import tariffs from Caribbean basin countries has seriously reduced the potential for export of fresh produce from Puerto Rico. To increase exports under these conditions, Puerto Rico probably will need to both reduce production costs and improve product quality to become more competitive.

Cooperatives

Cooperatives seem to be a practical way of organizing and mobilizing capital and people in developing communities. Local producers might be encouraged to expand crop production if cooperative processing and/or marketing facilities guaranteed sale of surplus produce. Agriculture and fishery cooperatives can also competitively purchase supplies, services, and equipment that individuals cannot afford. The more highly organized cooperatives provide fully integrated programs for their members, and cover equipment purchases, offer assistance in processing and marketing, and even research and development.

While some cooperatives are successfully operating on the islands (e.g., Saipan Farmer’s Cooperative Association), others have struggled or failed. Local governments might encourage their development through investing in infrastructure and providing tax benefits and technical assistance.

Vertical Integration of Operations

Contract farming to vertically integrate small farmers with large agricultural production/ processing and marketing operations is likely to help increase food production on U.S.-affiliated islands. Small farmers contract with a large company to raise products, which the company purchases at a guaranteed price, processes, and markets. The company may also provide farmer-contractors with some agricultural inputs and production assistance. Such enterprises are capable of economies of scale and benefit both producers and consumers. There are several successful, vertically integrated agricultural enterprises in Puerto Rico. Black pepper production on Pohnpei is also integrated, although the processing and marketing unit is government run.

TECHNOLOGIES TO SUPPORT RESOURCE SUSTAINABILITY

Agriculture cannot be a productive sector of island economies if soils become too nutrient-depleted or if soil erosion is uncontrolled. Maximum economic yield cannot be attained offshore if marine resources are harvested indiscriminantly. Many technologies supportive of resource sustainability are aimed at minimizing depletion, and at regulating use of resources.

Agriculture

Soil Conservation

Soil erosion and degradation is greatest in conventional clean-tilled row-cropping, particularly when fallow periods are short, Prevention might include lengthening fallow periods to take advantage of the natural regeneration capacity of the ecosystem, restricting and controlling burning, and applying soil-conserving cultivation and culture practices (i.e., terracing, contour farming, mulching, conservation tillage, and planting of soil-conserving crops and hedgerows).

Each technology has advantages and disadvantages. For example, conservation tillage contributes to reducing soil erosion and labor and equipment requirements, and increases soil moisture retention. However, this technique relies heavily on herbicides for weed control and creates potential habitat for pests. Contour farming is inexpensive, but becomes less effective as the inherent potential for erosion increases. Steep lands can be terraced, but surface compaction and pending may result. Terrace construction is expensive and may require removal of topsoil from large areas. Considerable expertise will be needed to determine which soil-conserving technology is appropriate for application in a specific area.

Soil Amendments

The development of local soil amendments may be necessary to offset the nutrient draining effects of commercial agriculture technologies. Most soils in the islands are relatively nutrient poor due to a variety of factors, thus, the need for fertilizers (organic or commercial) to produce and sustain commercial yields is imperative.

Despite evidence that tropical soils respond much differently to such fertilizers than temperate soils, and despite the potential adverse impacts of fertilizers on groundwater and marine ecosystems, commercial fertilizers are commonly used on the islands. Research is needed on other methods of maintaining soil fertility such as green manuring, intercropping with legumes, fallow periods, and crop rotation. The possibility of using municipal wastes as compost also might be explored. Evidence suggests that the efficiency of commercial fertilizers may be increased if they are used in combination with organic fertilizers and/or mycorrhizae, or with zeolite minerals.

Fisheries

For many Pacific islands, management of resources to ensure sustained yield is even more imperative in the marine than in the terrestrial environment. These resources provide for many subsistence needs and represent a food reserve in the event of natural calamities.

Photo credit: Office of Technology Assessment

Plastic mulches, applied **here** on St. Croix, USVI, serve to inhibit weed growth and enhance soil moisture retention.

Modern Regulatory Measure

Although marine resource management was traditionally practiced by islanders, rigorous scientific efforts to manage these resources are relatively recent. These commonly involve regulatory measures to restrict harvest methods and seasons in order to conserve individual stocks and to restrict access to critical habitats. The Caribbean Fishery Management Council has placed restrictions on types of gear that may be used for harvest and has established minimum permissible sizes for some species. Other restrictions on seasons or areas are also possible, but have not been enacted. Modern management efforts in the Caribbean and the Pacific are also limited in that they focus on single species or groups of species rather than on entire ecosystems.

Parks

Ultimately, some extremely sensitive ecosystems may have to be given special status as marine parks or reserves. Ecosystems such as coral reefs and mangrove forests which are important habitat for many marine species and are highly vulnerable to degradation are prime candidates. As yet there are few protected marine areas in the U.S. island territories. If successfully sited, established, and managed, marine parks and reserves could protect critical areas, and also provide a source of recruitment for restocking exploited surroundings.

Traditional Management Methods

While fishing efforts might be limited by any or all of the above methods, enforcement is dif-

Photo credit: Office of Technology Assessment

The Ngerukewid Islands Wildlife Refuge in Palau, encompassing 640 acres, includes considerable open marine areas and unique marine lakes.

ficult in tropical areas where species numbers are high, and catch and market data are scarce. Biologists also know less about tropical than temperate fisheries. Despite attempts to protect overexploited resources, western cultures largely have been unable to manage tropical reef fisheries efficiently. Traditional management measures are a part of village lore in some Pacific islands. Some management measures, reveal a sophisticated knowledge of ecological relationships. Traditional use rights in fisheries (TURFS) of the Pacific islands are based on the principle of limited entry and other conservation strategies. TURFS continue to play a major role in some island cultures. On some islands, they have been seriously disrupted by western technologies and by economic pressures of commercialization.

Existing TURFS may contribute to fisheries conservation in the U.S. Pacific islands. Management schemes and regulations recognizing traditional marine tenure in the islands could be established. Private enterprises, such as seaweed and giant clam farming, pearl culture and trochus fisheries, would be likely to respond well to exclusive ownership. In areas where TURFS have lapsed, local management and enforcement responsibilities could be instituted.

TURFS cannot, however, guarantee successful conservation. TURF systems are diverse and some are more useful in fishery management than others. TURFS pose an impediment to commercial tuna fishermen who obtain bait fish from these areas, often with great difficulty. TURFS may also impede nearshore harvest of migratory pelagic species.

Artificial Habitats

Management of marine resources for sustained yields might also involve use of artificial reefs and fish aggregation devices (FADs). Artificial reefs range from scrap automobiles and tires to specially designed and engineered structures. Whether the introduction of artificial reef habitats enhances overall fisheries productivity or merely increases local populations by attracting fish from elsewhere is not known—there is evidence for both results. FADs are anchored buoys placed beyond reefs to attract pelagic fish. Although catch rates are significantly increased by their deployment, the impact of FADs on regional fish stocks and the sustainability of high catch rates have not been evaluated. Until such questions are answered, artificial reefs and FADs probably cannot be determined to contribute to fisheries management for sustained yields.

TECHNOLOGIES TO SUPPORT RESOURCE RECOVERY

Extensive degradation of terrestrial resources and overexploitation of nearshore marine resources is apparent in many insular areas. Programs aimed at resource restoration and recovery will likely be important to long-term ecologic and economic stability of the U. S.-affiliated islands. A primary cause of soil and land degradation has been forest clearing, thus, revegetation programs represent a potential strategy for improving terrestrial productivity. Traditional and commercial agroforestry, short or long rotation forestry, or growth of ground cover in the form of nitrogen-fixing legumes all offer possible options. Selection of plant species and of rotational strategies is critically important to the creation of stable and productive ecosystems. Reforestation or afforestation of degraded lands brings many benefits aside from products. Forests contribute to reducing wind erosion, protect and improve soil fertility, regulate soil water and contribute to flood control. They also provide wildlife habitat. Agroforests provide the additional benefits of mixed cropping.

Like terrestrial forests, mangrove and seagrass habitats have suffered extensive damage. Success of natural or induced recovery schemes is variable, but recovery programs represent management options. Few attempts are currently being made to restore such habitats. From an ecological viewpoint, the best strategy is probably to protect these habitats from adverse impacts. They are valuable resources that may take up to 100 years to recover naturally, if at all. Where possible, restoration is costly and success is not guaranteed.

As the nearshore resources of the Pacific and Caribbean regions are becoming overfished or degraded, the idea of enhancement and reseeding of these resources is gaining attention. Restoration of marine resources generally means restocking of selected species. Farming, or aquiculture of marine organisms may become important to restock or reseed depleted fishery stocks. However, without appropriate controls on subsequent harvests, a reestablished population may be exploited at a greater than optimal rate and possibly reextinguished.

Integrating Technologies

Many technologies for renewable resource development can be integrated with technologies for energy production and conservation, waste treatment, or with each other. Potential exists for development of energy integrated farms, and operations that integrate aquiculture with agriculture, waste treatment, and energy production.

Energy Integrated Farms

Energy integrated farming offers a means of transforming animal and crop wastes into use-

Photo *credit: Office of Technology Assessment*

Slurry from biogas digesters can be directed through aquaculture—here, tilapia and water hyacinth culture—before being discharged through agricultural irrigation systems, providing numerous additional benefits to energy generation.

ful products. Organic matter is fermented into biogas (a methane-rich gas mixture) and a thick slurry in oxygen-free digesters. Completely fermented slurry is virtually odorless, has reduced harmful organisms, and retains the fertilizer value of the original materials. It can be used as a livestock feed additive, potting soil, and fertilizer. Biogas can be used to generate light, and to operate stoves, refrigerators and even modified gas engines.

The quantity of useful products depends on the amount and type of organic matter, digestor capacity, and ambient temperature. Abroad scope of applications are possible, ranging from small, single-household digesters, to huge "high-tech" complexes requiring corporate backing. Widespread application is constrained by lack of large livestock operations, design and operation expertise, and capital.

Use of energy-integrated farming technologies in the near term will probably be limited to a few farmers with large manure supplies and sufficient water resources for system operation. Within 8 to 10 years, small-farm biogas units could probably be implemented more widely. Energy derived from animal and crop wastes, wood, and other plant materials offer a potentially important substitute to imported oil for many islands.

Aquaculture/Energy Production Systems

Considerable energy is needed to pump seawater to mariculture farms. If such farms could be integrated with powerplants, which pump and discharge large quantities of water for cooling, considerable savings might be realized. Powerplants and mariculture systems could be

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designed to maximize benefits. Water pumped from under the thermocline is relatively rich in nutrients for aquiculture and would provide cooling for the powerplant,

Integration of aquiculture with innovative forms of energy production that exploit the energy of the sea (i.e., ocean thermal energy conversion systems, wave energy systems and hypersaline solar ponds) may also be possible once such systems become more readily available. Integration of aquiculture with these technologies may enhance their economic feasibility for some islands.

Waste Treatment Systems

Cultivation of seaweeds or other aquatic plants has been integrated with water treatment in the United States and has potential for application on tropical islands. There may also be opportunities for increasing agricultural productivity with land application of sewage sludge, treated wastewater, and municipally derived compost.

Planning/Policy Considerations

Improved resource management planning requires careful consideration of development constraints and opportunities as well as numerous other factors: information needs, possible sources and management, choice of strategies for plan implementation, and the role of traditional law and local people in management planning and implementation.

Each of the U.S.-affiliated island governments has designated a Planning Office to compile information on factors affecting economic development and to present a framework for rational development planning. A number of plans analyzing resource management and development activities have been prepared in each island area either by these offices (e.g., Coastal Zone Management plans) or by the United Nations. However, different plans are rarely centralized or aggregated. The 5-year comprehensive development plans prepared by the Freely Associated States (under the terms of the Compact of Free Association) tend to be too general to provide real guidance to decisionmakers. Planning processes may go awry for these and other reasons, including:

- inadequate "in-house" planning expertise and heavy demand on existing island planners,
- inadequate problem specification,
- lack of understanding of natural processes,
- inadequate specification of management alternatives,
- use of planning as a substitute for management,
- lack of resources for planning, and
- lack of understanding of the social and political contexts in which plans are to be implemented.

Information Procurement and Management

A primary obstacle to the development of baseline ecological surveys is the cost of data collection, storage, and retrieval. Since few islands can afford a major data acquisition effort, an initial priority could be to ensure collection of data essential to program implementation. An incremental approach could then be taken to collect desirable data, this could emphasize the use of island residents as sources of resource-related information,

Within many governments, data are collected by more than one agency, sometimes resulting in duplication of effort. Data maybe collected in different formats and on different scales making sharing of information difficult. Opportunities to ameliorate these problems include reorganization or centralization of data collection, storage, and processing responsibilities, and ensuring coordination among various agencies that currently share these responsibilities. An island-by-island assessment of data collection could be a first step toward identifying opportunities for data sharing, and for collaboration on new data acquisition.

Traveling workshops could provide short-course training on information collection and mapping techniques. Distribution of data to users may be facilitated with data lists and inventories; reproduction of reports, air photos, and maps; workshops and seminars; and participatory approaches to planning.

Analytical Planning Techniques

Restriction of resource use to activities with minimal adverse impacts is currently the dominant approach to resource management on the U.S.-affiliated islands. In the short run, therefore, environmental impact statements (EISs) will probably remain the primary technique used for resource and plan assessments. Several "off-the-shelf approaches to impact assessment make it a relatively cost-effective and simple procedure. A review of procedures for conducting EISs could help planners develop those most relevant to island environments. Post-project evaluations are one way to reveal the strengths and weaknesses of current EIS procedures.

Environmental impact analysis, however, is a short-term investigation of the likely impacts of previously identified policy or project options and, thus, does not permit evaluation of the full range of development alternatives. Other methods are being developed to allow consideration of environmental and resource information early in resource development planning, including resource suitability analysis, carrying capacity analysis, extended benefit/cost analysis and multi-objective analysis. Few of these techniques have been applied to U.S.-affiliated islands. If such methods were fully developed and implemented, however, repeated EISs might be rendered redundant.

Resource suitability analyses, which can range from simple map overlays to complicated computerized geographic information systems, provide information about the supply of resources at various levels of suitability for various uses. Such analyses generally comprise a method of delineating landscape or seascape units on a map and assessing the capability of these areas to sustain an array of potential uses without unacceptable degradation and given certain levels of management and technology. Carrying capacity analysis, a method of determining the optimal human population that can be supported at given levels of technology and amenity, also has been used to help identify critical resource use decisions.

Benefit-cost and multi-objective analyses both attempt to encompass the array of secondary and intangible benefits and costs from alternative programs or projects. Benefit-cost analysis incorporates value judgments regarding the translation of unquantifiable variables and social preferences into money values. Multi-objective planning does not force all effects into the same measurement units, but relies on decisionmakers' assignment of relative or weighted values for each category of impact.

Although based in science, interpretations of factors such as custom, skills, innovativeness, likely technology and institutional capability come into play in making the ratings. Thus, each technique depends on expert judgment and public participation as well as on manipulation and interpretation of scientific information,

Participatory Approaches to Planning and Management

The need to incorporate public participation in resource development planning is based on several factors: 1) local knowledge and understanding of an area's natural systems often complements or exceeds scientific knowledge, 2) public participation in resource-related planning and policymaking may yield benefits in compliance and enforcement of local regulations; and 3) actions that respect people's priorities and that are planned with local input and approval are more likely to succeed than actions that require intensive regulation and enforcement.

Generating public participation in resource management projects can be extremely time-consuming and costly. In order to tap local sources of information, it usually is necessary to give equally in return. The following conditions have been suggested as guidelines for public participation in resource management:

1. long-term presence to understand a community's structure, build rapport, and foster mutual respect;

2. local involvement in all aspects of a project from design to implementation, as well as respect for local input and objectives;
3. local participation in concrete activities from which people can gain tangible benefits; and
4. education and research activities in which local people are equal partners with government, project staff, and professionals.

Modern Law and Traditional Custom

Custom is a valued asset of U.S.-affiliated island communities. Values such as respect for traditional leaders, consensus-based dispute resolution, and significance of clan membership have survived the impact of colonization and modernization, and form a significant part of the identity of island peoples. The opportunity exists to blend traditional management methods and the democratic system as Micronesia develops self-government. One advantage of retaining traditional methods of guiding social behavior is that these require no legislative decree or policing—they are ingrained in local belief and custom. Traditional resource management tenets often have ecologic rationale.

A formalized system for incorporation of Pacific island custom into a system of law appropriate for use in island societies could include: explicit recognition in constitutions, statutes and case law of the value and primacy of custom; recognition of custom whenever a new law is adopted; and court adherence to the constitutional and legislative mandates to preserve custom. Judges knowledgeable of local customs could use that knowledge in decision and rule-making in a way that ensures preservation of customary values and principles. Further, they could recognize that access to resources is a part of the livelihood of island peoples, and that complex systems of ownership and use have evolved that do not resemble western concepts of ownership. In resolving resource-related disputes, judges may wish to delay intervention until traditional leaders are consulted and other methods of dispute resolution are exhausted.

SUMMARY OF ISSUES AND OPTIONS FOR THE U.S. CONGRESS

Economic growth of the U.S.-affiliated islands is likely to be largely dependent on the sustainable development and management of renewable resources, and on a tourist industry that is compatible with development and management goals. As the primary policy-making body for the islands, Congress can foster pursuit and achievement of these objectives in a variety of ways:

- by tuning appropriate Federal agencies and assistance programs to the special situation and needs of islands;
- by coordinating the work of agencies responsible for various aspects of resource management on the islands;
- by making opportunities for Federal assistance directed at developing sustainability of resource uses readily apparent and more easily available to islands; and
- by providing additional assistance in the areas of data collection and management, planning, education, extension, training, and research.

Various options exist within all of these areas to improve and expand Federal support for agriculture, forestry, fisheries, and aquaculture development on the islands.

Congressional Oversight and Federal Agency Coordination Issues

This study reveals important links among renewable resource use, environmental protection, island cultures, political systems, and economic development. However, no single congressional subcommittee of the House Committee of Interior and Insular Affairs, or of the Senate Committee on Energy and Natural resources is structured to deal with all of these interrelated issues as they apply to resource management on the islands. Activities related to the U.S. islands, moreover, are spread through many programs of USDA, the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Department of the Interior (USDOI), making coordination and congressional oversight difficult. The USDOI's Office of Territorial and International Affairs (OTIA) is responsible for promoting the economic, social, and political development of the U.S.-affiliated islands and for analyzing, developing, and coordinating USDOI's policies and programs pertaining to international activities.

To take advantage of the OTA findings in this assessment, mechanisms are needed to coordinate and perhaps increase appropriate support of Federal island-related activities and to facilitate congressional oversight of these activities.

Option: New Congressional Subcommittees.—Congress could establish new House and Senate subcommittees to deal with integrated resource management on the U.S.-affiliated islands.[1] These would provide focal points within Congress where approaches to island resource development could be handled and integrated. This could benefit island officials and strengthen existing links between the U.S. Government and the U.S.-affiliated islands. The importance of the islands to national security will probably increase in the next decade, making such links more important. Alternatively, Congress could establish a congressional Joint Territorial Policy Study group to analyze island matters requiring congressional action.

Option: Increase Federal Program Coordination.—Congress could hold oversight hearings on OTIA coordination of Federal agencies programs and plans for activities in the islands. Alternatively, or in addition, Congress could authorize and support establishment of an Interagency Coordinating Group on Resource and Economic Development in U.S.-affiliated Islands which could represent the relevant Federal territorial policy and resource-related Federal agencies. This group could assess current insular participation in Federal resource programs, identify means for integrating programs within and among agencies into more effective and cost-effective packages and suggest funding priorities for technical assistance from the agencies. Representatives could serve as insular government contacts with Federal agencies.

Finally, Congress could designate the U.S. Man and the Biosphere Program (U.S. MAB) as the lead coordinating agency for Federal resource-related activities on the islands and encourage increased coordination between U.S. MAB, OTIA and other Federal agencies, in addition to those already involved in U.S. MAB activities. Research on the ecology and rational use of small island ecosystems has been identified as a priority for U.S. MAB support. Increased support for the U.S. MAB islands program could allow expansion of research and training in the U.S.-affiliated islands, especially in the Pacific, where the MAB Directorate has been inactive, and could improve coordination of federally supported, resource-related activities in the islands.

Option: Review Effectiveness of Federal Island Programs.—Many executive agency programs focused on island resource issues receive favorable comment from island resource managers, planners, and government representatives, some do not. To help determine which approaches have worked best in the islands and which ones should be modified to improve their chances of success, Congress could direct USDA, NOAA, and USDOI each to evaluate the effectiveness of their own programs related to renewable resource management on the islands, and to appear at oversight hearings related to island issues.

Alternatively Congress could direct the General Accounting Office to conduct such reviews. While individual agencies are familiar with their own programs' details and likely could perform reviews more easily, there may be advantages to having an outside agency perform the task,

I Moving in this direction, the House Committee on Interior and Insular Affairs established a new Subcommittee on Insular and International Affairs early in the 100th Congress.

Data Collection and Information Management Issues

A first requirement for resource and economic development planning in the U.S.-affiliated islands is to collect comprehensive and up-to-date resource, economic, and social data and make it easily accessible to planners. Techniques also are needed to store, synthesize, analyze, and manipulate data in ways useful for resource development planning. With the modern, reasonably inexpensive computer systems available today, data storage, synthesis, analysis, and dissemination are not insurmountable problems.

Existing natural resource databases on most islands generally are inadequate, as are the appropriate economic and social data needed for informed judgments on future island development. Efforts to collect data in several broad areas could greatly assist planners. For example, in order to minimize the possibility that economically or environmentally inappropriate agricultural technologies are introduced on islands, and to determine which production technologies have the greatest chance for ready and profitable adaptation, there is a need for specific information on existing farm operation methods. Before new aquiculture or fisheries technologies are introduced, similar marine resource use data must be collected. While local departments of marine resources collect aquatic and fisheries data in the Caribbean, there is no data collection and aggregation structure for the Pacific Islands.

The U.S.-affiliated islands also have difficulty identifying what island-relevant Federal data/information programs exist, and which of various Federal agencies house what kinds of data that might be useful for resource planning.

Option: Analyze Island Databases and Information Management Systems.—Congress could direct USDOI to lead an interagency task force with island representation to conduct a critical evaluation of the natural resource, social, and economic databases, and data-handling methodologies for the various U.S.-affiliated islands. The task force could report to Congress on the status of island databases and on data management needs of the islands, including both equipment and personnel needs. At subsequent hearings, Congress could determine appropriate actions. Such an analysis has long been needed and could foster improved linkages between the Federal agencies and island governments. However, it maybe argued that immediate direct action to collect needed data is preferable to "another study. "

Option: Assess Federal Data and Information Programs Likely To Be of Benefit to the U.S.-Affiliated Islands.–Congress could direct USDOI to lead another, perhaps subsequent, interagency task force with island representation to assess the data/information and programs of each Federal agency likely to benefit islands in integrated renewable resource management and planning. A summary of findings could be published, and congressional hearings held. This action could reduce the possibility of duplicating data collection efforts or of overlooking Federal programs that could be applied appropriately to the islands, as well as expedite island resource-related planning activities.

Option: Establish Regional Information Clearinghouse(s).–Congress could establish, or support one or more existing regional island centers (e.g., the Pacific Basin Development Council, East-West Center, Micronesia Area Research Center Information System, Eastern Caribbean Center) to act as a clearinghouse for: Federal announcements on new programs pertaining to islands; island government announcements; similar international program information; market information on agriculture and aquiculture; and information on specialty, background, and availability of various island experts. Once gathered, this information could be assessed and disseminated to island governments.

Such a structure could facilitate and speed communications between the continental United States and the affiliated islands, and possibly between the Pacific and Caribbean regions. However, development of this network would require additional funding at a time when new funding is scarce.

Option: Reactivate USDA Minor Economic Crops Computer Database.—USDA previously maintained a database on minor economic crops, many of which could grow in tropical climates. This database no longer is kept active, and no other similar database is known to exist. Congress could direct USDA to reactivate, update, and maintain this database, and continue to include information on: climate and soil conditions necessary for various crops, crop yields, nutritional and medicinal properties of various crops, and their potential for intercropping and for use in agroforestry.

The database provides one mechanism for information sharing between the Caribbean and Pacific islands, and historically costs little to maintain.

Option: Develop Small-Scale Island Farmer and Fishermen Profiles.—Congress could direct the USDA Extension Service to gather data and prepare profiles of small-scale farmers in the U.S.-affiliated islands for use in the process of identifying environmentally appropriate and economically beneficial agricultural technologies for introduction to the islands. While such profiles are being developed the rate of new technological implementation might be slowed, but the risk of unsuccessful introductions also may be reduced. In addition, Congress could direct the Sea Grant Marine Extension Service to develop Artisanal Fisheries Profiles, similar to the farmer profiles.

Option: Fisheries Statistics Collection.—Congress could provide funding to the Pacific Fisheries Development Foundation for island fisheries statistics collection programs, under either the Saltonstall-Kennedy grant program or appropriations to the Central, Western and South Pacific Fisheries Development Act. Sea resource atlases could be prepared using these and other data, perhaps by the U.S. Army Corps of Engineers, which has prepared atlases for some Pacific islands.

Congress could also direct the USDA National Agricultural Library to provide assistance to the Micronesia Area Tropical Agriculture Data Center at the University of Guam to include appropriate aquiculture information. An aquiculture database also could be developed at the University of Puerto Rico, or another appropriate Caribbean institution.

Option: Training in Data Collection, Management, and Use.—Congress could direct USDOI in cooperation with USDA to arrange periodic training programs on computerized data management techniques and analysis at the land-grant institutions on U.S.-affiliated islands and on Hawaii for data managers/users from island governments. Such programs could integrate current island databases, expanding their usefulness.

Where no local data collection expertise is available, U.S. agencies could allocate funds for a local person to work side by side with Federal data collectors. This on-the-job training could emphasize the need for sensitivity to eventual interpretation of data.

Research Issues

Island governments have limited capability to conduct research on other than critical local needs, and this constrains progress in several areas of sustainable resource development. While insular research centers in tropical agriculture and island forestry exist, there are no corresponding centers for tropical aquiculture research. Funding for Sea Grant research, moreover, has been declining and program representatives in Puerto Rico and Guam have little capability to direct research towards the needs of other islands.

Federal research organizations have considerable expertise in resource-related fields and technologies. However, little research is oriented to tropical environments, and still less is aimed at the social and cultural aspects of the U.S.-affiliated islands. The findings of resource-related research conducted in the temperate continental United States do not commonly apply to tropical island areas. Reliance on such research in the implementation of Federal programs on the islands results in "environmental misfits. " This has caused some of these programs to fail and may even cause hardships to island inhabitants.

Federal agency research designed for a tropical environment relates mostly to renewable resource management in tropical developing countries (i.e., U.S. Agency for International Development (AID) research). The islands benefit little from this relevant renewable resource research.

Option: Increase Regional Research and Information Dissemination Activities.—The East-West Center was formed in 1972 to provide analysis of social, political, and other issues for Asia and the Pacific. Congress could direct the East-West Center to increase resource research and analysis for the U.S. Pacific islands and increase funding for such activities. Similarly, Congress could accelerate the development of the Eastern Caribbean Center to provide similar services for the U.S. Caribbean islands.

Option: Screen U.S.-Funded Research for Applicability to Tropical Islands.—Congress could direct USDA's Office of International Cooperation and Development and its Forestry Support Service to screen U.S.-funded research for findings in agriculture, aquiculture, forestry, and other renewable resource areas that can be applied to the U.S. tropical islands, and to provide this information to the islands. AID, for example, has accumulated a storehouse of information on tropical resource management planning and development in the tropics, large parts of which might benefit island governments.

A small screening committee within USDA could use the department's Current Research Information System to identify planned or ongoing research of potential benefit to the islands, and could suggest to appropriate researchers possible means of addressing issues of relevance to the islands in their projects. Small modifications in some USDA-funded research plans may result in significant contributions to tropical island agriculture if researchers keep island problems in mind.

Option: Link Tropical and Nontropical Land-Grant Institutions.–Congress could direct AID to develop a mechanism whereby Title XII-funded research activities of tropical land-grant institutions on the U.S.-affiliated islands. This would allow for suitability testing of certain temperate technologies in tropical environments, and would likely strengthen the island land-grant institutions' activities in integrated renewable resource planning and management, as well as the United States' overall competence in tropical natural resource management. Travel costs for research exchange between island and U.S. continental researchers would be high however, reducing the Title XII funds available for research.

Congress also could direct the U.S. Department of State to assist insular government research organizations in establishing cooperative relationships with regional and international research institutions or major universities which can help with broad strategic and basic research.

Option: Extend Section 406 Programs and Funding to All Tropical Land-Grant Institutions.—Congress could extend Section 406 of the 1966 Food for Peace Act to cover all tropical land-grant institutions, and provide funding to pursue the section's two major goals, which are: 1) to provide USDA and land-grant scientists with tropical experience and training, and 2) to provide foreign nationals with a place to learn techniques and methodologies from U.S. specialists under tropical conditions. Extending funding beyond the two original tropical institutions to receive Section 406 research funds (the Universities of Hawaii and Puerto Rico) to the five additional tropical land-grant institutions that now exist (in Guam, American Samoa, FSM, CNMI, and the Virgin Islands) could substantially increase tropical agricultural research in the United States and its territories, and give island residents local access to training they commonly must seek hundreds or thousands of miles away. However, it may take years for these schools to become as productive in research as the Universities of Hawaii and Puerto Rico, during which time substantial funds must be committed.

Option: Expand Tropical Agricultural, Forestry, and Aquiculture Research.—Congress could direct USDA to increase support for applied research in agriculture and forestry development conducted by the tropical agriculture research stations and the institutes of tropical forestry in Puerto Rico and Hawaii. Congress could also increase support for basic and applied NOAA Sea Grant research in various aspects of aquiculture and fisheries.

Congress also could direct NOAA to establish one or more Institutes of Tropical Aquiculture Research in the U.S.-affiliated islands to serve as a center for tropical aquiculture technology development. The center could be associated with established Sea Grant institutions, but still be mandated to serve other islands.

Education, Extension, and Training issues

Sustainable resource development programs, and maintenance of aesthetic, productive environments depend heavily on an educated, ecologically aware public, technologically capable and informed practitioners, and skilled managers. While education is well-developed in the U.S.-affiliated islands, few primary and secondary school curricula specifically address island ecology, agriculture, or fisheries, or the relationships between environment and development, and between resources and traditional cultures. Moreover, most Pacific island colleges are 2-year community colleges necessitating off-island undergraduate and graduate level study.

Even where research information is available, and technologies appropriate to island conditions have been identified, implementation can fail if the pertinent information is not extended to potential practitioners. In part because graduate education is weak or absent, technologically trained personnel and people capable of providing training or technical advice are scarce on most islands.

Island extension offices tend to be small, underfunded, and overworked, all of which hinder their effectiveness in technology transfer. In addition, neither local land-grant colleges nor local governments in the Pacific have adequate funds to maintain the staff needed to reach remote and outlying populations. Similarly, the Marine Advisory Services of the Sea Grant programs at the Universities of Hawaii and Puerto Rico lack the staff and funds to provide assistance to other U.S.-affiliated islands, although both are interested in doing so.

Option: Develop Environmental Education Programs.–Congress could direct the U.S. Department of Education's Office of Education Research and Improvement, in cooperation with various island government units and programs involved in environmental education, to assess ecology curricula materials for potential use in island schools. Where appropriate, financial assistance could be provided to disseminate identified materials and to develop primary and secondary school ecology curricula.

Development of an "environmental ethic" in this way could reduce the need for regulatory and incentive programs to maintain environmental quality; however, some regulatory measures and incentives are still needed to prevent resource and environmental degradation in the short term. Early education in ecology could also spark student interest in resource-related careers.

Option: Increase Island Training and Extension Services.–Congress could direct USDA, NOAA, and USDOI to develop joint training workshops for field extension agents in the islands, and to apprise extension agents of the assistance opportunities offered by both local and Federal agencies.

Congress also could direct USDA to increase support of insular agricultural extension programs to allow expansion to remote populations. Congress also could direct NOAA to increase Sea Grant assistance in training and extension for aquiculture, fisheries, and marine resource management for islands having Sea Grant representatives, and to make such services available to the other U.S.-affiliated islands. This will require identification and funding of new personnel.

Congress also could direct the U.S. Fish and Wildlife Service and NOAA Office of Sea Grant jointly to supply a resident scientist to the regions to provide expert advice on aquiculture species introductions, and to conduct the necessary backup research.

Incentive Issues

Incentives, or removal of disincentives may be necessary to encourage island peoples to undertake new or potentially high economic risk activities. These could initially include availability and knowledge of potentially profitable technologies (provided by research and extension) and ability to implement them (provided by education and training). Incentives can be technical (marketing assistance), or financial (cost-sharing). Agricultural producers, for example, must have accurate, thorough market information, and may need help in accessing markets for their products. Cost-sharing programs have, in some cases, formed the basis for local government activities to develop resource enterprises.

Some analysts argue that eligibility for and participation in U.S. income support programs creates a disincentive to investing money and labor in resource-related enterprises in the U. S.-affiliated islands.

Option: Marketing Assistance.—Congress could direct USDA's Agricultural Marketing Service to assist insular governments through three major programs:

1. the Federal-State Marketing Improvement Program, which provides funds to States to solve marketing problems through Federal-State cooperation;
2. Market News, which provides timely information on prices, demand, movement, volume, and quality of all major agricultural commodities; and
3. Agricultural Product Grading, which provides producers and marketers with meaningful grades indicative of agricultural product quality.

Congress could also direct the Department of Commerce to have NOAA's Office of Sea Grant programs assess aquacultural marketing and economics issues for island aquiculture development.

Option: Establish Insular Resource Management Cost-Sharing Programs.—Congress could establish and authorize a new USDA program to provide cost-sharing and technical assistance to individuals undertaking federally approved agriculture, soil conservation, forestry, fishery, and aquiculture activities. Local administration of such a program would mitigate travel and other problems.

Option: Analyze Income and Other Support Programs.–Congress could direct USDA and the Department of Health and Human Services (DHHS) jointly to analyze eligibility formulae for social aid, and nutritional and other impacts of such aid. If there are large numbers of people who participate, but do not substantially benefit from aid programs, support funding could be gradually reduced, or partially redirected to cost-sharing programs.

Congress could direct USDA to assess and report on the current and potential role of local produce in island school hot lunch and other food and nutrition programs, addressing questions of nutrition, and possible economic impacts, and suggesting a target level for home-grown contributions, Increased use of locally grown foods in such programs could provide markets and incentives for expanded island agricultural activities and thus, increased economic benefits to the islands. However, local storage and refrigeration facilities may not be adequate to assure regular delivery. Food accessibility at open markets may also decline.

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INSULAR RELATIONSHIPS TO THE FEDERAL GOVERNMENT

The U.S.-affiliated tropical islands have a wide range of relationships to the U.S. Government (table 2-1), Two are commonwealths—Puerto Rico and the Northern Mariana Islands (NMI)–having local autonomy but voluntarily associated with the United States. The U.S. Virgin Islands, American Samoa, and Guam are unincorporated territories (to which only certain provisions of the U.S. Constitution have been expressly extended) under the administration of elected Governors. Finally, the Republic of the Marshall Islands (RMI), and the Federated States of Micronesia (FSM) (which, together with the NMI and the Republic of Palau form the former Trust Territory of the Pacific Islands) have signed agreements with the United States to become Freely Associated States.[1]

The peoples of Puerto Rico and the territories of Guam and the U.S. Virgin Islands are U.S. citizens, those of Palau and American Samoa are U.S. nationals. Guam, American Samoa and the USVI are represented in the U.S. Congress by nonvoting Delegates. Puerto Rico is represented by a nonvoting Resident Commissioner. The Resident Commissioner and Delegates sit in the House of Representatives, have a voice in legislation pertaining to their islands, and can vote in Committee. While the territories are eligible for many Federal programs on the same basis as a State, the islanders do not contribute to the national treasury through Federal income taxes,

Determination of U.S. policy for the territories is within the jurisdiction of Congress. Although Congress has given the Secretary of the Interior certain authorities and responsibilities toward these territorial governments (excluding Puerto Rico), and many Federal programs are available to them, the territories are not agencies or instrumentalities of the Executive Branch of the Federal Government.

Commonwealths

A U.S. commonwealth is an autonomous government in voluntary association with the United States. It is responsible for its own welfare and has full legislative authority. Puerto Ricans were granted U.S. citizenship in 1917 and Puerto Rico's Constitution was approved by the electorate in 1952. The Northern Mariana Islands in effect became a commonwealth

[1]Although Puerto Rico is a Commonwealth of the United States, it is referred to as "Estado Libre Asociado" or free associated state. This should not be confused with the legal relationship defined by free association with the Freely Associated States in the Pacific.

Table 2-1.—United States Insular Area Relationships

Insular area	Initiation of U.S. administration	Relationship to the United States
Puerto Rico	1898 (ceded to the United States)	Commonwealth
U.S. Virgin Islands	1917 (purchased from Denmark)	Unincorporated territory
American Samoa	1900 (ceded to the United States)	Unincorporated territory
Guam	1898 (ceded to the United States)	Unincorporated territory
Northern Mariana Islands	1946 (U.S. Strategic Trusteeship)	Commonwealth
Marshall Islands	1946 (U. S, Strategic Trusteeship)	Freely Associated State
Federated States of Micronesia	1946 (U.S. Strategic Trusteeship)	Freely Associated State
Palau	1946 (U.S. Strategic Trusteeship))	Strategic Trusteeship[a]

[a]Expected to become Freely Associated State in 1987

SOURCE Office of Technology Assessment 1987 in 1978,[2] but remained officially a part of the Trust Territory of the Pacific Islands until its dissolution in 1986.

Unincorporated Territories

Unincorporated territories are not integral parts of the United States and no promise of statehood or a status approaching statehood is held out to them. Only certain parts of the U.S. Constitution apply to unincorporated territories. And, unlike States which write their own constitutions, the laws and principles that prescribe the nature, functions, and limits of a territorial government are determined by Congress (13).

Guam was annexed from Spain at the close of the Spanish-American War. Although relations between the Government of Guam and the U.S. Government also are conducted under the jurisdiction of the Department of the Interior, residents of Guam elect their own officials. Most aspects of the U.S. Constitution apply to Guam. Similar to Guam, the American Samoa Government is semiautonomous and operates under a constitution adopted in 1960. American Samoa has been administered by the United States since 1900. The U.S. Virgin Islands were sold by the Danish Government to the United States in 1917. U.S. citizenship was granted to Virgin Islanders in 1927,

Freely Associated States

The Freely Associated States, along with the Northern Mariana Islands, comprise the Trust Territory of the Pacific Islands (TTPI), the last of 11 trusteeships established under United Nations' sanction after World War II. Despite preliminary agreements, the Compact of Free Association with the Republic of Palau has not yet received 75 percent Palauan approval in a plebiscite vote and, therefore, has not been approved by the United States or the United Nations. Until the Compact with Palau is approved by the United Nations and the trusteeship is dissolved, the United States retains its responsibility to promote the economic advancement and self-reliance of these islands.

The trusteeship was intended as a temporary arrangement under which the United States accepted the responsibility of advancing the TTPI —politically, socially, economically, and educationally—toward greater self-reliance, including undertaking obligations to:

> . . . promote the economic advancement and self-sufficiency of the inhabitants, and to this end shall regulate the use of natural resources; encourage the development of fisheries, agriculture and industries; [and] protect the inhabitants against the loss of their lands and resources (Trusteeship Agreement for the United States Trust Territory of the Pacific Islands, Article 6(2)).

The United States also was charged with preparing the Micronesians for a political status of their own choosing.

Civilian administration of the TTPI was the responsibility of the Department of the Interior, but each administrative district was given the opportunity to determine its own form of government and degree of independence from the United States. By January 1981, each emerging entity had installed a constitutional government with democratically elected officials.

The Commonwealth of the Northern Mariana Islands was established and separated from the other existing TTPI entities in 1978, although some relations between the Northern Marianas and the U.S. Government continued under the jurisdiction of the Department of the Interior. Two of the remaining political entities—the FSM (Yap, Truk, Pohnpei, and Kosrae), and the RMI—have signed Compacts of Free Association with the United States; the FSM and RMI compacts were approved by the United States in early 1986 and put into effect at the end of the year.[3]

Free association allows the polities full control of internal and external affairs while de-

[2] The Northern Mariana Covenant (Public Law 94-241) was passed by Congress in 1976, but the major part of the Covenant did not become effective until 1978 when the Commonwealth government was installed.

[3] Because approval of a Compact of Free Association with the Republic of Palau is expected shortly, Palau shall be referred to as a Freely Associated State in the remainder of this assessment unless otherwise indicated.

fense and security responsibilities are delegated to the United States. They become eligible for foreign aid from international organizations, such as the Asian Development Bank. Finally, they are guaranteed a specified level of funding from the United States (15 years for the RMI and FSM and 50 years for Palau) part of which must be directed to planning long-term economic development.

THE IMPORTANCE OF U.S.-AFFILIATED ISLANDS TO U.S. NATIONAL SECURITY

The U.S.-affiliated islands are of considerable importance to national security, and the United States is committed to their defense and to maintaining lines of communication to and through them. The islands vary in strategic importance, but all represent the U.S. presence in spheres of strategic interest.

The U.S.-affiliated Caribbean islands are of special security significance to the United States, primarily because of their close proximity to Caribbean and Central American countries. Puerto Rico is of particular significance due to the presence of major naval installations there and its location astride major routes of communication. The Caribbean area has been viewed as "America's third border" and, thus, expansion of inimical forces or influence in this area is likely to be viewed with alarm (9).

Although the U.S.-affiliated Pacific islands do not play an important role in current or projected Department of Defense programs, they might likewise be viewed as the United States' fourth border. According to the Annual Report of the Secretary of Defense to Congress for fiscal year 1986, at least 30 percent of U.S. trade is conducted with the nations of East Asia, and five of our mutual security treaties link us with East Asian countries (9). Only a few islands (e.g., Guam, Kwajelein) have major U.S. bases; the U.S. Navy, however, has a keen interest in certain contingency base rights in the Northern Mariana Islands and Palau. (See app. B for a brief discussion of military installations and activities in the U.S.-affiliated islands.)

ECONOMIC DEVELOPMENT IN U.S.-AFFILIATED ISLANDS: THE PROBLEM

U.S. policy towards the insular areas is founded on common interests in the creation of close and mutually beneficial relationships between the insular governments and the U.S. Government. As such, the United States has attempted to encourage political self-determination and promote economic advancement and self-reliance in the territories while protecting its national security interests in the Pacific and the Caribbean. Thus, applicable Federal programs are extended to some or all of the territories, and their special needs are recognized in direct assistance to the territories.

Many U.S. islands are highly dependent on U.S. financial assistance for local Government revenues. For example, the Federal portion of Micronesia government revenues ranges from 30 percent (CNMI) to 87 percent (FSM) (17). Puerto Rico is a notable exception, deriving nearly two-thirds of its annual operating budget from internal sources (10). Nearly $5 billion are spent annually by the U.S. Government in direct financial assistance and under Federal programs to the territories (16). Much of these funds are used, in turn, to purchase food and other goods and services, primarily from the United States. Imports greatly exceed exports on many islands, and on most local food production has been declining. A combination of geographical, socioeconomic, and ecological factors hinder the sustainable management and development of renewable resources in the U.S. territories (table z-2).

Ecological Factors

The nature of tropical land and nearshore resources constrain the applicability of resource development and management technologies which have been developed for temperate areas. The islands have considerable diversity in soil types and, although fertile soil types exist on some islands, soil fertility generally is low compared to most temperate soils, and to the nutrient needs of the high-yielding crops used in intensive agriculture. For example, three-quarters of Puerto Rico is covered by relatively infertile soils (i.e., soils rated 6 or higher on a *1* to *10*—best to worst–scale of soil productivity) (12).

Table 2-2.—General Characteristics of Islands

Ecological characteristics:
- small size,
- narrow range of natural resources,
- little natural organic biological diversity,
- distance from continents and external competition fosters species endemism,
- generally little overall climatic variability, but potential for climatic upsets,
- ecologic vulnerability, and
- tendency toward ecologic instability when isolation is breached.

Geographical characteristics:
- relative isolation;
- a completely circumferential sea frontier and EEZ, giving a high ratio of EEZ to island land mass resulting in very high importance of sea v. land resources;
- no internal land transport option to link the islands making up a polity or to link the island to other countries, only air and sea transport; and
- no interior hinterland or central terrestrial core area that is essentially distant from the sea such that coastal resource planning and management is essentially synonymous with national resource planning and management.

***Socioeconomic* characteristics:**
- more dependent on foreign trade than large countries and having less influence on the terms in which that trade is carried on;
- a narrow range of resources and, hence, specialized economies;
- heavily dependent on one or more large foreign companies;
- dependent for key services on external institutions such as universities, regional training facilities, banking and marketing arrangements;
- a narrow range of local skills and specific difficulty in matching local skills with jobs;
- difficulty in providing some infrastructure services as there may be costly diseconomies of scale in the provision of such services; and
- a small Gross Domestic Product such that import substitution industries may face special difficulties.

SOURCE: E. Towle, The *Island Microcosm,* prepared for the U.S. National Park Service under contract to the US. Agency for International Development, 1983.

Not only do infertile soils require greater amounts of fertilizer per acre for crop and pasture management, but they require more frequent applications. A deficiency of organic material in infertile soils hinders their ability to adsorb needed plant nutrients. Consequently, plant nutrients may be lost to leaching and erosion during heavy rains. Much of the land is not suitable for clean-cultivated crops due to erosion hazards. However, land management practices which include soil building through a good fertility program and erosion control may increase soil fertility over time.

Moreover, past poor land-use practices have degraded land resources in the U.S. Caribbean and Pacific and have resulted in significant amounts of abandoned land. Colonial histories of each of these areas contain an era of land exploitation for agricultural export which resulted in loss of vegetative cover over large areas and intensive production of only a few crops. Most of the local soils have minimal fertility. Once cleared, continued exposure to strong sunlight, heavy rainfall, and erosion reduced their marginal fertility further.

The consequences of this land degradation are widespread. Erosion rates have increased; for example, soil erosion rates in the Caribbean have reached as high as **18** times the U.S. average (14). Land clearing on many islands has resulted in turbid, erratic, and intermittent stream flow. Erratic freshwater flows and siltation from land runoff endangers coral reefs and other nearshore productive marine ecosystems.

Mangrove forests, which serve as natural filters and as breeding grounds for many aquatic species, have been overexploited for timber in many areas and some have been destroyed by impacts from development activities. The loss of mangrove forests further exposes marine ecosystems to degradation. Thus, the physical potential for local food production may be declining along with the incentives to undertake sustainable resource development.

Tropical ocean nutrient levels are lower than in temperate regions and primary biological production is correspondingly reduced. Conversely, the coral reef environment has high levels of biological activity made possible by organisms which increase available nitrogen and recycle nitrogen and other nutrients within the ecosystems. Despite seemingly large reef and lagoon areas, the size of the U.S. islands' productive nearshore areas is smaller than in other islands where commercial fisheries have developed (e.g., the Bahamas). The continental shelf of Puerto Rico and the U.S. Virgin Islands combined is less than 3,000 square miles, of which less than half is considered highly productive. The U.S.-affiliated Pacific islands are not associated with continental shelves, but with steeply sloping drop-offs into deep ocean. A substantial submerged reef area exists (approximately 14,287 square nautical miles) near the Pacific islands of Yap and Truk, and has been the site of a highly productive fishery in the recent past (18).

Coral reef systems and the associated seagrass beds and mangrove swamp forests are responsible for much of the islands' nearshore fisheries potential. Unlike temperate areas, nearshore tropical fish stocks tend to be diverse and diffuse, rarely aggregating in large schools or beds (for invertebrates). The multispecies nature of most tropical fishery stocks means that catches often contain a mixture of high-value and less desirable species.

Perhaps beneficial for sustained populations of nearshore species, the rugged coral reef topography makes it impossible to use towed, nonselective gear (e.g., trawls) employed in many commercial fisheries. However, these and most other tropical island ecosystems are more vulnerable to degradation than most temperate systems.

Geographical Factors

Of the U.S.-affiliated islands, only Puerto Rico contains a population significantly greater than 100,000 inhabitants. Large population centers in the U.S.-affiliated Pacific islands characteristically are 10,000 to 20,000. The Micronesia islands are scattered widely over 3 million square miles of the Pacific Ocean—an area as large as the contiguous United States, yet, their total land area is about two-thirds that of Rhode Island. Modern concepts of mass production, distribution, marketing, and competition cannot be applied on such small scales. Moreover, transportation and communications by conventional means is difficult and expensive.

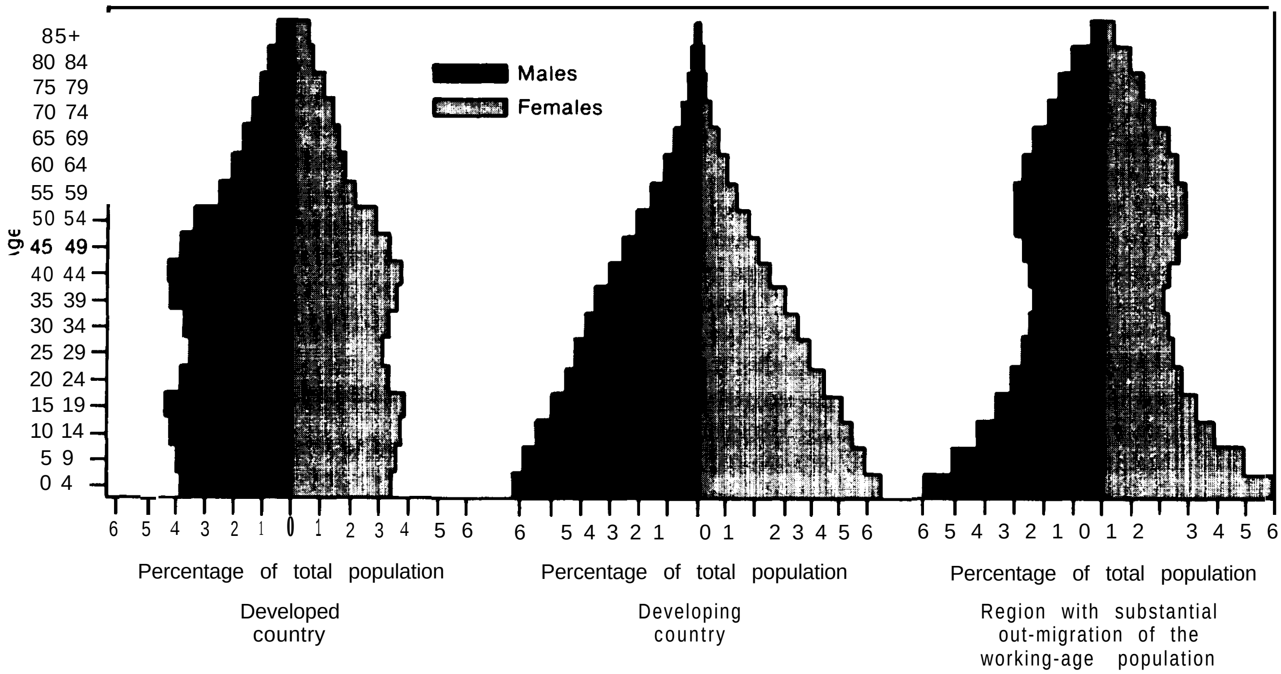
Socioeconomic Factors

All of the island territories exhibit a high ratio of imports to exports, particularly in food. The high level of imports compared to local production means that funds transferred to the territories have little impact on economic development. These funds leave the economies in payments for imports. Due to rapidly growing populations and rising aspirations, reducing consumer demand for imported products seems unlikely.

Population growth rates in the U.S.-affiliated Pacific and Caribbean islands increased considerably faster than the 4.2 percent U.S. population growth between 1980 and 1984 (8). Only Puerto Rico, with a growth rate of 2.3 percent, was below the United States for this period (8). Such population growth rates maybe supported only by readily available emigration opportunities; for example, 2 million Puerto Ricans live in the mainland United States (1) and more American Samoans live in the United States than in Samoa (7). At the same time, migration into the islands from the United States and surrounding islands is high.

Present and future human needs and labor availability are reflected, in part, by an island's overall demographic pattern. Population pyramids (figure 2-1) for many islands have a shape more like those of developing countries than developed countries. For instance, nearly 50 percent of most island populations are below 15 years of age, creating a large sector dependent on the working age population (2,3,4,5,6,7). This indicates that each year increasing num-

Figure 2-1.—Comparison of Typical Population Pyramids



SOURCE: Office of Technology Assessment, 1987.

bers will enter the work force and the demand for goods and services will increase significantly.

Such population distributions can be altered quickly either by in-or out-migration, but where the people come from or go to poses additional concerns. The major urbanized centers—most of which are on coastlines—are growing rapidly whereas the rural population is decreasing. Consequently, the choice of technologies will be influenced by the changing population characteristics in island rural and urban areas.

Sustainable renewable resource management depends not only on the capability of the ecological resources, but also on availability of skilled labor and willingness to engage in resource management and development activities. Although all of the islands have rapidly growing populations, many young adults seek education and employment in the U.S. mainland. Many of those who remain either depend on extended family relationships or social support programs to supply their needs. Most formal labor is captured by local governments and services for the public sector and its employees. Wages, security, and prestige are higher in government employment. Skilled labor, training, and interest in the productive sectors of agriculture and fisheries are low on all the islands.

Land tenure systems and opportunities for acquiring land pose considerable obstacles to commercial development of renewable resources. Traditional values of Micronesians and Samoans place great prestige on land and other resource use rights. This results in increasing fragmentation of parcels over time, as ownership is retained in families that have increased in size. In addition, land often is communally held in the U.S.-affiliated Pacific islands. Acquiring land for commercial use—where the products of the property are not to be used for subsistence and sharing—may be difficult or impossible. For example, a recent U.S. District Court decision upheld an American Samoan law that communally owned land

(90 percent of the land area) can be transferred only to a person of at least 50 percent Samoan blood (11). (See app. C for *a* discussion of integration of modern and traditional legal systems in the U.S.-affiliated Pacific islands.)

In the more developed—and more westernized—islands of Guam, Saipan, Puerto Rico, and the U.S. Virgin Islands, fee-simple land ownership is more common. However, on these islands competing land uses, such as residential and tourism development, push land values beyond the reach of many potential entrepreneurs, The price of rural land has come to reflect scarcity rather than productivity. Second-growth forestlands in Puerto Rico may cost $1,000 to $2,000 per acre and land values in the U.S. Virgin Islands have exceeded $10,000 per acre (14).

Further, rapidly appreciating land values reduce incentives to derive productive use of lands held for speculation. Consequently, much land lies idle awaiting development, Puerto Rico maintains a law against private individuals or corporations holding more than 500 acres and, in general, the land is in small holdings. Nearly 85 percent of the land ownerships are less than 48 acres (15).

GOALS OF RENEWABLE RESOURCE MANAGEMENT AND DEVELOPMENT

Increasing the economic self-reliance of the islands is the most often stated objective of renewable resource development in the U. S.-affiliated islands. However, self-reliance should not be interpreted to mean economic independence, but rather a healthy interdependence within regional and world economies. Economic self-reliance can be defined as an economy's capacity to produce to meet as many domestic needs as is economically feasible and to gain the revenue, through exports, to pay for the imports required to support an acceptable standard of living. Even with this definition, increasing self-reliance in economies heavily dependent on outside aid and with large (in relation to resources) and growing dependent populations will be extremely difficult.[4]

A mechanism for increasing economic self-reliance is to develop a skilled and active private sector, Efforts to undertake such development reflect myriad subgoals, including:

- provision of employment, especially in rural areas,
- provision of stable incomes for commonly risk-averse producers,
- reduction in consumer food prices,
- reduction in rural or outer island to urban migration,
- development of private sector technical and managerial skills,
- stabilization of personal and national revenues through diversification of local production, and
- safeguarding valuable human and natural resources.

Thus, resource development projects and technologies that can contribute to the achievement of several of these objectives while offering acceptable yields and profitability y are preferred to those designed solely to maximize yields or profits.

In addition, a number of conditions (which also can be thought of as goals) under which renewable resource and other development must be evaluated for acceptability may be derived. Generally, development policies, programs, and projects are sustainable and, thus, desirable if they:

4Unless resident populations are stabilized (through reduction in population growth rates or continued free emigration), substantial improvements in self-reliance are unlikely, Technologies directly related to population growth are outside the scope of this assessment but have been addressed in another OTA assessment, U.S. Congress, Office of Technology Assessment, *World Population and Fertility Planning Technologies: The Next 20 Years,* NTIS order #PB 82- (Springfield, VA: National Technical Information Service, February 1982),

- do not reduce the long-term productivity of the resources involved;
- do not degrade nearby or "downstream" environments, be they terrestrial, riverine, or marine;
- do not irrevocably reduce future development options; and
- do not unacceptably conflict with local cultures and customs.

Few forms of economic development can satisfy all of these objectives and conditions. The decision as to which objectives will receive priority, which resources and areas will be developed, and which technologies and technology systems will be encouraged or implemented depend on far more than feasibility and profitability; they depend on the acceptability of their economic, social, political, and environmental impacts.

CHAPTER 2 REFERENCES

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Chapter 3
Island Structure and Resource Systems

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Chapter 3

Island Structure and Resource Systems

ISLAND FORMATION

Islands in tropical waters of the Pacific Ocean and the Caribbean Sea commonly bring to mind only white sandy beaches backed with a fringe of coconut palm trees. Yet, a close examination of the form and geology of the islands shows that major differences exist between island types that significantly affect opportunities for renewable resource management and development. These fundamental differences play an important role in determining what kinds of technologies can be applied that are likely to prove productive for island residents over the long term and which others, though perhaps leading to short-term gains, ultimately may produce long-lasting adverse impacts on the island resource base—the soil, water, vegetation, and wildlife.

Details of the geologic formation of the islands are beyond the scope of this assessment. Nevertheless, a simple fourfold classification of island types based on their geology should assist the reader in assessing potential impacts to an island's environment from proposed technological applications. In addition, it should help to improve understanding of why islanders, past and present, have chosen particular methods of resource use.

Although many of the islands' origins relate largely to volcanic processes, their name classification only partly reflects this. The four categories of islands used in this assessment are: high volcanic islands, atolls and low coral islands, raised limestone islands, and continental islands.

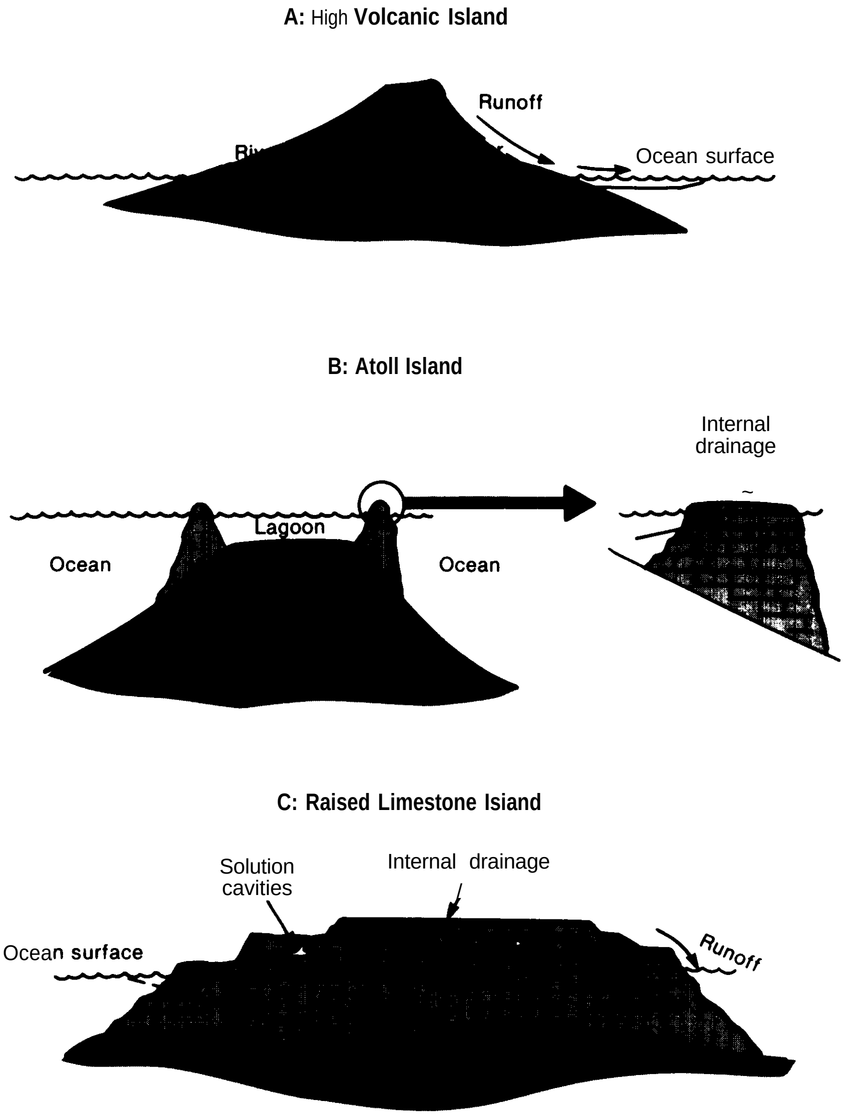
High Volcanic Islands

High volcanic islands are the cone-shaped peaks of volcanoes (perhaps 1,000 feet or more in altitude) that extend upward from the ocean floor. The conical shape is preserved best on young volcanic islands; older islands become deeply incised with stream valleys because of erosion from running water (figure 3-1 (A)). Some volcanoes are still active such as Pagan Island in the Northern Mariana Islands; some are dormant such as Sariguan in the Northern Mariana Islands; and others are extinct such as Pohnpei or Kosrae. Measured from the sea floor to the island summits, these volcanoes represent some of the highest mountains in the world. The predominant rock forming the volcanic islands is basalt, a dark-colored igneous rock rich in minerals containing silicon, aluminum, calcium, magnesium, and iron as dominant elements.

Once volcanoes reach the ocean's surface, marine organisms like corals, algae, and sponges start to grow and reproduce on the bottom of the sunlit, warm nearshore waters that surround the new island. In the early stages of growth, the marine organisms of the colony grow on one another until they reach the surface of the water. Coral structures that are close to the island (generally within one-quarter of a mile from shore) and often surround it, are called fringing reefs. Such reefs may become barrier reefs if the central island begins to submerge. Barrier reefs generally are 1 to 5 miles offshore and are separated from the island by a lagoon which is relatively deep (60 to 300 feet) (40).

Many volcanic islands over geologic time have slowly subsided beneath the ocean surface. The living marine organisms of the surrounding reefs in many cases have been able to grow rapidly enough to keep their surfaces at or near sea level, thus offsetting the rate at which the volcanic island subsides. Through this process, the reefs can maintain their existence even when the enclosed island gradually sinks below the ocean's surface. With the disappearance of the central island, the ringlike reef complex then becomes an atoll.

Figure 3-1.—Depiction of Island Types



SOURCE: Office of Technology Assessment, 1986

Atoll Islands

Atolls are low-lying, narrow, ring-like coral reefs composed of highly permeable coralline limestone (calcium carbonate) derived from the remains of marine reef organisms. Individual atoll islands occur as part of the atoll reef and rise only a few "feet to a few tens of feet above mean high tide. For example, the highest point in the Marshall Islands is 25 feet above sea level on Likiep Atoll (40). Atolls enclose a lagoon of several feet to several hundred feet in depth. Submarine landslides, wave action, currents, tides, and storms commonly produce or maintain breaks in the atoll thereby providing boats or ships with passages connecting the open sea with the shallow lagoon (figure 3-I (B)).

Growth of atoll reefs is greatest on their windward sides where the food supply is highest for reef organisms. Storm and wave action carry reef or atoll fragments into the atoll's lagoon and pile them on the reef above the water level to form islands. This sediment source keeps the waters of the atoll's lagoon shallow.

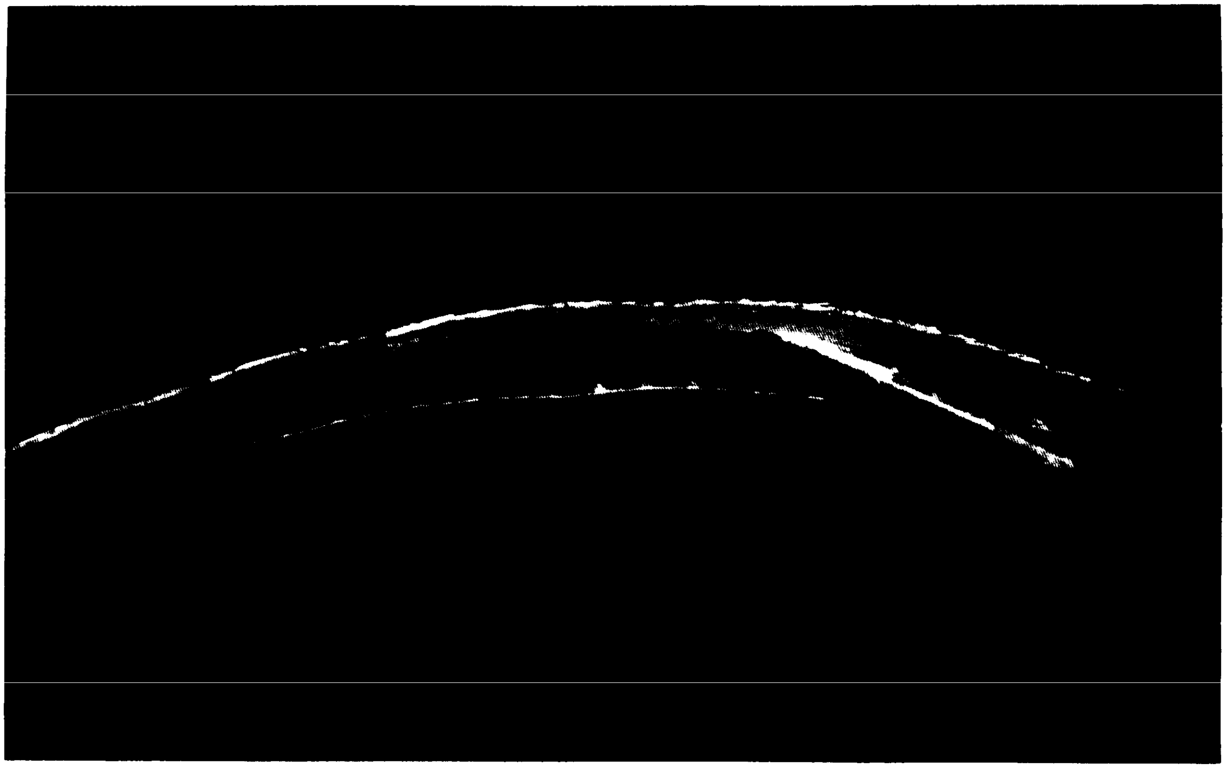


Photo credit: Office of Technology Assessment

A low-lying atoll island in the Marshall Islands, built on the inside edge of an encircling coral reef.

Some low coral islands in Micronesia form on top of coral pinnacles and are not associated with lagoons. These islands, such as Nama and Kili, otherwise resemble atoll islands.

Raised Limestone Islands

Raised limestone islands consist of nearly horizontal beds of coralline limestone that originally were formed in the waters surrounding older volcanic islands. Over geologic time, the marine limestone beds have been raised above sea level by upward moving volcanic islands, or by lowering of the sea level. The extensive uplifted limestone beds of Guam, for example, now reach about 500 feet above the sea surface. Many such islands have prominent wave-cut terraces carved into the limestone layers indicating times during the Pleistocene ice age when the sea level was different than it is today, times when continental glacial ice sheets in regions closer to the poles were thicker or thinner.

Because of their origin, raised limestone islands may contain exposed land surfaces of older volcanic rocks. Like high volcanic islands, they are also likely to have fringing reefs along their coasts.

The porous limestone layers are composed mostly of calcium carbonate which dissolves over time as plentiful tropical rainfall moves downward through the permeable beds. Solution cavities like sinkholes and caves result (figure 3-1 (C)).

Continental Islands

Continental islands are extensions of continents or of certain undersea mountain ranges. The rocks comprising such islands are of a much wider variety than those of the other island types and signify a more complex geological history. Puerto Rico and the U.S. Virgin Islands, for example, are part of the Antilles, a sea-floor mountain range geologically associated with the structure of the extreme southeastern part of the United States. Similarly, Palau is the surface expression of the eastern extremity of a continental-type mountain range running-from west to east in Indonesia.

Continental islands do not have a characteristic form. They may, however, have a border of fringing reefs or lagoons with barrier reefs like those of high volcanic islands and raised limestone islands.

PREVAILING CLIMATE

Introduction

The majority of the U.S.-affiliated islands lie in the Northern Hemisphere, with American Samoa being the only U.S. Territory in the Southern Hemisphere. All of the islands are within the tropical marine climatic region, between the Equator and 23.5° north/south latitude. Weather changes in tropical climates are complex and may occur frequently(4). Further, considerable climatic differences may exist between island areas. Differences in the amount and seasonality of rainfall, wind, and tidal conditions exist throughout the Pacific and Caribbean area. While tropical climates are characterized by warm, often wet, fair weather, they are equally known for producing major disturbances such as cyclonic storms.[1]

Overall weather patterns may be predictable (e.g., temperature, rainy seasons, tropical storm seasons, and afternoon rainstorms), however, tropical weather also may be highly variable. The high level of solar radiation received by tropical areas gives rise to this variability. High energy levels may allow the rapid formation of storm systems and sudden rainfall, and may also affect wind patterns and occasionally ocean currents. The high energy level of tropical air masses means that even small trigger mechanisms may produce disturbances (4).

The action of the ocean may compound impacts of sudden storm system formations. The ocean also may serve to transfer impacts of weather or other natural events such as earthquakes to islands some distance from the source of the disturbance. The small size and isolation of islands increases their vulnerability to disturbances, however, their existence indicates that these areas possess a highly effective capacity for recovery.

Winds

The northeast and southeast tradewinds prevail upon the U.S.-affiliated tropical islands. The tradewinds converge in the equatorial trough of low pressure forming what is known as the Intertropical Convergence Zone (ITCZ) [4). The low pressure of this area gives rise to the sporadic cloudiness and frequent rainfall associated with tropical regions. The ITCZ shifts during the year accompanied by seasonal changes in the direction and intensity of the winds. For example, the islands in the Caribbean experience relatively consistent winds year round; however, the direction changes from a slightly stronger northeast wind during winter months to a southeast wind during summer months. Guam experiences a similar seasonal wind shift, receiving the strongest winds during winter months. American Samoa, in the southern hemisphere, also experiences seasonality in winds, receiving the southeast tradewinds with relative consistency for 9 months of the year (46). The Northern Mariana Islands receive strong northeast tradewinds for 9 months of the year, November through June, while July through October is marked by more variable winds. These islands also lie on the eastern fringe of the Asiatic monsoon circulation system (47).

Precipitation

Precipitation levels in the tropical climatic region generally are high, however, variations

[1] The term cyclonic storms will be used in this text to cover such weather formations as typhoons and hurricanes.

Box 3-A.—General Characteristics of Tropical Climates

- **High humidity except in arid regions.** Humidity is driven by high levels of insolation in tropical regions, coupled with large areas of freely evaporating surface (oceans). generally constant winds help transfer water vapor from ocean surface to atmosphere and ensure a continuous supply of unsaturated air.
- **Cloudiness commensurate with humidity.** Cloudiness associated with tropical regions generally is a function of the atmospheric moisture levels in combination with the high insolation levels which encourage uplift of air. Topographic barriers also may cause cloud formation by forcing moisture laden air high enough to reach the lifting condensation level.
- **Small seasonal temperature variation; diurnal variations often greater than seasonal.** Temperature in tropical regions generally fluctuates around the low 80s Fahrenheit year round. This is caused by the high, and generally stable, levels of insolation received, combined with the moderating effect of the ocean. As a result diurnal temperature fluctuations are generally greater than seasonal variations.
- **Annual rainfall ranges from 80 inches or greater in wet environments to less than 10 inches in arid environments.** Precipitation is a function of [illegible]

exist among islands (table 3-1). Variation also may exist in the geographic distribution of precipitation on a single island. The variation in rainfall amounts among island areas largely is attributable to topographical differences, island size, and geographic location. Generally, as latitude increases rainfall patterns become more seasonal, with annually occurring dry periods. The seasonality of rainfall patterns is attributed, at least in part, to the shifting of the ITCZ and the associated change in the moisture content of the atmosphere in relation to island location. High islands generally receive larger levels of rainfall due to an orographic effect; air is forced up and over a topographic feature causing condensation of atmospheric moisture and gener-

Table 3-1.—Mean Annual Precipitation Level and Temperatures

Polity/island	Latitude	Mean annual rainfall (inches)
Puerto Rico	18° N[a]	40-200[a]
U.S. Virgin Islands	18° N[a]	40- 60[a,f]
American Samoa	14° S[e]	100-200[b]
Guam	13° N[e]	80- 95[c]
Northern Mariana Islands	14° N 20.5° N[e]	75-121[d]
Marshall Islands	5° N 12° N[e]	135[g] (Majuro)
Federated States of Micronesia:		
Kosrae	5° 30' N[e]	227[g]
Pohnpei	7° N[e]	190[g]
Truk	5°-7° N[e]	139[g]
Yap	6°-12° N[e]	122[g]
Palau	7° 30' N[e]	147[g]

SOURCES:
[a]D. Smedley, *Climates of the States: Puerto Rico and U.S. Virgin Islands,* U.S. Department of Commerce, Weather Bureau, Climatography of the United States No. 60-52 (Washington, DC: U.S. Government Printing Office, 1961).
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[f]Caribbean Research Institute, *Waterplan:A Comprehensive Water Management Framework* for the U.S. *Virgin* Islands, *Virgin Islands Water Resources Center,* June, 1979.
[g]National Center for Atmospheric Research (NCAR) Boulder, CO, rainfall data—measured at one location for each island area—does not reflect variation in geographic distribution.

ally precipitation. Islands of lower altitude depend in part on the convective force of the air over the island to promote rainfall; the moist air is heated over the island and rises to a point at which condensation occurs.

Guam and the Western Caroline islands of Yap and Palau are subject to a monsoon-like pattern with dry spells often occurring between December and June (15). Other islands such as Pohnpei experience less variation in rainfall patterns, receiving generally stable amounts throughout the year. High average rainfall in the central Carolines (100 to 130 inches/year) promotes lush vegetation. On coral islands the rainfall partially compensates for the inherent small freshwater storage capacity (2,40).

Considerable variation in precipitation regimes exist between Puerto Rico and the USVI, despite their proximity. Puerto Rico receives a mean annual rainfall of 65 to 70 inches, while the USVI recieves a mean annual amount of approximately 40 inches. The topographic features of Puerto Rico, larger land mass and mountain peaks in excess of 4,000 feet, promote both convective and orographic precipitation. These features contribute to Puerto Rico's significant variation in the geographic distribution of precipitation that gives rise to a number of different environments ranging from a tropical rainforest (Luquillo) to an arid southwest coast. Although the USVI receives both orographic and convective stimulated precipitation, the much smaller land area and lower elevations result in a less marked variation in precipitation distribution. Both island areas experience a relatively dry season that generally occurs between December and April.

Temperature

Island climates are strongly influenced by the persistently high levels of solar radiation received throughout the year as well as by the tempering effect of the surrounding ocean waters. The ocean acts as a heat sink/source to regulate temperature variation through the year. During warmer seasons the ocean retains energy and during the cooler seasons is able to release energy, resulting in relatively little seasonal temperature fluctuation. Diurnal temperature changes commonly are greater than those experienced from one season to the next (29).

Disturbances

The major climatic disturbances associated with the island areas take the form of cyclonic storms. Cyclonic storms, which severely affect Puerto Rico and the USVI, generally develop over the southern North Atlantic Ocean east of the Lesser Antilles (4,36). Those most affecting Micronesia originate in the central tropical Pacific Ocean (4). Prediction of cyclone paths can prove difficult because of the variability of wind patterns in the tropical region. The Caribbean islands generally receive fewer cyclonic storms than the Pacific islands north of the Equator, which lie in a major path of cyclonic storms (4). Tropical cyclones are frequent events in the Mariana and Western Caroline Islands of Yap and Truk (24), but less common in the Eastern Carolines, the Marshalls, and American Samoa (7,13). Cyclonic storms are not considered a severe problem on Pohnpei, although four cyclonic storms have hit the island in this century, most recently in May of 1986.

Satellite image courtesy of C. Wahle

Cyclonic storms are relatively frequent events for many U.S.-affiliated islands and often cause severe damage to island populations and ecosystems.

Cyclonic storms develop from tropical depressions when pressure and temperature conditions are favorable. These storms may produce winds of 60 to 200 miles per hour and generally are accompanied by heavy rainfall and thunderstorms. The storm is generated by the release of energy through massive condensation of water vapor. The bodies of water surrounding the tropical areas experience their highest temperatures in the late summer months providing the energy levels necessary for the generation of a cyclonic storm (30). Thus, such disturbances generally occur during late summer and autumn when the ITCZ is shifting towards land south of the Equator. However, exceptions do occur. For example, on Yap, cyclonic storms are most frequent during the transitional months (particularly November) when the tradewinds are returning. Cyclonic storms that pass quite near or over an island can cause severe destruction. The high winds and torrential rainfall may cause wind damage, flooding, landslides, and loss of life. Puerto Rico was severely damaged by a cyclonic storm in 1928; the vortex of the storm moved southeast to northwest affecting the entire island.

Cyclonic storms may have both primary and secondary effects on the island ecosystem. Primary effects include physical damage to the reef and shore areas and land erosion. High winds and torrential rainfall may cause destruction on land. Storm wave assault may cause coastal erosion, fragmentation of corals, slumping of reef framework, and abrasion and scouring of the reef (39). Secondary effects include the loss of biota dependent on the physically damaged systems (55). Structural damage to the reef framework was minimal after Typhoon Pamela passed Guam in 1976, but damage to living coral and algal communities was intense and widespread on the deeper forereef slope zone (13). Recovery of the affected ecosystems generally is slow because the base from which to build is so small (9).

A less common but equally destructive disturbance of tropical oceans is the tsunami. Tsunamis, also known as seismic sea waves, may be produced by earthquakes, landslides, or volcanic eruptions on the ocean floor and may reach velocities of up to 500 mph and heights of up to 115 feet as they hit the shoreline. Both the Pacific and Caribbean U. S.-affiliated islands are located in seismically active areas. The Pacific Ocean is ringed with earthquake-producing trenches and active volcanic areas. However, the deep waters surrounding the islands preclude major disruption by tsunamis (39). The narrow continental shelf structure of the Caribbean islands generally does not allow the tsunami to build sufficient height to cause major disruption. However, the tsunami remains a potential hazard for islands.

ISLAND HYDROLOGY

Many tropical islands receive high levels of rainfall annually; some, however, exhibit semi-arid conditions. Even with high levels of rainfall, islands are not necessarily exempt from surface and groundwater shortages. An island's topography and geology largely determine where rainfall will accumulate and how long it will remain available.

The fundamental, unifying concept in understanding water movement in islands is the hydrologic cycle (figure 3-2). The cycle is a dynamic, conceptual model that relates the continuous movement of water through the vapor and liquid phases. The components of the hydrologic cycle important to tropical islands are:

- Precipitation: Water added to an island's surface from the atmosphere (e.g., rain, fog, and dew).
- Evaporation: The process by which water is changed into vapor. In the context of the hydrologic cycle, the most important form of evaporation in a quantitative sense is that from the seas and oceans. Its return as precipitation is the main source of water for islands. Because islands surfaces are

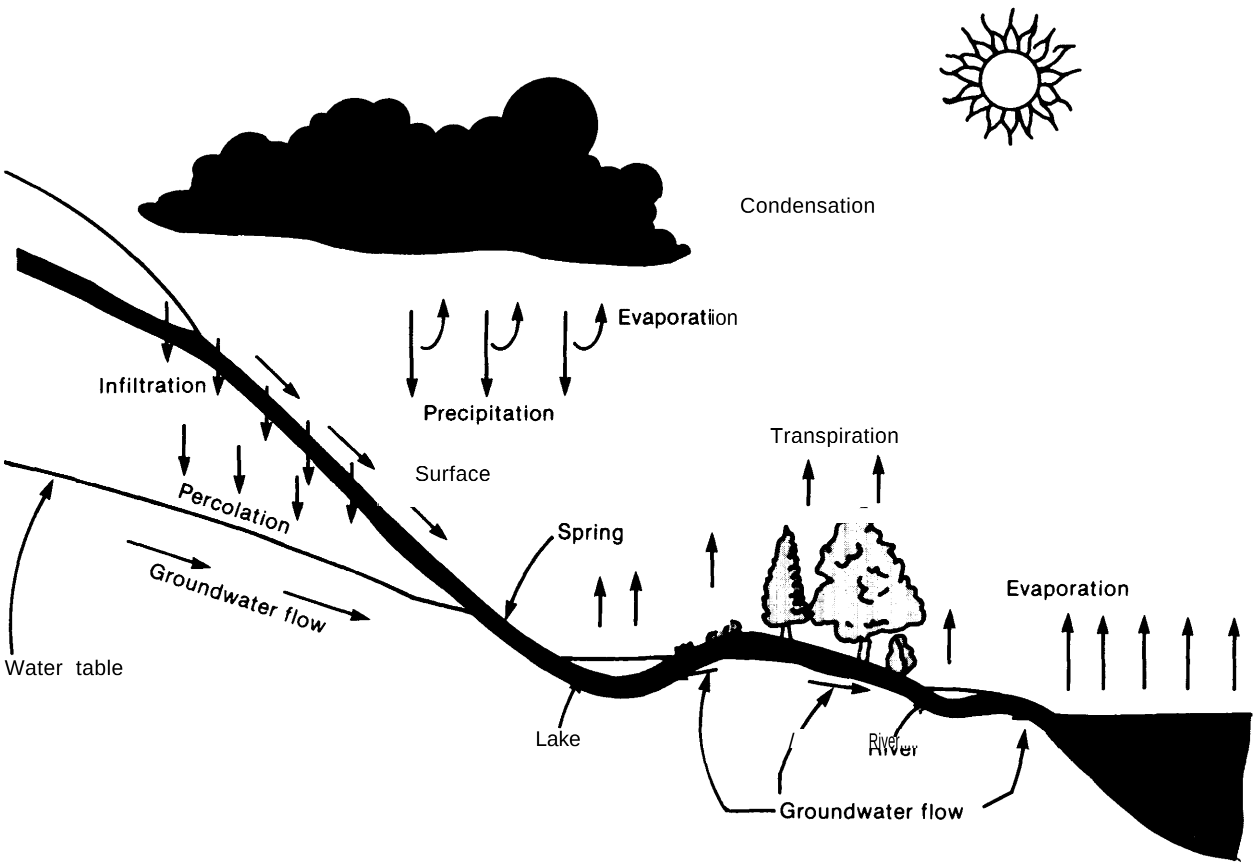
small in comparison to the ocean surface, evaporation from islands contributes a small part to overall precipitation.

- Transpiration: The process by which water passes through a living plant and enters the atmosphere as vapor.
- Infiltration: The process whereby water soaks into the soil layers.
- Percolation: The downward flow of water through soil and permeable rock formations to the water table.
- Runoff: The portion of precipitation that flows downhill on the island's surface to reservoirs and catchments and ultimately to the ocean (l).
- Retention: The proportion of water that is held in the substrate after recharge and transpiration.

The Sun is the driving force behind the hydrological cycle. It causes the evaporation of water from the ocean surface. The water vapor may condense to form clouds and ultimately return to the Earth's surface as precipitation. Some precipitation evaporates again as it falls.

Water reaching the surface of a watershed—the fundamental geographic unit of hydrology where an area of geographically low land is partly surrounded by relatively higher lands—may follow one of four courses. First, it may remain on the surface as pools or as surface moisture that evaporates back into the atmosphere. Second, precipitation reaching the ground may flow over the surface into depressions and channels to become surface runoff in the form of streams. Surface runoff expressed

Figure 3.2.—The Hydrologic Cycle



Water passes continuously through this cycle from evaporation from the oceans into the atmosphere through precipitation onto the islands and eventual runoff into the oceans. Human use of water may modify this cycle at virtually every point.

SOURCE: H Hengeveld and C. DeVocht, *Urban Ecology* 6(1-4):19, 1982.

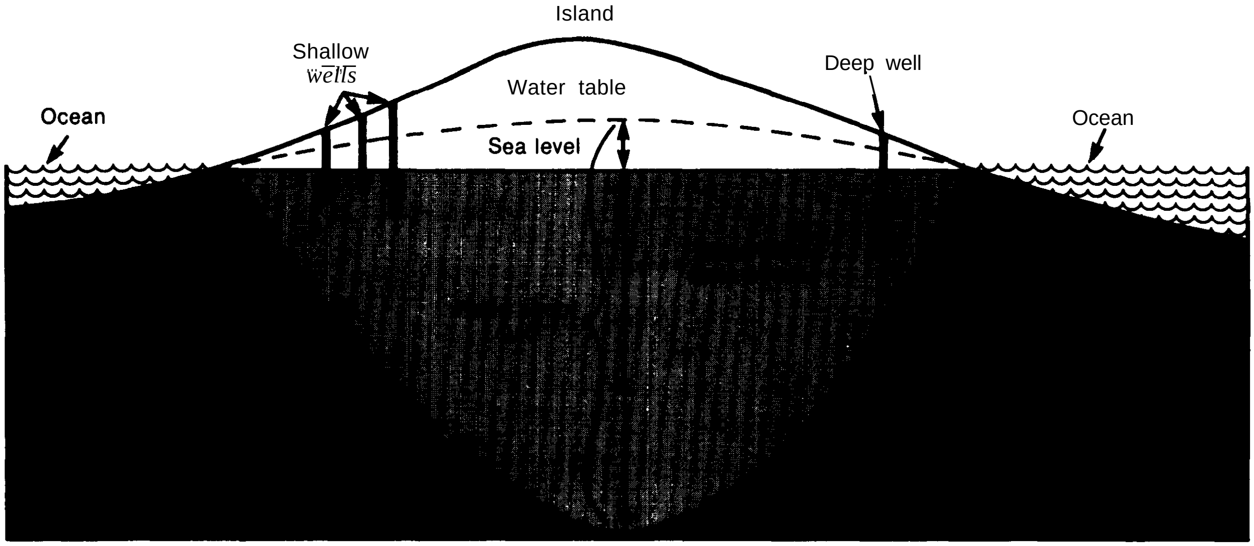
as rivers or streams, generally occurs only after evapotranspiration and soil and groundwater recharge have been satisfied or when precipitation is heavy. Third, precipitation may infiltrate the land's surface directly and percolate downward to groundwater where it may be stored. Fourth, it may recharge the soil and be partly recycled through evapotranspiration.[2] Shallow groundwater can move upward to the soil surface and plant root zone by capillary action where it is taken up by plants and transpired, or it can move laterally until it intersects the land's surface as a spring, or by underground flow into streams, ponds, or the ocean.

[2]The combined processes of evaporation of water from the land and vegetation surfaces and transpiration of water vapor through plant leaves.

The amount of rainfall that can infiltrate the soil is determined largely by the permeability of soil (governed by the size and interconnectiveness of the spaces within the soil or rock layers) and the amount of water already present in those spaces. For most soils, infiltration rates are highest at the beginning of a rainstorm when the soil is dryest, gradually decreasing with time. Some infiltrated water will be retained near the surface by capillary forces. Where percolation and/or infiltration rates are high relative to annual precipitation, no runoff will take place (e.g., sandy, calcareous soils). Commonly, the water will percolate downward where it will enter into groundwater storage.

Water that exists below the surface of the Earth in interconnected openings of soil or rock

Figure 3-3.—Ghyben-Herzberg Lens



NOTE: Diagram is vertically exaggerated for Illustrative purposes,

SOURCE: R.J. Ordway, Earth *Science and the Environment (New* **York, NY: Van Nostrand, 1974),**

is called "subsurface water. " That zone, where the pores of the sediments and rocks are filled with water, is called the groundwater zone. The top surface of this zone is called the water table. Between the water table and the surface of the Earth is the "zone of aeration," where the pores of soil and rock contain some water but less than total saturation. The water table commonly rises and falls with time as the availability of water at the surface changes.

Groundwaters storage beneath oceanic islands has certain special characteristics that differ from continental areas. Fresh water that has percolated downward through the soil to a level below which it saturates all of the interconnected pores and openings in bedrock or in consolidated sediments forms a lens commonly referred to as the Ghyben-Herzberg Lens (figure 3-3). The groundwater table is the top of this lens and is situated above sea level because the fresh water is less dense than the seawater that saturates the rocks below. The groundwater lens extends a greater distance below sea level than above in a manner similar to that of an iceberg. The basal contact of the fresh water with the seawater is transitional. For every 1 foot of groundwater that is situated above sea level, approximately another 40 feet will exist below. Many small, drier islands and atolls may have only a 20:1 ratio, and some may have no fresh water lens (34). Therefore, small changes in the altitude of the groundwater table correspond to large changes in the thickness of the fresh water extending below sea level (32).

The lens tapers from being thickest at the island's center to being thinnest at the island's edge. Close to the shoreline the entire lens may be brackish from tidal induced mixing of seawater and fresh water. As a consequence, salt-tolerant trees commonly grow near an island's edge, above the thinnest part of the freshwater lens, and salt-intolerant trees, like breadfruit, grow better toward the center of atolls (40).

High Volcanic Islands

Basaltic rocks forming the main part of high volcanic islands may be quite permeable because of the numerous joints, cracks, and bedding planes they contain (35). Consequently, precipitation can be trapped quickly by these

[3]While the term groundwater covers all subterranean water, fresh, brackish or saline, the groundwater that is most limiting in the island context is fresh water and thus is the focus of interest.

Photo credit: A. Vargo

The steep slopes of high volcanic islands, such as American Samoa, predispose island communities to flood and landslide hazards.

rocks and a thin soil cover. Nevertheless, during heavy rainstorms, large amounts of water still run off such islands quickly because of the generally steep slopes, the small size of watersheds, and sometimes because of the small total amount of water storage space in the rocks. Large amounts of erosion are common in such situations. Flash flooding from high rainfall of short duration flowing through narrow stream valleys often is a serious problem.

High islands that are either active or dormant volcanoes may emit some of the groundwater as steam and water vapor at holes or fissures called fumaroles. Groundwater in contact with rocks having elevated temperatures is likely to contain large amounts of dissolved solids that commonly precipitate around hot springs (32).

Atolls

Coralline limestone atoll islands and low coral islands are highly permeable and, thus, readily accept heavy rainfall. Most atolls rise only a few feet to a few tens of feet above mean high tide and, because of their narrow dimensions, the groundwater lens beneath them is not large. Storms can drive saltwater onto and over some atolls thereby contaminating the fresh groundwater lens with seawater. Salt carried in sea spray can build up in atoll soils, but where rainfall is heavy over short periods of time salt will be flushed from the soil (40).

Raised Limestone Islands

Raised limestone islands are lithologically similar to atolls in composition and permeability. Raised limestone islands generally are considerably larger than atolls, thus, the freshwater lens beneath is larger. Precipitation on these raised islands quickly moves downward through the porous rock and along openings formed by solution along joints and bedding planes. The vertical distance from the land's surface of raised limestone islands to the water table may be as much as several hundred feet depending on the island's elevation. Contamination of the fresh groundwater lens by seawater is most likely to be limited to nearshore areas affected by storm surges.

Natural surface-water supplies from streams and ponds are sparse on limestone islands because of the rock's high permeability. However, springs may occur along the shore near sea level where the groundwater flows laterally into the sea. Larger solution features like caves and sinkholes are common on such islands.

Continental Islands

Continental islands have the most complex hydrologic systems of all the island types because of their complex geologic origin. Groundwater infiltration rates, in general, will be much more variable on continental islands than on volcanic islands, atolls, and raised limestone islands. For example, Puerto Rico is a continental island with a wide variety of rock types, each

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with differing porosity and permeability. It is the composite of these characteristics plus local climatic variations that make up the island's overall hydrologic system. As such, continental island hydrology does not lend itself to a simple description of the sort suitable to other island types.

Some parts of continental islands have a local geology and lithology similar to the other island types. In these cases, the workings of the hydrology will parallel the other island types. Such would be the case for volcanic and limestone terranes. But where terranes of other lithologies exist major differences can occur.

Typically, continental islands have a core of igneous rock with limited aquifer development in the zones of fracture and faulting. Alluvial and limestone deposits commonly occur around the flanks of the island's core to produce coastal plains which may be of considerable size (e.g., Puerto Rico's coastal plain extends nearly 4 miles in width). Rainfall is most plentiful in the mountainous regions and diminishes toward the coast promoting significant variation in precipitation levels between coastal and mountain areas. Major coastal aquifers may exist in some areas, recharged by precipitation on the alluvium as well as by streamflow from upper watersheds (28).

ISLAND SOILS

Soils form from the chemical and physical breakdown of rocks and minerals. Limestone and basalt and the alluvium derived from their erosion constitute a large part of volcanic and limestone islands' surface material, while on continental islands a wider range of rock types exist. Chemical weathering processes predominate where precipitation is high and physical weathering processes predominate where precipitation is low; a continuum exists between the two extremes. Where chemical weathering processes predominate, soils largely are depleted of nutrients regardless of the parent rock type.

Many soils that form in hot, wet tropical areas have significant fertility problems. This is the case for most parts of many Pacific islands and much of Puerto Rico. Under such conditions, chemical weathering of parent rock materials is the predominant soil forming mechanism. High temperatures, high precipitation levels (approximately 50 inches and above) and the action of plant roots combine to accelerate leaching of nutrients from the rock and soil mineral particles, transforming the primary minerals to secondary minerals. The secondary soil minerals are composed largely of aluminum, silicon, iron, oxygen, and water (16). The chemical composition often is imbalance so that many food or tree crops planted on such soils will have limited productivity or will not survive. In some soils, silicon and iron concentrations are so low, and aluminum so high that the composition of bauxite, an aluminum ore, is approached or reached.

On islands where the annual rainfall is lower (southwestern Puerto Rico and much of the Virgin Islands) and where the temperature generally remains high year-round (average of 800 to 850 F), physical breakdown of rocks and soil minerals plays an increasingly larger role in soil formation. In this process, the particles become smaller but their chemical composition is less affected and leaching of soil nutrients is more limited. Physical disintegration can occur in a number of ways; for instance, salts and certain minerals in small cracks in rocks and soil particles expand when wet (hydration) and contract when dry (dehydration), thus causing grains to break (5). And, of course, the growth of plant roots is a powerful agent in breaking up rock and soil particles.

In drier areas where rainfall is seasonal, nutrients needed by many plants commonly are in the soil but become available to the plants only if sufficient water is available (6). If most of the water evaporates from the soil surface rather than percolating downward into the soil, dissolved solids or salts can accumulate as

Box 3-C.—Common Characteristics of Island Soils

- Most island soils, [illegible] rainfall exceeds 50 inches, [illegible] and soil [illegible].
- In drier island areas, [illegible] of Puerto Rico and the U.S. Virgin Islands, the soils are less leached and thus contain more plant nutrients. However, in some cases, continued evaporation of soil moisture [illegible] salts upward in the soils and tends to render them alkaline [illegible] plant growth.
- Soils formed from weathered limestone on atolls and high limestone islands tend to have especially poor water- and nutrient-holding capacity.
- Steeply sloping [illegible] shallow and easily eroded. [illegible] rainfall is heavy, [illegible] and soil may be thick. [illegible] landslides.
- Alluvial soils, created [illegible] have substantially greater fertility than those of the original site, but they will have the advantages of being mostly on flat land and closer to [illegible] sources.
- Soils in natural or manmade lowlying, wet areas filled with fine-grained sediments and decaying plant materials (e.g., swamps, taro pits) tend to be fertile but may become acid when drained and exposed to air.
- Maintaining [illegible] matter in highly leached [illegible] way of partially [illegible] problem.

crusts at or near the land surface in concentrations that few plants can tolerate (21). Similarly, if the groundwater table is high, evaporation of the groundwater may occur, which also results in accumulated salts in the soil. Thus, soils in drier zones tend to be alkaline such that even with irrigation systems and fertilizer applications, the availability of nutrients, and particularly of important trace elements can be a problem (28).

On high islands where slopes are steep, much of the rainfall runs off in streams rather than percolating into the ground. The soils that form on slopes remain shallow and can be more easily eroded than those on flatter lowlands (6).

The presence of soil organic matter from plant litter and roots plays a key role in maintaining soil productivity because it:

- contributes to the development of soil aggregates, which enhance root development and reduce the energy needed to work the soil;
- increases the air- and water-holding capacity (porosity) of the soil, which is necessary for plant growth and helps to reduce erosion;
- releases essential nutrients as it decays;
- holds nutrients in storage until the plants need them; and
- enhances the abundance and distribution of vital biota (45).

Soils formed from basaltic rocks in their early stages of chemical weathering can be quite fertile. Where annual precipitation is below 50 inches such soils can support high agricultural productivity; above 50 inches fertility decreases rapidly as leaching increasingly removes soil nutrients. As the weathering process continues, soil fertility will decrease even at the lower rainfall levels. Thus, geologically old, inactive volcanic islands generally will have soils with serious fertility problems and often aluminum toxicity as they become very acidic (pH 4.0). Those islands having geologically recent volcanic activity are more likely to have soils of higher fertility derived from basaltic lava flows and ash deposits. Where volcanic islands are still active or where they have been active recently it is less likely that sufficient time has elapsed for natural vegetation to develop to convert the rock materials into soil especially if precipitation is low.

Where rainfall is heavy the layer of weathered rock and soil material may become thick. Land-

m G m mm w g w

slides sometimes occur in such areas where heavy rains saturate this weathered zone and where the slope of the land is steep. Landslides of this sort are more common on high volcanic islands and continental islands than on raised limestone islands. Puerto Rico, for example, in 1981 and 1985 experienced severe landsliding on the south side of the island after saturating rains.

Soils formed from the weathering of limestone even where precipitation is moderate are composed of the residual insoluble minerals that have accumulated as the limestone dissolves (32). In this solution process the resulting soils are highly leached and, therefore, have fertility problems. Maintaining an adequate supply of organic matter in highly leached, infertile soils is a way of partly offsetting the infertility problem. Soils formed on coralline limestone atolls are composed of sand and silt-sized particles of limestone and, consequently, are alkaline (pH 7.5 to 8.5). The soils' lack of abundant amounts of clay-sized particles results in their poor water- and nutrient-holding ability. Decomposition of soil organic matter produces weak acids that in turn help dissolve the limestone soil particles (40).

Alluvial soils are those formed of eroded sediments that have been transported by running water. These sediments are deposited along floodplains and at the mouths of streams. The composition of the alluvium and, thus, the soil is a reflection of the eroded and weathered rocks of the watershed. For example, in a watershed comprised mostly of limestone, the alluvium on which the soil forms will be mostly limestone. Such soils are not likely to have greater fertility than the watershed soils, but they will have the advantages of being mostly on relatively flat land and closer to "significant" groundwater resources.

In low-lying wet areas, depressions sometimes are filled with a mixture of fine-grained sediment (clay, silt, and shell fragments) and decaying plant materials (peat). These dark colored, wet, soft deposits formed under anaerobic conditions generally are called "muck" soils. They are common beneath swamps and, thus, are restricted mostly to atolls and to lands of low relief surrounding some high volcanic islands, raised limestone islands and continental islands. The organic matter assists in holding added plant nutrients in a form available to living plant cover and provides other useful functions (see above). Because of their topographic position and nearness to the ocean, some have a high salt content. Others, when drained and exposed to air, become acid as certain sulfide minerals oxidize, adversely affecting plant growth.

Certain atolls, including some of those in the Marshall and Caroline Islands, are known for their rich deposits of rock phosphate. These deposits and soils have formed over time from dung or "guano" deposited on the atoll by fish-eating birds. Mild acids formed from the decomposition of organic matter carry the guano (phosphate bearing organic material) downward in the soil to limestone layers where the acids are neutralized and the calcium phosphate is deposited (40). Many of these phosphate deposits have been mined over the years and exported for agricultural use.

RENEWABLE RESOURCE SYSTEMS IN U.S.-AFFILIATED TROPICAL ISLANDS

The island ecosystems and the efforts to sustain, enhance, conserve, or restore these resources represent major positive factors of the U.S.-affiliated tropical islands. Each island ecosystem contributes to the supply and effective sustained use of island renewable resources (9). Island biological resources provide both direct and indirect benefits to the inhabitants. The small size of islands makes them easier to study as complete systems, and thus makes it possible to integrate management of island resources (9).

Local government efforts to maintain existing resources are numerous, including such actions as the creation of parks and protected areas, regulation of resource use, and development planning in coordination with sustainable use of local resources. The new entities emerging under the Compacts of Free Association now will have the opportunity to develop similar resource management programs. Previously, resource management and regulation, including protection of endangered species and critical areas, fell under the jurisdiction of the Trust Territory of the Pacific Islands regulations (47). However, regulatory efforts often were minimally effective and resources generally were well protected only on islands remote from human populations (14).

Common Characteristics of Tropical Island Resources

Endomism of Species

Tropical forests have a history of species-richness, and endemism. Puerto Rico has 547 native tree species, approximately the same number found in the continental United States. The U.S. Virgin Islands has between 800 and 1,000 native plant species and several hundred introduced or exotic species (44). The Western Pacific islands are especially rich in rare endemic species; for some tree species only one or two individuals are known[4] (44). In many

[4] For example, there are only a few individuals left of a native Pacific tree *Tabernaemontana rotensis* (M. Falanruw, pers. comm., 7/86).

Photo credit: J. Bauer

Habitat modification has reduced the range of the Puerto Rican parrot significantly. The only known remaining habitat for these birds, pictured here in an artificial nest, is in the Caribbean National Forest.

cases the insular bird and mammal life also are endemic. Examples include the Puerto Rican parrot and the Mariana fruit bat.

The number of species an island can accommodate is proportionate to island size (i.e., a greater number of species may live on a larger island); however, the number of species present on the island also depends on distance from colonizing sources (i.e., continents or other islands) and diversity of island habitat (9). Islands tend to develop new varieties and species that are found nowhere else (endemic species). This occurs as populations develop characteristics of adaptation to the isolated island environment. The small size of the island limits the species populations, thus, any reduction in habitat size, such as by human development, eventually may lead to extirpation or extinction of some species (table 3-2). Environmental perturbations easily may affect an entire population. The distance of islands from colonizing sources affects the probability that an extirpated population will naturally reestablish.

Value to Science

Island ecosystems provide values to science disproportionate to their small size. Because of the high rates of endemicity, islands may provide species of particular scientific interest for botanical and zoological investigation. The clearly defined boundaries facilitate study of species migration, competition, adaptation, and extinction. General principles of evolution can be derived from island studies (44).

The genetic resource represented by the unique island biota, although on a smaller scale than continental areas, represents potential gene banks of tropical species. Johnston Atoll is of particular scientific interest because of its geographic isolation and age (26). It is an ancient reef and, except for Wake Island, is the only atoll of the Marcus-Necker ridge still surviving in shallow water (app. B), The atoll has been designated a National Wildlife Refuge in order to protect the nesting seabird populations and well-developed coral reefs (26).

Vulnerability to Disruption

The isolation and small size of islands, which foster species endemicity and limit population size respectively, contribute to island species' vulnerability to disruption. Populations that evolved with limited competition or predator/prey relationships often cannot survive when forced to compete; further, small populations have lower capacities for recovery. Although isolation offers some protection from natural introduction of competing species, the importation (intentional or not) of animals, insects, and diseases has reduced island indigenous plant and animal populations (12,23). Guam's bird population has been declining steadily since World War II; the main culprit is thought to be the brown tree snake. The snake is believed responsible for severely reducing avian populations on Guam. The introduction of the snake has been estimated to have occurred in the early 1940s, however the method or reason for its arrival is not clear.

Table 3-2.—Endangered and Threatened Wildlife and Plant Species With Historic Range in the U.S.-Affiliated Tropical Islands

Common name	Scientific name	Historic range[a]	Status	Where endangered
Mammals:				
Little Mariana fruit bat	Pteropus tokudae	Western Pacific (Guam)	E	entire
Mariana fruit bat	Pteropus mariannus mariannus	Western Pacific (Guam) (Rota, Tinian, Saipan, Aguijan)	E	Guam
Dugong	Dugong dugon	East Africa to southern Japan, including RMI, CNMI, FSM, and Palau	E	entire
West Indian Manatee	Trichechus manatus	U. S. A., Caribbean Sea South America	E	entire
Caribbean Monk Seal	Monachus tropicalis	Caribbean Sea, Gulf of Mexico	E	entire
Hawaiian Monk Seal	Monachus schauinslandi	Hawaiian Archipelago	E	entire
Blue Whale ...	Balaenoptera musculus	Oceanic	E	entire
Bowhead Whale	Balaena mysticetus	Oceanic (north latitude)	E	entire
Finback Whale	Balaenoptera physalus	Oceanic	E	entire
Humpback Whale	Megaptera novaeangliae	Oceanic	E	entire
Right Whale, ...	Balaena glacialis	Oceanic	E	entire
Sei Whale . .	Balaenoptera borealis	Oceanic	E	entire
Sperm Whale . . . .,	Physeter catodon	Oceanic	E	entire
Birds:				
Guam Broadbill .,	Myiagra freycineti	Western Pacific Ocean (Guam)	E	entire
Mariana Crow	Corbus kubaryi	Western Pacific Ocean (Guam, Rota)	E	entire
Micronesia Kingfisher	Halcyon cinnamomina cinnamomina	Western Pacific Ocean (Guam)	E	entire
Mariana Mallard . .,	Anas oustaleti	West Pacific Ocean (Guam, Mariana Islands)	E	entire
Micronesia Megapode (= La Perouse's)	Megapodius laperouse	West Pacific Ocean (Palau, Mariana Islands)	E	entire
Tinian Monarch	Monarcha takatsukasae	Western Pacific Ocean (Mariana Islands)	E	entire
Mariana Common Moorhen (= Gallinule) . . . .,..,.	Gallinula chloropis guami	Western Pacific Ocean (Mariana Islands)	E	entire
Puerto Rico Nightjar (=Whip-poor-will),	Caprimulgus noctitherus	Puerto Rico	E	entire
Puerto Rican Parrot	Amazona vittata	Puerto Rico	E	entire
Puerto Rican Plain Pigeon ., ...	Columba inornata wetmorei	Puerto Rico	E	entire
Piping Plover	Charadrius melodus	USA (Great Lakes, northern Great Plains, Atlantic and Gulf coasts, PR, Vi), Canada, Mexico, Bahamas, West Indies	E	Great Lakes watershed in IL, IN, Ml, MN, NY, OH, PA, and WI and Province of Ontario; All other range locations
Guam Rail	Rallus owstoni	Western Pacific Ocean (Guam)	E	entire
Ponape Mountain Starling.	Aplonis pelzelni	Western Pacific Ocean (Caroline Islands)	E	entire
Vanikoro Swiftlet, ., .,	Aerodramus vanikorensis bartschi	Western Pacific Ocean (Guam, Rota, Tinian, Saipan, Aguijan)	E	entire
Least Tern	Sterna antillarum	USA (Atlantic and Gulf coasts, Mississippi River Basin), Greater and Lesser Antilles, Bahamas and Mexico	E	range in contiguous States
Nightingale Reed Warbler	Acrocephalus Iuscinia	Western Pacific Ocean	E	Mariana Islands
Bridled White-eye	Zosterops conspicillata conspicillata	Western Pacific Ocean (Guam)	E	entire
Ponape Greater White-eye	Rukia Iongirostra	West Pacific Ocean (Caroline Islands)	E	entire
Reptiles:				
Culebra Island Giant Anole . .	Anolis roosevelti	Puerto Rico: Culebra Island	E	entire
Mona Boa ., ...	Epicrates monensis monensis	Puerto Rico	T	entire
Puerto Rico Boa, ... ,	Epicrates inornatus	Puerto Rico	E	entire
Virgin Islands Tree Boa	Epicrates monensis granti	U.S. and British VI	E	entire
American Crocodile	Crocodylus acutus	USA (FL), Mexico, South America, Central America, Caribbean	E	entire
Saltwater Crocodile	Crocodylus porosus	Southeast Asia, Australia, Papua New Guinea, Pacific Islands	E	entire
Monito Gecko ., ...,	Sphaerodactylus micropithecus	Puerto Rico	E	entire
Mona Ground Iguana . . .	Cyclura stejnegeri	Mona Island	T	entire
St. Croix Ground Lizard	Ameiva polops	U.S. Virgin Islands	E	entire

Table 3.2.—Endangered and Threatened Wildlife and Plant Species With Historic Range in the U.S.-Affiliated Tropical Islands—Continued

Common name	Scientific name	Historic range[a]	Status	Where endangered
Sea *Turtles:*				
Green, ...	Chelonia mydas	circumglobal tropical & temperate seas and oceans	T	entire
Hawksbill. ., ., ., . .	Eretmochelys imbricata	tropical seas	E	entire
Kemps Ridley (= Atlantic)	Lepidochelys kempii	tropical and temperate seas in Atlantic Basin	E	entire
Leatherback . .	Dermochelys coriacea	tropical, temperate & subpolar seas	E	entire
Loggerhead	Caretta caretta	circumglobal in tropical & temperate seas & oceans	T	entire
Olive Ridley (= Pacific)	Lepidochelys olivacea	tropical and temperate seas in Pacific Basin	T	entire
Golden Coqui	Eleutherodactylus jasperi	Puerto Rico	T	entire
Plants:				
Prickly-Ash . .	Zanthoxylum thomasianum	Northern Puerto Rico	E	entire
Beautiful Goetza, Matabuey	Goetzea elegans	Puerto Rico	E	entire
Vahl's Boxwood	Buxus vahli	Puerto Rico	E	entire
Palo de Ramon[b]. . .	Banara vanderbiltii	Puerto Rico	E	entire
Hayun Lagu, Trokon guafi[c].	Serianthes nelsonii	Guam, CNMI	E	entire

Species Removed from the Endangered and Threatened Lists
(for informational purposes only, not codified in the Code of Federal Regulations)

Common name	Scientific name	Historic range	Prior status	Where endangered	Reason for delisting
Palau Dove	Gallicolumba canifrons	West Pacific Palau Islands	E	entire	recovered
Palau Fantail	Rhipidura lepida	West Pacific Palau Islands	E	entire	recovered
Palau Owl .,, , ,,, ,, .,,,,,,., .,, .., ..,	Pyroglaux podargina	West Pacific Palau Islands	E	entire	recovered

[a]Historic Range indicates the known general distribution of the species or subspecies as reported in the current scientific literature. The present distribution may be greatly reduced from this historic range.

SOURCE: U.S. Department of the Interior, U.S. Fish and Wildlife Service, January 1966. [for all but the following]

[b]*Ecology USA,* "Recent Actions Under the Endangered Species Act, " 16(3):24, Jan. 16, 1987.
[c]Ecology USA, "Recent Actions Under the Endangered Species Act, " 16(4):32, Mar. 2, 1987.

A primary method of protecting island fauna is through the maintenance of appropriate habitat. However, the small size of islands means that park and protected area designs need to make optimum use of limited land area and may need to combine protection of fauna and flora. Undisturbed sanctuaries may be necessary for those species that cannot tolerate disturbance as opposed to those that maybe integrated into parks with recreational potential. Some extremely vulnerable species may only be effectively protected on islands remote from human population.

Surveys of many island areas still are needed to determine the incidence of endemism, and the status of native species. The importance of quarantine regulations and enforcement cannot be understated in island areas (23). Local governments can play a major role in identifying and protecting rare, threatened and endangered species. A native Guamanian plant species, Serianthes nelsonii, while pending Federal listing as "endangered" already possessed that status and protection under local law (42).[5]

Vulnerability to Overexploitation

Island species are particularly vulnerable to overexploitation, often because the base from which to build generally is small. Several island species have been exploited to the extent that they are now endangered (table 3-2). The Mariana fruit bat, *Pteropus mariannus mariannus,* is considered a great delicacy in the Marianas and bat populations on some islands have been heavily exploited. Overexploitation of fruit bat populations on Guam resulted in increased exploitation of fruit bat populations on other islands, including Yap, to satisfy the market. Consequently, Yapese fruit bat populations were severely reduced and in 1980 the hunting and exportation of these animals was

[5]S. *nelsonii* has been listed as Endangered under the Endangered Species Act, effective 3/20187.

Photo credit: E. Petteys

Overexploitation of the Mariana fruit bat has severely reduced populations in the Pacific. Despite protective legislation, poaching continues to threaten remaining fruit bat populations in some island areas.

banned. The species was placed on the Endangered and Threatened Wildlife and Plant list and given "endangered" status in 1984. Populations in some areas are in recovery stages (22).

Major Island Resource Systems

Upland Forests

The higher parts of most high islands in the U.S.-affiliated Pacific and Caribbean originally were covered by dense forests (9). The remaining higher elevation forests are important in contributing to control of erosion and landslides on steep slopes. The topography generally precludes timber harvesting operations but may allow some agroforestry practices.

Upland forests are important as wildlife habitat and in maintaining watershed function. These forests may enhance the watershed by increasing interception of rainfall, increasing percolation, improving infiltration, and reducing the rainfall impact on the soil. Upland forests are not easily reestablished once cleared, often leading to chronic erosion problems.

Mountainside submontane rain forests are comprised of predominantly broad-leaved trees with an even canopy, many epiphytes, and in some areas with abundant undergrowth including tree ferns and small palms. Forests of this type are found on several of the U.S.-affiliated islands. Some of the remaining submontane forests have been disturbed, such as one present on Truk, which now covers approximately only 2 acres on the top of one volcanic island.

Cloud forest (also called dwarf, elfin, or moss forest), a specialized, highly vulnerable upland forest, has developed on high ridges and mountain tops on some islands. These forests, kept moist by the constant presence of cloud formations, generally are composed of gnarled or dwarfed trees burdened with mosses and lichens. The ground commonly is covered with club mosses and ferns. Cloud forests are high in endemic species and are extremely vulnerable to disruption. Endangered status recently has been proposed for two plant species, *Cyathea dryopteroides* and hex cookii, endemic to Puerto Rico's cloud forests of the Central Cordillera (11). Although cloud forests are present on several of the islands, their areal extent is extremely limited.

Implications for Management.—Upland forests are important for watersheds, contribute to erosion control, provide habitat for wildlife, and often contain many endemic species. While development of forestland may be necessary for provision of goods and services to island populations, such activities might be preceded by objective analyses of the cost of artificially providing those services which will be lost because of development. Development

Table 3-3.—Ecosystems Present on the U.S.-Affiliated Islands

Island Areas	Puerto Rico	USVI	American Samoa	Guam	CNMI
Cloud forest	Present on mountain tops	May have been present on mountain tops	Undisturbed formation on top of Ta'u	Possibly on top of Mount Lamlam	Mount Tapachau, Saipan; other islands unknown
Submontane rain. forest	Formerly on higher mountains	None	Midelevation ridges and as secondary growth	None	None
Lowland rainforest	Little remains	None	Remains on steep slopes	Scattered remains of limestone, species-rich forest	Lava forest on northern island
Riverine and swamp forest	Limited extent remains	None	Limited amount present along streams	Present along rivers, moist ravines; mostly in south	In ravines on smaller islands
Subtropical moist/ seasonal forest	Little remains	Limited areas in mountains or remote areas	None	None	None
Subtropical dry forest	Present, little of original ecosystem	Present, considerably reduced from original extent	None	None	None
Savanna and grasslands	Considerable man-made areas maintained as pasture or ground cover	Present in former agricultural areas	Present as early sere after disturbance	Extensive fire-adapted areas in south	Extensive natural formation in northern islands, man-made on Saipan and others
Scrub	Present, often as secondary growth	Present	Present on on Matafao and Piao mountains, Tutuila	On rocky limestone coast and some southern areas	Coastal volcanic rock in north and limestone coast in south
Wetlands	Some rivers, and marshes, and some saltwater marshes occur behind mangroves	Saltwater ponds in bays behind mangroves	Streams and coastal marshes; lakes on Ta'u and Anu'u	Some streams and rivers; reed swamps; saltwater and freshwater marshes; man-made lake	Saltwater and freshwater marshes, freshwater lakes on Saipan and Pagan, brackish on Pagan
Mangrove forest	25 mi^2 scattered around coast	Forests only on St. Thomas and St. Croix	Pala lagoon (stressed) on Tutuila, and on Aunu'u	Small areas, particularly Apra Habor	Limited areas in southern islands
Atoll/beach forest and scrub	Present in some areas	Present	Widespread, special types on Rose Atoll and Swain's island	Common, includes some endemics	Present on some of the southern islands
Lagoons/shallow bottoms	Behind barrier reefs and other offshore features	Extensive in bays, inside reef and along shelf	Lagoons on Rose Atoll, Swain's Island and Tutuila	Cocos lagoon	Shallow lagoon inside some reefs on Saipan and Tinian
Coral reefs	Barrier, fringing and patch reef areas, most damaged	Bank barrier reef and algal ridge; also fringing barrier and patch reef complexes; some damaged	Main islands largely bordered by fringing reefs; some damaged	Barrier reef near Cocos island, variety of patch and fringing reefs elsewhere, some damaged	Fringing reefs common in southern islands, some damaged

SOURCE: A.L. Dahl, "Tropical Island Ecosystems and Protection Technologies To Sustain Renewable Resources in the U.S.-Affiliated Islands," OTA commissioned paper, Washington, DC, 1986.

could be redirected from areas where forest-provided services (i.e., important watersheds) are critical to the island and its inhabitants. Further, additional benefits maybe derived when required development is done in such a way as to protect or maintain the natural function of the-vegetation, thereby maintaining or only slightly reducing the services provided by the forest. The vulnerability of cloud forests to disturbance is so extreme that these forests cannot withstand development activities.

Lowland Forests

Lowland forests, which grow on hillsides and in coastal plains, are composed mostly of nu-

Table 3-3.—Ecosystems Present on the U.S.-Affiliated Islands—Continued

		Federated States of Micronesia			
Marshalls	**Palau**	**Kosrae**	**Pohnpei**	**Yap**	**Truk**
None	None	Present on mountain top	At highest elevations	None	None
None	None	At midelevations, some disturbed	At midelevations	None	Limited area on top of one volcanic mountain
None	Limestone, species-rich	Present with many endemics, nearly undisturbed	Present, most areas disturbed	Species-rich forests, most are disturbed or replaced	Present, disturbed
None	Along rivers and inland of mangroves	Along rivers and inland of mangroves	Dense along rivers, inland of mangroves	Present, inland of mangroves	Present, inland of mangroves
None	None	None	None	None	None
None	None	None	None	None	None
On smaller islets of some atolls	Present on clay soils, and where fire-maintained	Present	Present often from burning	Now predominant on clay soils, or where frequently burned	Present
Some on northern islands	Outer edges of limestone forest, rocky coasts and strip mined areas	Present	On rocky coasts and some ravines	Present in some degraded areas	Present
Freshwater pond on Lib; tidal saltwater marshes	Streams, rivers, lakes, ponds, swamps, freshwater and saltwater marshes	Short streams, and other freshwater habitat	Streams, rivers, lakes, ponds, swamps, and marshes	Freshwater streams, ponds, swamps, and marshes	Low swamps and marshes
In depressions on a few atolls	11,513 acres in estuaries and along coasts of archipelago	3,859 acres around island	13,562 acres along coast and estuaries, some on Pingelap Atoll	2,894 acres on Yap, and some on Elato and Woleai Atolls	3,315 acres around main islands
Largely replaced by coconut and breadfruit, except on some northern atolls	In a few areas behind beaches and on Kayangel Atoll	Present behind beaches	On high islands, largely replaced by planted trees	On atolls and behind beaches, often replaced by coconut	On atolls, islets; and in some coast areas
Large open lagoons, closed lagoon in Namorik	Lagoons within barrier reef, also Kayangel Atoll and Helen Reef	Some shallow lagoons inside reef	Extensive lagoon with seagrasses, and atoll lagoons	Some shallow lagoons within reef and atoll lagoons	Over 2,000 mi^2 including atoll lagoons
Islands built by coral reef ecosystems, some damaged	Barrier, fringing and patch reefs; rich and diverse; also some atolls; some areas damaged	Largely surrounded by fringing reef	Extensive barrier reef enclosing lagoon with fringing and patch reefs, and outer atoll islands	Wide, fringing reefs, outer atoll islands	Major barrier reef with islet enclosing lagoon with complex structures, outer atoll islands; considerable damage

merous species of fast-growing trees. Many of these reach 80 to 120 feet in height and exhibit a closed, uneven canopy and little undergrowth. Lowland rain forests occur on many of the U. S.-affiliated islands and most of these have been disturbed, some to great extent. The lowland forests of Kosrae and Palau probably represent the least disturbed communities.

Lowland rain forests are important for water catchment and for building soil nutrients and humus, often growing on and giving rise to the best island soils. They have the highest timber production potential of any island forest, however the land they cover often is under pressure for competing uses such as agriculture and human settlements. These activities, plus log-

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ging, have caused significant genetic resources and wildlife to be lost. Continuing disturbance, a lack of seed sources, and competition from introduced plants impede recovery, which might take decades under good conditions (9).

The drier Caribbean climate produces a type of lowland forest not found in the U.S. Pacific islands. The tree species of subtropical moist or seasonal forests are more resistant to drought and may lose some leaves in the dry season. Sixty percent of Puerto Rico originally was covered with this type of forest; this is down to 15 percent today (54). In the U.S. Virgin Islands, about 25 percent of the land area was covered with this type of forest. What remains today is mostly in mountainous regions with lesser amounts existing in the dry foothills (27). The conversion of land to agricultural purposes resulted in the clearing of the majority of this forest type.

Subtropical dry forest, a drought-resistant forest with many species and commonly with an understory of shrubs, also is found in the U.S. Caribbean. This type of forest is slower growing than the moist forest type. Sixteen percent of Puerto Rico was once covered by this vegetation type, mostly on the southern side and forest communities were distinguished between those growing on coastal areas and those of limestone soils (9). Five percent of the original forest type remains today primarily because of the conversion of land to agricultural purposes (54).

In the Virgin Islands this type of forest covered nearly three-quarters of the island (9). Today few original forest stands remain, most areas having been once cleared for grazing lands or other agricultural purposes. Forests of this type along the immediate coastal strip may be important in filtering runoff from the land and thus preventing or reducing coastal pollution from sedimentation and agricultural chemicals. Generally, relatively large areas are needed to maintain production and regeneration making the conservation of such forests difficult. Smaller areas, if effectively protected, may be managed to conserve this forest type (27).

Implications for Management.—These forests are important for water catchment, soil and humus building, and offer timber production potential. However, the relatively flat lands occupied by this forest type generally are under pressure for competing uses such as agriculture. Development and management activities might be directed to allow profitable use for timber and agroforestry production while maintaining the natural functions of the forest. Lands needed for other agricultural pursuits could be designated, so as to maintain sufficient amounts of natural and modified forest area. Abandoned agricultural areas could be reforested to restore soil fertility.

Freshwater Wetlands

Wetlands and freshwater island environments include freshwater marshes and reed swamps, lakes, rivers and streams with aquatic plants, and freshwater fauna. Dense forests of hydrophytic species also occur along rivers and in swampy areas inland of mangrove forests. Forests of this type occur in American Samoa, Guam, Northern Marianas, Pohnpei, Kosrae, Truk, Yap, Palau, and Puerto Rico. These forests are important in contributing to erosion and flood control along streambanks and thus prevention of pollution of water supplies.

Marsh and stream vegetation slows runoff, contributing to erosion and flood control and reducing water turbidity. They also may provide a filtration system which buffers reefs and lagoons from terrestrial sedimentation and pollution.

Wetland environments have been recognized as critical areas in island coastal management programs and as such are accorded some degree of protection (46,47,48,49,50,51). These environments also provide critical habitat for many wildlife species, including some that are federally protected under the Endangered Species Act,

These ecosystems may be very restricted on small islands and are generally quite vulnerable to disturbance. Some systems have evolved to adapt to a wide salinity range, or to temporary disappearance, regenerating when conditions permit. However, recovery from severe stress, such as from agricultural chemicals or heavy sedimentation, may be very slow even after sources of stress are removed (9).

Implications for Management.—Wetland environments provide critical habitat for many wildlife species and are important in contributing to erosion and flood control. Through mitigation of erosion and flooding they provide for the protection of nearshore areas from pollution and extreme freshwater discharge. Generally, wetland plant species are quite vulnerable to disruption and recovery may be slow; wildlife species may be extirpated if alternate wetland habitat is not available. Development activities could take precautions to protect the wetland environment, or be redirected to less vulnerable areas.

Grass and Fern Savanna Lands

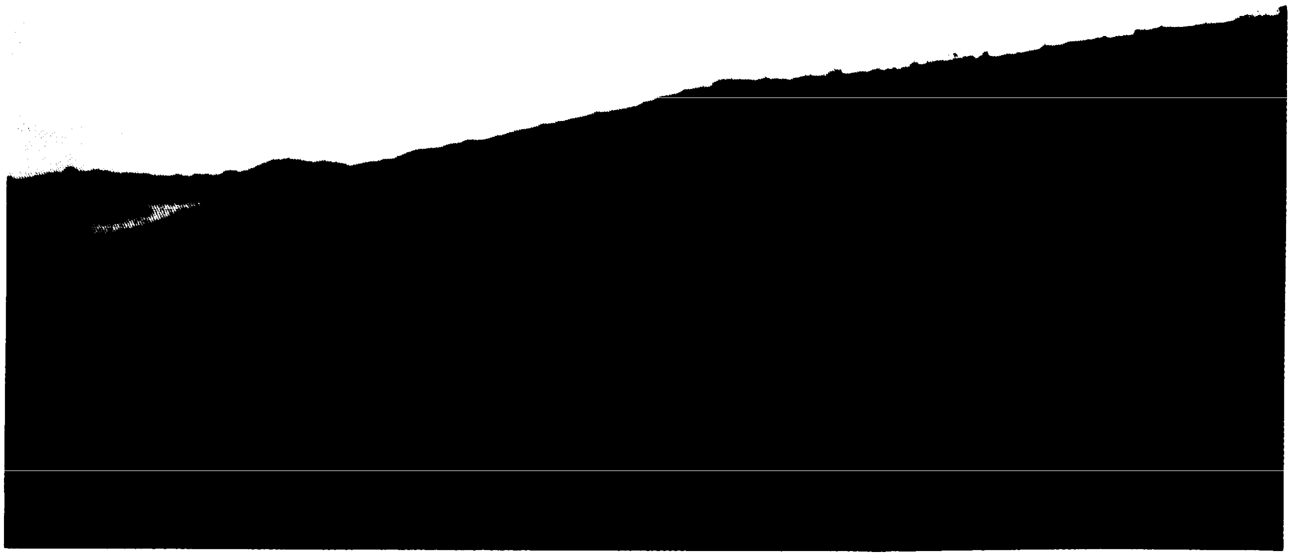
Savannas composed of grasses (commonly *Miscanthus*, or sword grass) or fern *(Gleichenia)* are found on many islands, alone or in association with scattered trees and shrubs. A number of endemic plants may be found in these areas. Many grasslands are maintained by frequent burning, often to attract game species, or provide pasture for domesticated animals. It is believed that the habitat has long been present in areas such as southern Guam and Babelthaup (Palau) although to a considerably lesser extent than at present (15).

Ferns and grasses tend to contribute to erosion control and some areas may be used as pasture land for livestock. However, improvement often is necessary to allow profitable use as pasture. Regrowth generally is rapid after burning, however, repeated burning degrades the soil by removing the organic content; and there is risk of fire spreading to adjacent more valuable forest types.

Implications for Management.—Primary management attention should be given to fire control and public education on the ecological impacts of frequent burning. Management or development activities could involve active improvement of those areas which might be used profitably for pasture, or agriculture, or for urban and residential development; and encourage reforestation of other areas. Such reforestation schemes could consider using fire tolerant species.

Strand and Beach

Vegetation comprised of a few widely distributed species of trees and shrubs, including some endemics, occupies the sand and rubble along the coastal beach strand close to sea level. This is the major vegetative formation on atolls and low coral islands. This coastal fringe contributes to stabilization of the coastline and offers protection from storm damage and salt-spray



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to inland areas. Strand forest and scrub can be found to some extent on all U.S.-affiliated islands. In many areas the forest has been cleared to allow for development. This type of forest has the capability to recover or recolonize readily when disturbance or stress is removed (9).

In some areas much of the strand and beach vegetation has been removed and replaced with more economically profitable plant species. On many of the Marshall Islands, for example, areas formerly occupied by beach and strand vegetation now are planted largely with coconut palms and breadfruit trees.

Implications for Management.—Strand and beach vegetation contribute to retardation of coastal erosion as well as protection of inland areas from salt-spray and storm damage. Development activities could strive to maintain some extent of this vegetation zone for its protective function, particularly on more vulnerable atolls and low coral islands. Enrichment of existing stands with more desirable or profitable species may offer an opportunity to preserve some protective functions as well as provide a food or income source.

Mangrove Forests

Mangrove forests are characterized by salt-resistant trees, some with stilt roots or pneumatophores, growing in the intertidal range along ocean shores or estuaries. Nutrients from terrestrial runoff and the leaves falling from the trees provide food and shelter for marine life living among the roots. A significant amount of mangrove forest area remains in the U. S.-affiliated Caribbean islands; nearly 25 square miles of mangrove forest is scattered around Puerto Rico's coastline. While scattered mangrove trees occur along the coast of the U.S. Virgin Islands, mangrove forests only survive

Photo credit: C. Wahle

Mangrove forests, found to some extent on most of the U.S.-affiliated islands, provide important habitat and nursery areas for many marine and terrestrial species. The extent of these forests has been significantly reduced through human development activities.

at Salt River, St. Croix and Jersey Bay, St. Thomas; the larger mangrove areas have been cleared for development (9).

In the U.S.-affiliated Pacific islands, Pohnpei and Palau have the largest extent of mangrove forests (13,652 and 11,513 acres respectively), followed by Kosrae (3,859 acres), Truk (3,315 acres), and Yap (2,894 acres) (9,56). American Samoa has limited mangrove forest areas (130 acres) (56), one of which (Pala Lagoon) is under stress from nearby development. In the Northern Mariana Islands there are only small mangrove areas and they may be threatened by dredging and development.

Mangrove forests are important in the maintenance of the nearshore coastal water quality. They are important for many marine species that are dependent on the protected habitat for food and shelter (8). They also trap and stabilize sediment from runoff, thus building land and protecting the coral reefs and lagoons from pollution. Mangroves may regenerate after short-term physical disturbances such as storms, however longer term disturbances such as changes in runoff can destroy a forest. Reestablishment of mangroves has been practiced in Florida and Puerto Rico indicating that, if conditions are appropriate, the forest can regenerate in a period of 10 to 15 years. An oil-damaged mangrove stand in Guam has been successfully rehabilitated through a replanting program. The program involved removing the damaged trees and replanting seedlings that were harvested from an undisturbed area of the forest. However, regeneration of clear-felled areas in Southeast Asia has not been successful (9).

Implications for Management.—Mangrove formations are important for a variety of functions including, filtration of freshwater, wildlife habitat, nutrient provision for nearshore marine life, erosion control, and limited timber production. Development activities which would remove mangroves should be redirected to other areas, and timber harvesting should be limited to sustainable yields.

Seagrass Meadows

Seagrass meadows commonly are found in association with coral reefs and provide shelter and nursery areas for many marine species. Lagoon bottoms and other shallow coastal waters support seagrass and algal beds. The sand and mud bottoms create habitat for many burrowing and benthic organisms (9).

Algal and seagrass meadows are highly productive ecosystems that serve as "pastures" for many commercially important marine species (9) and appear to foster an increased variety of reef fishes (20). They also act to stabilize bottom sediments and thus help prevent coastal erosion. To some extent they may absorb organic wastes, however heavy sedimentation can cut off light and smother the bottom (9).

Implications for Management.—Seagrass meadows contribute to the retardation of coastal erosion, provide habitat and feeding grounds, and may absorb some organic wastes. Destruction of seagrass meadows generally is a repercussive impact from other actions. For example, increased sedimentation from development activities may smother bottom communities and boat anchors may remove large patches of seagrass. Recovery is slow from such disturbances. Seagrass meadows could be protected through appropriate actions incorporated in development activities, such as efforts to reduce erosion, or establishment of permanent moorings in frequently used areas.

Coral Reefs

Although tropical waters commonly have low nutrient levels, coral reef areas are sites of high biological productivity. Coral reef areas, associated with most of the U.S.-affiliated tropical islands, are among the most productive of tropical marine areas (55) and represent a highly valuable resource.

The reef areas provide shelter and habitat as well as a nursery for many marine organisms. Hundreds of edible varieties of fish including jacks and some species of snapper, commonly are members of the reef community, as are many mollusks and crustaceans (17,41,52). Harvesting of nearshore marine resources takes place primarily in the vicinity of coral reefs and seagrass beds (20) and thus much of the nearshore fishery potential corresponds to the interrelation of the coral reef, seagrass meadow, and mangrove forest ecosystems.

The nearshore waters of many of the U. S.-affiliated Pacific islands support important subsistence fisheries. A recent survey indicated that at least 40 percent of American Samoa's households exploit the nearshore fisheries for a part of their food (46). This level is estimated to be as high as 90 percent in the Caroline and Marshall islands (17).

The physical structure of the coral reef provides a natural breakwater which retards shoreline erosion (20) and provides for the replenishment of beach sand; as wave action scours the reef structure, particles break off and are carried to shore. Coral reefs also represent a major tourist attraction and valuable recreational resource for activities such as diving and snorkeling.

Destructive fishing practices (e.g., dynamiting, bleaching), coastal development activities that increase freshwater discharge or turbidity of nearshore waters, or expulsion of thermal or chemical effluent all may cause reef destruction. Pest outbreaks such as the crown-of-thorns starfish *(Acanthaster plancii)* similarly damage coral reefs. While the values of coral reefs are well understood, enforcement of protective regulations still poses a problem in some areas.

Implications for Management.—The diverse benefits provided by coral reefs, including enhancement of fishery potential, marine species habitat, protection from shoreline erosion, beach sand replenishment, and recreational value, clearly demonstrate the importance of this nearshore marine structure. Activities which are known to have adverse impacts on coral reefs should be discontinued through an effective regulation and enforcement program. Coral reef management should consider sustainable multiple use of the resource: allowing recreation (snorkeling, fishing), fishery, and tourist use of reef areas while affording necessary protection.

EFFORTS TO SUSTAIN RESOURCES ON U.S.-AFFILIATED ISLANDS

The favorable climate of the U.S.-affiliated islands of the Pacific and Caribbean contributes to conditions capable of sustaining relatively high rates of aquatic and agricultural productivity. Although some island areas experience an annually occurring dry period, the warm temperatures and generally substantial rainfall common to the islands allow a continuous growing season. Puerto Rico has features that allow cultivation of subtropical crops. The climate and esthetic characteristics of tropical islands also make them prime tourist attractions, and in some cases tourism and related enterprises comprise a large part of the island economy.

Tropical island ecosystems offer a wide variety of products and services to island inhabitants. The importance of these ecosystems to the quality of life has long been understood by the islanders and traditional practices were inextricably linked to the workings of nature. As modernization increased and less conservative practices were adopted, some of the unique island environment was transformed or damaged, Nevertheless, some undisturbed areas remain today.

Efforts to maintain and enhance existing resources have resulted as concerns have increased over adverse trends in resource use, degradation, and associated productivity loss. In some cases, these concerns have prompted the development of resource sustaining management plans which provide for the creation of parks and protected areas, regulation of resource use, consideration of development's impacts on the environment, and investigation of alternatives to heavily exploited resources (see app. E).

Efforts To Maintain the Resource Base

Traditional subsistence economies embodied conservation of critical renewable resources. As economies shift from subsistence to cash and populations increase, the impacts of rapid growth on renewable resources becomes evident. Attention is now being given to mechanisms to protect and maintain critical renewable biological resources. Resource areas and wild populations which suffered past degradation have been examined in order to develop methods to maintain their viability. In some areas, resources, although perhaps modified by human activities, remain in good condition.

Regulatory or conservation actions instituted at both the local and Federal level have acted to preserve areas of critical importance. The Caribbean National Forest, federally established in Puerto Rico's Luquillo Mountains in 1903, originally consisted of 18,000 acres and, was the first tropical National Forest (10). Subsequently, additional tracts of land were protected under the Commonwealth forest system. Today there are 14 protected forests on Puerto Rico comprising nearly 100,000 acres of protected forestland.

The United Nations Man and the Biosphere Program (UNESCO-MAB), established in 1971, works to promote international scientific cooperation and the study of human interaction with the environment. Biosphere reserves are part of a worldwide network of protected land and coastal environments and enfold many functions including conservation, research and monitoring activities, education and training, and cooperative efforts with various scientific organizations. The design of the biosphere reserve attempts to integrate conservation with surrounding socioeconomic needs. There are three designated biosphere reserves within the U.S.-affiliated Caribbean islands: Luquillo Forest (28,112 acres) part of the Caribbean National Forest on Puerto Rico; Virgin Islands National Park (15,188 acres) on St. Johns Island in the U.S. Virgin Islands; and Guanica Commonwealth Forest Reserve on Puerto Rico (9,930 acres). The only designated biosphere reserve in the U.S. Pacific islands is located on Hawaii (43,53).

Local and National Wildlife Refuges have been established on many of the U.S.-affiliated islands. In some cases entire islands are designated as refuges, such as Howland, Baker, Jarvis, and Rose atolls in the Pacific. Habitat loss has been implicated as a major cause for loss of wildlife species (51), thus, through the establishment of wildlife refuges native fauna and flora may be afforded protection.

Similarly, the harvesting of corals and other sessile marine animals is restricted in the waters of u. S.-affiliated islands in the Caribbean by various Federal and Commonwealth statutes. Conchs and four species of sea turtles (hawksbill, green, leatherback, and loggerhead) are protected from harvesting because of their endangered species status (55).

The Coastal Management Plans created by many of the U.S.-affiliated islands contain provisions for establishment of Areas of Particular Concern–areas recognized to fulfill valuable functions (ecological, social, esthetic) in the island ecosystems. These areas are being protected on some islands, and uses to which they are best suited are being encouraged. For example, the Commonwealth of the Northern Mariana Islands Coastal Management Program contains plans to assure adequate water flow, nutrient levels, and oxygen levels for mangrove/wetland environments. These environments are recognized to be important in natural drainage patterns and as wildlife habitat (47).

In addition, progress has been made in the last few years in the preparation of resource inventories in some of the U.S.-affiliated islands. Some are already complete and others are underway (9). However, a need for biological inventories still exists on many of the islands. Such information can assist in creating protected park areas that in turn can help reduce resource overharvesting (55).

Efforts To Restore the Renewable Resource Base

Despite the fact that population needs exceed the supply of renewable resources on most islands, interest in conservation exists. Many basic marine conservation measures developed in the West in the past century were traditionally practiced in the Pacific islands. Examples include establishing closed seasons and restricting the kinds of fishing gear allowed (15,25),

Federal and local efforts to increase forest area in Puerto Rico have been quite successful. Since 1981, the Puerto Rican Forest Service, with technical assistance from the U.S. Forest Service, has taken an active role in promotion of resource conservation and forestry development (10).

Other cooperative efforts involve species recovery programs. For example, efforts focused largely on the bird population of Guam are being carried out in conjunction with the U.S. Fish and Wildlife Service (23). Similar efforts to recover the Puerto Rican parrot have been ongoing since 1968 (54).

Efforts To Redirect Use Of Underused Resources

Although many renewable resources have suffered degradation from overexploitation, some seem to be underused: exploited at rates below their maximum sustainable yield. Some local governments are working to identify these resources and redirect resource use. For example, current fisheries development policy in Puerto Rico emphasizes underused resources, such as swordfish, which may help divert fishing effort from overexploited nearshore stocks (20).

Many nonfood resources of the U.S.-affiliated Pacific islands, such as pearl oysters, have been underexploited since World War II because little effort has been made to develop their potential. The success of the Japanese pearl culture prior to World War II suggests that such an operation is viable, given proper planning and management. Although the status of the species introduced by the Japanese is not known, several species of pearl oysters occur naturally in Palau, Yap, Truk, and Pohnpei, and black-lipped pearl oysters have been found in high densities near some atolls in Pohnpei State.

Further opportunities exist to develop underused land, plant, and animal resources. For example, a survey of Guam's agricultural land resources indicated that no more than 2 percent of the land is actively cultivated (23); this percentage may change seasonally and in relation to market and climate conditions (33). In Puerto Rico, abandonment of coffee plantations and farmlands, particularly on steep slopes, released 1.1 million acres which are now potentially available for forestry and agroforestry activities and recreation (44).

Efforts To Culture Species

Another avenue to reduce stress on natural populations and environments is to develop culture systems for those species currently harvested on a fishing, hunting, or gathering basis. The success of culture systems may depend on more than just the biological factors of the desired species. Considerations include the availability of primary research, development of appropriate techniques, technical assistance, and sociocultural and economic factors.

The level of interest in aquiculture of numerous species that already are a part of islanders' diets is high in all of the islands. Most island groups have done preliminary work to determine the feasibility of culturing a number of marine and freshwater species of fish and shellfish (31). Developing culture techniques for such organisms can transform them from roles of only subsistence importance to those of economic importance. Of course, if markets expand faster than culture activities, increased pressure may be put on natural populations due to their increased value. Despite the growing interest in and knowledge about aquiculture of warmwater species, numerous projects have been unsuccessful.

A number of products currently are gathered from indigenous and naturalized plants. Development of culture systems for some of these plants might allow increased yields such that they could develop economic as well as nutritional significance. For example, a wild variety of cinnamon *(Cinnammnum carolinensis)* grows on Pohnpei and is used as medicine and a tea-like beverage. Similarly, perfume oils can be extracted from certain plants now growing wild on Pacific islands (e. g., ambretta oil from *Hibiscus abelmoschus;* ylang-ylang oil from *Cananga odorata).* Ylang-ylang petals currently are used for traditional ornamental headwear (mwarmwars). Research and small-scale production at the Ponape Agriculture and Trade School indicates that ylang-ylang can be cultured profitably and processed to supply fragrance oils for locally produced coconut soap and for export.

Finally, native and naturalized plants have, over time, adapted to a range of environmental conditions (2). They represent a reservoir of genetic resources that could be used in plant selection programs, and might allow expansion of agriculture to infertile, saline, and degraded lands. Biological inventories that characterize plant species composition (e.g., nutritional, medicinal values) and land race characteristics are needed in many areas to promote this effort *(27).*

Enhancement of Existing Renewable Resources

Programs to enhance existing resources have developed concurrently with interest in alternatives to heavily exploited resources. For example, in 1984, one-third of Puerto Rico was covered by forest, mostly in second-growth forests, fruit tree plantations, and shade trees for coffee. These forests supply little useful timber, although they provide excellent watershed protection, wildlife habitat, and recreational and esthetic opportunities. Enrichment of forests through underplanting of valuable species offers one method of increasing forest value. Many larger Pacific islands could sustain timber production to help meet local needs through similar efforts (44).

In most island areas, efforts have been made and continuing studies are underway aimed at enhancing the productivity of reef flats through the introduction of artificial habitats. Studies indicate that artificial reef habitat enhancement can increase local fish abundance and potential harvests (3). Similarly, artificial upwellings, which draw nutrient rich water to the surface, may enhance fishery potential. Enhancement programs, as well as research to determine impacts of reorganization of ecological structure, will be necessary in order to allow the sustainable production of some species (e.g., trochus) while maintaining the balance of the associated natural systems (39).

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Chapter 4

Island Renewable Resource History and Trends

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Boxes

Chapter 4

Island Renewable Resource History and Trends

HISTORY OF THE ISLANDERS

Introduction

Although histories of the peoples and settlement of the U.S.-affiliated island areas are diverse, certain common factors exist: 1) at one time all but American Samoa were colonized or administered by foreign nations, and 2) at one time they have been of some strategic importance to the United States. Nearly all of the indigenous island populations suffered population depletion as a result of colonization. Direct causes ranged from the introduction of disease to the active removal or relocation of inhabitants (e.g., decimation of the Caribbean Arawak population, Chamorro wars in the Marianas).

The majority of the U.S.-affiliated islands were subject to one or more colonial powers.[1] American Samoa is the only island group which remained independent until the United States gained authority over the eastern Samoa Islands in 1899. Guam and Puerto Rico essentially experienced only one colonial authority—Spain. Both island areas were ceded to the United States at the close of the Spanish-American War in 1898. Spain's authority lasted close to 400 years in Puerto Rico and some 300 years in Guam. Although several colonial interests developed in the U.S. Virgin Islands, the Danes had the most extensive interests and authority lasting nearly 245 years. The United States purchased the Danish West Indies in 1917 after nearly 50 years of intermittent "negotiations."

Traditional island cultures depended on a variety of island resources for their sustenance and they developed many resource management and conservation techniques (18). Traditional resource management required supernatural sanctions, a harsh discipline, inequality of people, resource apportionment, and curtailment of individual freedom (25). An ethic of minimal exploitation of necessary resources allowed for recovery of those renewable resources exploited in the traditional system. Original inhabitants of the islands were essentially self-sufficient; living off the surrounding terrestrial and marine resources or acquiring necessary resources through intra- and interisland exchange systems (1,25,46,88).

Although the social organization of individual island groups was unique, some display common characteristics. Social structure on most islands was a well-defined hierarchy that clearly outlined individual rights and duties. Most of these social hierarchies included a head or paramount chief, lesser chiefs, clans, lineages, and upper and lower classes (46,61). Although, many variations in social organization existed, they all contained some mechanism for critical resource control through social hierarchy (46).

Generally, native island resource-use techniques were not adopted by the colonial powers; although some colonial agriculturalists did adopt indigenous cropping regimes (97), the primary impetus for colonization was to secure high-value goods and minerals to supply the homeland economy. As such, the colonial attitude was not one of conservation, but rather exploitation. New production methods and values were introduced as well as new crops and livestock. Islands which were heavily exploited suffered land degradation and resource depletion.

Subsistence agriculture and fishing continued to be an important part of the indigenous society of the Pacific islands during the colonial period although, in some areas, cash crops en-

[1] Colonial authority in this report refers to the various powers who claimed the islands prior to their entering various political associations with the United States.

croached on lands available for subsistence agriculture (e.g., sugarcane and copra plantations). Traditional production methods slowly became more restricted to those rural and outlying areas in least contact with the trade centers. Islanders became more accustomed to a lifestyle involving imported goods, the status of traditional subsistence methods decreased and, correspondingly, dependence on outside sources increased.

The colonial authorities in the U.S.-affiliated Caribbean islands focused on commercial agricultural production for export purposes. Nevertheless, a subsistence sector developed and persisted in Puerto Rico (97). Although the Danish West Indies were inhabited by Amerindian agriculturalists at the time of Columbus, by the time these islands were colonized in the 17th century the Indian population had disappeared.

U.S.-Affiliated Western Pacific Islands

Introduction

Ancestors of Pacific island peoples originated in Southeast Asia. Western Micronesia—the Marianas, Yap, and Palau–was first settled by migrants from the southeast. Ancestors of the peoples of eastern Micronesia and Polynesia moved through northern Melanesia and up through Vanuatu (5). These settlers brought with them nearly all the food crops that became their staples (1) and may have introduced animal species as well (46).

Social Organization

The fundamental difference between the ecologies and resource bases of the high islands and coral atoll islands was reflected in traditional cultural systems. High islands generally have larger land mass, better soils, and more abundant freshwater resources than do atoll islands (46). Despite the number of exigencies of atoll life, population densities were generally greater than on high islands.

The stratified social organization which developed in the Pacific islands was designed to provide for the subsistence needs of the members, settle disputes, and manage essential resources. For most of Micronesia, the systems of social organization and land tenure were based on matrilineal descent. Individuals were members of lineages and several lineages could comprise a clan; these units were further ranked within the society. Authority generally flowed from paramount chief, to lesser chiefs, to commoners. Inmost areas, certain lineages or clans were in charge, with the lineage chief being paramount and the junior ranking males serving as lesser chiefs (46). Better quality land went to higher ranking members of society in some instances; however, individuals had access to necessary raw materials (46).

One variation of this structure existed in the Carolinian atoll islands between Yap and Truk. In the Carolinian group little stratification existed and each atoll or section of a larger island was a politically autonomous community. Lineages were ranked according to their arrival and settlement on the island with the lineage of greatest antiquity being most senior and its head being the community's chief (46).

The matriclans in Yapese society functioned as in the other Micronesia islands; however, there was no lower order of landholding matrilineages. Rather each village was comprised of a number of patrilineages each with its own head and these were the landholding units of the society. Village lands were ranked as higher low-caste land and then further subdivided. High caste villages often occupied the best land and additionally "owned" the land of the low caste villages (46).

An exchange system, sawei, once linked the high island of Yap to all the atoll islands from Ulithi in the west to Namonuito in the east. This system provided a mechanism for peoples of small, vulnerable atoll islands to move freely between islands, in turn establishing a network allowing members to request aid from other is-

Photo credit: Office of Technology Assessment

Traditional Micronesian villages still exist, such as this one on a Trukese atoll island.

lands in times of need (e.g., typhoons or food shortages) (1,2).

Traditional Subsistence Economies

Traditional subsistence economies have been characterized as "nature-intensive" (25), which implies the optimum use of naturally functioning ecosystem processes to provide for the subsistence needs of the population. Islanders developed production techniques that took advantage of the natural workings of the island (e.g., stream diversion for irrigation) and the limited land resources. Atoll dwellers, with little arable land, focused on improving and increasing marine harvest methods. Trade between atoll dwellers and high islanders was common (e.g., the Yapese sawei system). Evidence exists that a form of aquiculture was practiced on several of the western pacific islands (Pohnpei, Kosrae) (115) and remains of old fish ponds still exist on Yap.

Most agriculture involved food-bearing trees and root crops, many of which were imported with the first influx of settlers. Coconut palms were of major importance, as well as breadfruit, papaya, bananas, and pandanus. Root crops included wet- and dry-land tare, yams, sweet potatoes, and arrowroot. Agricultural terraces similar to those found in Southeast Asia existed in the Marianas and Palau (5). Several tree species were used for construction of dwellings and canoes; pandanus leaves were used for canoe sails, and thatch for houses. Coconut fronds, especially Nipa palm, also were used for thatch.

Marine resources were important, especially for the atoll dwellers where terrestrial resources were extremely limited. Coral reefs associated

Photo *credit: Office of Technology Assessment*

These Kosraean craftsmen combine traditional skills with modern tools to carve a canoe from a breadfruit tree.

with islands and lagoons of atolls supported a variety of reef fish, turtles, and shellfish. Pelagic species often were critically important to meet the subsistence needs of the society. Canoes were used for trolling in the open ocean as well as still fishing in protected lagoons. Nets, traps, weirs, and spears also were used. The tools and fishhooks were fashioned from locally available materials such as wood, shell, stone, and coral. The behavior, movement patterns, and mating habits of marine species were known in detail by the islanders. Islanders knew much about the lifecycle of many organisms and their patterns of seasonal abundance (42). Mollusks and crustaceans were gathered within the intertidal area.

Throughout the region, fishing knowledge was property of great personal value and thus not lightly shared with others in the community (42). Harvest methods, distribution patterns, and customs differed, but these patterns resulted in an apparently effective resource management system. Rights to harvest certain species or to fish in certain grounds were often held exclusively by particular families or other specific groups within the community (93). Recent research in Palau has revealed that the traditional body of knowledge of marine species and behavior was quite sophisticated and comprehensive, rivaling that of today's marine biologist (42).

These traditional economies comprise three distinct sectors: a production sector, controlled and organized to serve individual family needs; an exchange sector, governed by kinship and traditional political organization to serve community needs; and an investment sector, through which the resources were managed (89).

The production sector centered almost entirely around the family unit with individual members performing specific tasks in providing for family needs. Each family had privileges to the land and sea apportioned to the clan (89).

The exchange sector was important in the daily working of the subsistence economy and served to ensure the flow of goods from the more productive to less productive members. This sector became particularly important when normal family production was insufficient (e.g., sick, injured member), or when there was a wider community need (e.g., natural disasters). At these times, the paramount chief could designate other members of the clan, or of other clans to assist in production, or summon labor for community benefit (89).

The investment sector characterizes the traditional economy's sustainable management of the resource base. It couples minimal exploitation of resources with fallow periods allowing recovery of renewable resources. These naturally regenerating resource areas were essentially an investment in biological capital to ensure future productivity. This relative underproduction provided the flexibility necessary to absorb sudden population immigrations and natural disasters (89).

Westerm Contact

Western contact in the Pacific began in 1521 with Ferdinand Magellan's arrival on Guam. The first Spanish colony established on Guam in 1565 served as a provisions stop for Spanish galleons sailing between Florida and the Philippines (67). Spain's primary interest in the Mariana islands was "saving souls" and little effort was spent in exploiting the islands' renewable resources.

Spain renewed its colonization efforts in the Mariana Islands nearly a century after the initial colony was established on Guam. With the arrival of Jesuit missionaries in 1668, Spain claimed the rest of the Mariana Islands. Missions were established on Rota, Tinian, and Saipan; and "Christianization" of the indigenous population began in earnest. The Jesuits instituted formal education, primarily of a vocational nature, with an emphasis on religion (67).

Western contact initially reduced the different indigenous Micronesia populations through introduction of disease (89) and conflicts that ensued over religious beliefs increased the toll. While Spain laid claim to most of Micronesia, they did not attempt to extend actual rule outside of the Marianas until other nations attempted to gain a foothold in the region (46).

Photo credit: Office of Technology Assessment

The copra industry still forms the basis of economies on many U.S.-affiliated Pacific islands.

American and English whaling vessels began to frequent the Micronesia islands in the 1830s and experienced a short-lived prosperity lasting for nearly two decades. Islanders became involved in world trade as they exchanged local commodities (e.g., sea cucumber, shells) for imported goods (e.g., iron, glass). During this period, American missionaries began arriving on some of the westernmost Micronesia islands (Kusaie–now Kosrae) to offer the Protestant religion to the indigenes. Throughout the Spanish period, various nations, including Germany, Japan, and the United States were present in the islands as traders and whalers.

The mid-19th century brought the beginning of the copra (dried coconut) industry. Successful copra operations were established by German traders in the Marshall Islands. The presence of the copra traders expanded the exposure of islanders to world markets and imported goods and encouraged islanders to develop coconut palm plantations. Several German companies were established in Micronesia by the 1860s and within 10 years copra was the primary export of Micronesia (76). Land remained in indigenous hands and Micronesians entered what was later to be called the era of the "coconut civilization" (69).

Development of the copra trade led to increasing German encroachment on previous Spanish territorial claims, ultimately resulting in a power struggle between Germany and Spain. Germany declared a protectorate over the Marshall Islands in 1885; took control of Yap; and claimed Truk, Kosrae, and Pohnpei. A papal decision, made in 1885, settled the conflict. Spain's authority over the Caroline islands was reaffirmed. Germany retained authority over the Marshall Islands and received trade and fishing privileges within the Spanish islands and the right to establish fueling stops (67).

The Spanish-American War brought an end to Spanish authority in Micronesia. Guam was ceded to the United States in 1898, and Germany purchased the remainder of Spanish Micronesia, Japanese companies continued to be active in Micronesia commerce during the German period until 1901 when they were barred from the region for selling firearms (69).

The German administration of Micronesia brought increased commercial activity, primarily in the area of copra trade. However, phosphate mining on Angaur (Palau) was also a successful operation. The Germans instituted a system of "indirect rule" with the islands being administered by the Germans through the hereditary chiefs. This period furthered the breakdown of land tenure practices in favor of individual ownership. The German administration prohibited alien purchase of Micronesia land. Any person or company interested in establishing a new business was required to negotiate a lease with the German Government, which in turn negotiated with the native owner. Mandatory education also was instituted, and although of a broader scope than Spanish schooling, the emphasis remained on religion (69).

Germany's rule ended in 1914 with the beginning of World War I and Japan seized control of Micronesia. Japan established a military administration which lasted from 1914 to 1920 when the League of Nations sanctioned Japanese authority by Mandate. Early in the military administration many of the old German policies were continued (e.g., tax system, mining operations) (89). A civilian government was established in 1922 and economic development based on resource exploitation began (89). Copra trade was further expanded, with islanders continuing to be the major producers, and commercial fishing increased in importance (46). A sugar industry was developed in the Marianas. Japanese nationals were brought in to cultivate and harvest sugar and soon outnumbered islanders. By 1940, 80 percent of the total labor force on the islands was Japanese or Okinawan (89).

The Japanese Mandate Period has been characterized as the most economically successful period in the history of the Micronesia islands. Fishing, sugarcane, copra, and pearl culture are a few of the many areas the Japanese developed (89,91). However, despite the increased economic success of the period, the benefits of the period went largely to the Japanese. Production skills remained concentrated in the hands of Japanese nationals. Traditional authority was greatly weakened and the Micronesians became accustomed to an authority imposed from outside. The Japanese era in Micronesia ended with World War II (46).

United States Administration

U.S. administrative involvement with the western Pacific islands began at the close of the Spanish-American War when the island of Guam was ceded to the United States. In 1947, the United States, in accordance with an agreement with the United Nations Security Council, assumed administration of most of Micronesia as a United Nations Strategic Trusteeship. The trusteeship allowed the United States plenary control over the islands including the right to establish military bases and foreclose access. The United States was to protect the welfare of the inhabitants and eventually prepare the islands for self-government or independence (89).

The U.S. Navy assumed initial administrative responsibility for the islands at the end of World War II. Administrative policy was a slow-paced approach to development that extended through the first 15 years of U.S. administration, largely as a reaction to the Japanese Mandate Period (89). All Japanese were repatriated by the end of 1946, thus removing the bulk of prewar era production expertise. promotion of the welfare of the Micronesia people was the objective of the naval administration.[2] Large development projects were excluded from the islands on the grounds that they did not promote the welfare of the Micronesia people.

The United States Commercial Company (USCC) was created within a few months of the inauguration of U.S. Naval administration in order to supervise the economic development of the Trust Territory of the Pacific Islands (TTPI) . USCC bought produce for export from islanders and offered a selection of import items. In an effort to develop the economic potential of Micronesia, the USCC conducted an economic survey of the territory (89). Rebuilding the copra industry, fishing, and agriculture activities, which were destroyed in the war, were the major USCC goals.

The USCC was replaced in late 1947 by the Island Trading Company (ITC), a corporation that was capitalized by the Navy and run by the Deputy High Commissioner. The purpose of ITC was to promote development by furnish-

[2] Ia a directive issued in December 1945 by Admiral Spruance, military governor of the islands, the American position was stated as follows: "indiscriminate exploitation of the meager resources of the area is to be avoided . . , The establishment, for the profit of aliens, of enterprises which tend to maintain the island economy at the level of cheap labor and which do not permit the islanders to enjoy the full benefits of their own labor shall not be tolerated" (40).

ing technical assistance and services to locally owned businesses. It provided loans and subsidies to island businessmen to stimulate growth of industry, and provided warehousing and importing services. Under ITC, retail stores proliferated in Micronesia. ITC purchased and marketed copra, handicrafts, and other exports much as USCC had done. However, efforts to encourage production of new crops did not fare well and numerous enterprises failed. ITC was liquidated in 1954 and by that time several local import companies were strong enough to survive on their own. The other functions ITC performed were dispersed to other organizations (89).

Civilian administration of the TTPI began in 1951 when the U.S. Department of the Interior assumed the responsibility. Self-sufficiency for the TTPI remained the goal under the Department of the Interior. The objective was to duplicate the successes of the Japanese era without the associated exploitation and alienation of land and labor. U.S. authorities encouraged government investment in lieu of private capital investment, and government subsidies were carefully controlled so as not to undermine the goal of self-reliance. The annual subsidy at this time remained at a level of $5 to $6 million each year and the value of exports remained between $2 to $3 million each year. The system of taxation developed during naval administration, though largely an insignificant source of revenue, was retained. Municipalities were encouraged to develop tax systems and use the revenue to sustain municipal needs (e.g., teacher salaries, school repairs) (89).

The direction of U.S. administration changed in 1963 to a program of intensive development in Micronesia. U.S. appropriations for the Trust Territory increased from $13 million in 1964 to over $60 million in 1971 and continued to rise until the close of the 1970s. Funding during this period was directed largely toward administration, schools, and health services. Between 40 and 45 percent of the TTPI government's annual budget was allocated for health and education (89).

With increased assistance, the Trust Territory government began to assume many responsibilities formerly handled by municipalities. The emergence of a bureaucracy was apparent. The government work force tripled during the 1960s and private sector service industries expanded accordingly. Concurrently, imported goods became available in unprecedented quantities and by 1970 import value had reached $20 million. Exports, however, remained at the earlier levels (about $3 million) with only minor fluctuations (89).

Capital improvement projects, with the goal of developing the solid infrastructure necessary for self-sufficiency, became a considerable budget item beginning in 1970. Construction of public buildings, roads, airports, and dock facilities, were some of the projects. The impact of these projects, however, was realized more in the nature of salaries than in an actual increase in productivity. Federal program grants also became available during this time, and much of this funding was directed toward improving social services. Total U.S. assistance peaked in 1979 at $138 million (89).

Exports increased notably during the 1970s, and by the end of the decade export values had reached $16 million annually. The increase was due largely to increasing tourism and industries producing tuna and coconut (copra and oil). Some of these gains were short-lived and, when considered with the rate of inflation, were near the 1948 1evels of export income (89).

The Compact of Free Association, which was approved for the Federated States of Micronesia and the Republic of the Marshall Islands by the U.S. Congress and the United Nations Trusteeship Council in 1986, offers an opportunity for the islands as well as the United States to foster increased Micronesia self-reliance. The Compact is designed to give Micronesians control over their internal and external affairs, and funds to develop a means of increasing self-support within a 15-year period; the United States retains defense and security responsibilities. Local government emphasis is now on economic development (25).

The United States' financial support for economic development in Micronesia initially will increase under the Compact of Free Association, Then, assistance will decline through the stipulated 15-year period, with decreases occurring every 5 years after the beginning of the compact. The Republic of Palau elected to maintain an even spread of funding throughout the 15-year period.[3] Funding available for capital improvements will initially increase while funding for social welfare programs and government bureaucracy will decrease. This represents a major aim of the compact: to provide a base for future local productive industries and prepare Micronesia for increased economic self-reliance. Almost 40 percent of U.S. assistance is earmarked for infrastructure and development projects (89).

Micronesia's cash economy today is roughly 90 percent dependent on U.S. aid, thus, aid reductions stipulated in the compact will have a pronounced impact on the area. Previous policy trends of rapidly expanding aid largely for social programs and support of the public sector will change under the Compact of Free Association. The change in U.S. policy perhaps will foster development of an independent private sector economy; with increasing importance placed on services, light industry, and development and sustainable exploitation of local renewable resources (89).

American Samoa

American Samoa is the southernmost U. S.-affiliated polity. It lies within the region known as Polynesia and the inhabitants are culturally and racially related to Hawaiians, Tongans, and Maori (New Zealand). Archeological evidence suggests initial settlement of the Samoa islands occurred before 1,000 B. C., probably from eastern Melanesia (53).

American Samoa is comprised of a group of seven islands, the largest of which is Tutuila with a land area of 54 square miles and on which the capital city of Pago Pago is located. Ninety percent of the territory's population reside on Tutuila (106).

[3]The compact with Palau has not yet been approved.

Social Organization

The social organization of American Samoa was more flexible than that found in Micronesia. The largest social unit was the **aiga,** and it included all those people who could trace descent from the founder of the group. Descent could be traced through males or females, and any given individual belonged to a number of aiga. The aiga held land in a particular village and each village had one or more **matai** (titled chiefs). The **matai** were selected by consensus by the **aiga** membership. The **matai** of a village formed its governing council or **fono.** Individuals could live and work the land of his or her **aiga,** and since an individual belonged to many **aigas** a choice had to made as to where he/she would actualize his/her potential rights. Thus, an individual selected to reside on land of one **aiga** to which he/she belonged and localized extended families formed within the **aiga** (46). Villages were self-sufficient entities and generally composed of one or more **aigas** (106).

The topography of American Samoa encouraged development of coastal settlements. Steep mountains, the relatively narrow band of flat lands adjacent to the shoreline, and accessibility of fresh stream water predicated the choice of coastal area (106). Samoan subsistence agriculture was similar in many ways to that of the

Photo credit: A. Vargo

Cultivation methods for steep hillsides were developed early in American Samoa's history; many of these techniques are still used today.

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U.S.-affiliated western Pacific islands; tare, breadfruit, yams, coconut, banana, pineapple, and papaya were cultivated (53).

The Samoans also relied heavily on marine resources, and were excellent fishermen and navigators. The large sail-rigged double canoes in use by the Polynesians could hold nearly 100 people (69). Most fish and shellfish were collected in streams, lagoons, and along reefs. Reef fish were typically part of the traditional Sunday Samoan Feast called fiafia (106). However, offshore species such as bonito and tuna were also collected. Implements used for farming and fishing were fashioned from wood, stone, and shell (69).

Western Contact

American Samoa's contact with the West began with the Dutch arrival in 1722, nearly two centuries after Magellan arrived on Guam. By the 19th century the United States, Great Britain, and Germany had established commercial enterprises within the island group. Conflicts arose between the foreign interests and in 1899 the islands were divided with the United States assuming authority over the eastern Samoa islands (Tutuila, Aunu'u, Tau, Ofu, and Olosega).[4] Germany assumed jurisdiction over the islands of Western Samoa which later became independent. The Cession of Tutuila and Aunu'u, signed in 1900, allowed for the traditional Samoan land-tenure system to remain in effect with allowances for government accession of land as necessary (106). Initial authority over the islands was held by the Department of the Navy. The Department of the Interior assumed oversight in 1951 and continues today in that capacity. The American Samoa Government operates under a constitution adopted in 1960.

The firmly established traditional lifestyle and social structure of American Samoa persevered throughout contact with western nations and continues today. This lifestyle, known as Fa'a Samoa ("The Samoan Way"), places considerable value on group dignity and achievements. The extended family, aiga, remains the keystone of traditional communal lifestyle. Land tenure is based on the communal lands of the aiga and the selected chief, matai, manages the communal economy, and protects and distributes the lands (53,106). Nearly all land in American Samoa is held by indigenous Samoans. Ninety-two percent of the land is held by aigas, 7 percent by the American Samoan Government and churches, and a fraction of the remaining 1 percent is in a freehold status (106).

American Samoa has experienced problems similar to those of Micronesia in the shift from subsistence to cash economies, including a drop in local agricultural production. Although nearly 80 percent of American Samoan households practice some form of gardening, Samoans purchase 75 percent of their food requirements (46,53). This shift has been accompanied by increased economic dependence on the United States' for imported goods and services (53). The largest employer is the American Samoa Government, followed by the tuna canneries; a range of retail and service enterprises comprise the third major portion of the economy (46).

U.S.-Affiliated Caribbean Islands

Precontact cultures of the U.S.-affiliated Caribbean islands share some commonalities with those of the Pacific. The indigenous populations were subsistence economies dependent on the available land and sea resources.

The origin of the early inhabitants of Puerto Rico and U.S. Virgin Islands still is uncertain. They have been described as seminomadic peoples; primarily hunters and fishermen, establishing their settlements near the island's coastline and mangrove forests, Archeological excavation of settlement sites show no evidence of agricultural practices (61).

[4]Swains Atoll, 225 miles north of Tutuila, was annexed by the United States in 1925.

'In 1980, the American Samoa Government budget was nearly $73 million, of which $32 million came from Federal sources (30).

[illegible]

1493 Puerto Rico and the USVI are encountered by Columbus
1508 Puerto Rico claimed for Spain by Juan Ponce De Leon
1511 First Spanish colony established in Puerto Rico
1630s First settlements on St. Croix—English, Dutch, French
1650 French control established in St. Croix
1672 Successful Danish settlement of St. Thomas
1695 French colony in St. Croix [illegible]
1717 St. John colonized
1724 St. Thomas declared a free port
1733 Danes purchase St. Croix from France
1754 Bankruptcy of the Danish West India Company—Danish Crown purchases rights over the colonies
1803 Danish Government abolishes slave trade in the Danish West Indies (DWI)
1815 Real Cedula de Gracias—Spain promotes development of Puerto Rico
1840 St. Croix "Bird Law"; [illegible]
1848 Slave emancipation in the DWI
1865 First efforts to sell DWI to the United States
1898 Puerto Rico ceded to the United States at the close of the Spanish-American War
1900 Organic Act of Puerto Rico [illegible] government, authorization for Resident Commissioner in Congress
1903 University of Puerto Rico established (originally normal school); Caribbean National Forest established [illegible] Resource survey performed for the DWI
1906 First fishery law passed in DWI—established size and closed season restrictions on certain species
1915 First degrees awarded from the University of Puerto Rico
1917 United States purchases the Danish West Indies; Temporary Government Act of 1917; Puerto Ricans granted U.S. citizenship
1927 Citizenship granted to U.S. Virgin Islanders
1930s Civilian Conservation Corps active in Puerto Rico and the USVI in such projects as reforestation and [illegible]
1931 [illegible]
1936 USVI Organic Act of 1936 created civilian government, transferred authority from the U.S. Navy to U.S. Department of the Interior
1938 [illegible]
1941 [illegible] clauses of Foraker Act
1947 [illegible] Puerto Rico; "Operation Bootstrap"—[illegible]
1950 [illegible] lands; Puerto Rico [illegible]
1952 Puerto Rico [illegible] Commonwealth of Puerto Rico; Virgin Islands [illegible]
1954 [illegible]
1956 [illegible]
1968 [illegible] Governor, provided [illegible]
1972 [illegible]
1981 [illegible] Constitution for the U.S. Virgin Islands

Subsequent migrants were of Arawak culture[6] with origins in the Orinoco Basin in South America. Archeological sites date their arrival on Puerto Rico in the vicinity of 120 A.D. The early Arawak settlers also were hunters and fishermen. Coastal areas were the original settlement sites, however later settlements were established in the interior of the island. A more complex social organization had developed among the Arawak by the time Puerto Rico was settled by the Spaniards (61).

Arawak culture is characterized as peaceful and sedentary; energies were directed towards hunting, agriculture, and fishing. The primary agricultural tool was a primitive hoe, and crops such as cassava and arrowroot were cultivated (61,88). Swidden, or slash and burn, clearing, was employed and root crops commonly were interplanted in mounds of soil (knee high by several feet wide). This method-conuco cultivation—provided soil aeration and maximized the range of arable land (88).

Evidence exists that fishing played a significant part in the lives of Indians who inhabited Caribbean islands prior to European settlement, although it is not possible to assess the relative importance of fishing compared to other resource use activities (34). Fish, shellfish, turtles, marine mammals, and waterfowl were harvested from nearshore environments and offshore waters (88). Precontact Indians of Puerto Rico harvested forest products for a variety of uses including construction, canoes, fuel, foods, dyes, and medicines (119).

The social organization of the Indian culture included a chieftain (caique) who exercised authority over a higher class (nitainos) and a lower class of workers (naborias). There were regional chieftains as well as a paramount chieftain (61,88).

Puerto Rico and the U.S. Virgin Islands were encountered by Christopher Columbus in 1493. Juan Ponce de Leon claimed Puerto Rico for Spain in 1509; the first colony was soon established in Puerto Rico. The island of St. Croix, in what was to become the Danish West Indies, was first colonized in the 1630s by several European nations.

Puerto Rico was inhabited by Arawak Indians at the time of colonization, and the population largely was decimated in the colonization process. The Virgin Islands, although populated by indigenes at the time of Columbus' arrival, were not inhabited at the time of colonization; the population having been eliminated largely through Spanish efforts during the 16th century (27).

Puerto Rico

Puerto Rico's forests were modified by the island's earliest inhabitants; however, population pressure was low enough to allow recovery of the exploited areas. Thus, essentially all of Puerto Rico was forested at the time of Spanish arrival (75,88,119).

Spain's interest in Puerto Rico was enhanced by the discovery of the island's gold resources. Gold was mined efficiently and deposits were essentially depleted by 1540 (61,75). Despite considerable outmigration at the end of the gold mining period, the colony was maintained (75, 97). The colonists that remained turned to an agricultural livelihood.

Forest clearing increased with the arrival of the Europeans, largely through efforts to access agricultural lands, although forest products also were harvested for construction and fuel (119). Highly valued Puerto Rican timber species became one of the early exports. Timber exports continued to rise and in 1815 the timber industry accounted for a large part of total exports.

Coastal areas provided the bulk of harvested timber, and mangrove species were popular for boat construction. The majority of forest products exported in the 19th century originated in coastal forests. Most wood harvested, up to the early 20th century, was used for fuel or construction; nevertheless, construction wood was being imported as early as the 1700s.

[6] The term *Arawak* shall be used in this discussion to refer to the Indian population of the U.S. Caribbean area present after the early inhabitants. This culture has been further divided by many historians to differentiate various tribes of Arawak culture including Taino, Carib, and Borrinqueno.

The small colonial population of Puerto Rico pursued an indigenous path of development until the late 1700s. A self-reliant, diversified agricultural economy evolved, geared toward production for domestic consumption rather than overseas markets. This economy was comprised of a large subsistence sector located primarily in the highlands, and an underdeveloped commercial sector concentrated on the coastal plains (92).

The subsistence sector was dominated by independent, small cultivators, who employed slash and burn agriculture to produce a variety of crops (plantains, rice, maize, beans, cassava, root crops) for home consumption and occasional exchange. Few of these peasants (jibaros) actually owned their land, many were squatters (desacomodados) on Crown land, or sharecroppers (agredados) on hacienda land (92).

The commercial sector consisted of large cattle ranches, plantations, and farms (haciendas), which produced an assortment of exportable cash crops, including sugarcane, ginger, tobacco, cacao, coffee, and cotton. Additionally tropical fruits, medicinal plants, and woods of high commercial value (satinwood, lignum vitae) were exported (61). While sugarcane, ginger, tobacco, and coffee each dominated the export sector at various times between 1550 and 1800, cattle raising proved to be the most stable agricultural enterprise throughout this period (61,97).

Sugarcane and sugar production became the island's major economic activity in the mid-16th century. The emerging sugar industry received royal assistance in the form of loans for mill construction, sugar transport to Spain, and the purchase of slave labor. Labor shortages, transportation problems, and default on loan payments all contributed to the gradual decline of the sugar industry (61).

Difficulties encountered by the sugar industry led to increasing cultivation of ginger or livestock raising—primarily cattle. Despite royal edicts forbidding ginger cultivation and urging return to a sugar economy, ginger became Puerto Rico's main crop. Eventually increased ginger production resulted in market price decrease and production efforts turned to tobacco and cacao (61). Livestock production remained an important part of the colonial economy; it provided for local consumption and hides were produced for export.

The Puerto Rican economy experienced little change until the end of the 18th century. Population remained small; external trade was limited to a few commodities. The constricted character of the export sector was reflected in the relatively small slave population, which was just over 5,000 in 1765 (97). Heavy taxes coupled with trade restrictions contributed to the island's limited economy.

Spanish colonial officials attempted to accelerate economic development after 1750. Reforms in existing tax laws and production restrictions emerged in 1813. Through a royal decree in 1815 (the Real Cedula de Gracias) the island's agriculture, industry, and commerce were promoted and immigration was encouraged. Uncultivated lands were distributed and some larger estates were divided resulting in an increase in the percentage of smallholders. Trade with friendly nations was liberalized. The sugar industry experienced a resurgence with increased worldwide demand for sugar (61).

These government efforts produced modest results prior to 1825; population increased substantially as did export crops. However, as late as 1828 less than 4 percent of the land was under cultivation, and the subsistence sector still dominated the agricultural economy, accounting for 71 percent of all cropland. At least 80 percent of the proprietors engaged in subsistence farming, as did nearly all of the agredados (92).

Expansion and transformation of the agricultural economy took place during the last seven decades of Spanish rule. Between 1828 and 1896 the amount of land under cultivation more than tripled, while pastureland doubled. Acreage devoted to export crops increased dramatically, overtaking acreage devoted to subsistence production (92).

Progression to a commercial economy based primarily on sugarcane production resulted in creation of larger landholdings, displacing some smallholders who moved into the highlands, and brought new forest areas under cultivation (97). Price fluctuations in the world sugar market during the 19th century caused redirection of agriculture exports to coffee. Although generally cultivated on small landholdings, coffee eventually replaced sugar as the major export crop.

Puerto Rico was ceded to the United States at the end of the Spanish-American War in 1898. The U.S. Congress established a civilian government in 1900 and Puerto Ricans were granted U.S. citizenship in 1917.

In the 1930s, a program was instituted by the Government of Puerto Rico to provide landless farmers and farmers living within public forestlands small parcels of land on which they could cultivate subsistence crops, firewood, and forest products in exchange for planting and caring for the public forestlands (78). Once the forest areas were successfully planted, the squatters were relocated (118).

Establishment of a forest research station was authorized by Congress in 1927 and the Tropical Forest Experiment Station was created in 1939 on the University of Puerto Rico at Rio Piedras. The station was established to provide technical knowledge for forestry programs which largely had been unsuccessful during the previous lo-year period. Reforestation attempts had produced many failures.[7] Agricultural colonization had reduced forest cover to only 9 percent of its original extent by 1950—4 percent government forests and 5 percent privately owned forests (99).

[7]The Tropical Forest Experiment Station was renamed the Institute of Tropical Forestry in 1961. The Institute's main research objective was timber management. Research has been conducted on: utilization of forest products, secondary forests, wildlife management, growth studies, and identification and description of promising tree species, Through Institute efforts, a technical base for forestland planning in Puerto Rico has been established. Various methods for postharvest treatment of timber products have been developed. The station was of regional significance, developing an information distribution network of more than 1,000 participants within 24 years of its inception. The Institute has accumulated a tropical forest library. Short courses, graduate-level teaching, and research planning assignments have been conducted by the Institute in several Caribbean, and South and Central American countries.

The 1900 Organic Act contained a resolution which limited corporate land ownership in Puerto Rico to 500 acres; however, this provision was not effectively enforced until 1941 (17,71). The Puerto Rico Land Authority was created in 1941 by the "Land Law" (Act No. 26 of 1941) to reorganize the island's land tenure. The law's purpose was to acquire and redistribute lands held in excess of 500 acres. Squatters were relocated on small plots where they could build homes and cultivate a small garden. Family size farms (15 to 20 acres) were established and large "proportional benefit" farms expropriated from large landholdings were to be managed by the Land Authority with workers sharing in the profits (17,116).

The program for relocating squatters was successful and most plots have been subdivided among descendants of the original owners. The "proportional benefit" farms, however, were inefficiently run and accumulated heavy losses. Most of these lands are now leased to private farmers for sugarcane and rice production (116). In 1978, the Land Authority owned a total of 94,943 acres of land which were devoted to various agricultural endeavors and real estate (111).

During World War II, Puerto Rico became important militarily, with naval bases established there (Roosevelt Roads) and on the nearby island of Culebra. The influx of military personnel substantially increased the local demand for fish, spawning the first commercial fishery development in Puerto Rico. The program was initiated by the U.S. Department of Agriculture. Authority for the program was transferred at the conclusion of World War II to the Puerto Rican Agricultural Development Corporation which emphasized offshore fisheries and conducted experimental operations. The program was terminated in 1947 (34).

A major shift in economic development strategy began in 1947, aimed at industrializing the island, diversifying agriculture, and providing full employment for the people (10). Diversification of the Puerto Rican economy was a goal of the program dubbed "Operation Bootstrap." Program goals included: 1) development of intensive and balanced use of the island's agri-

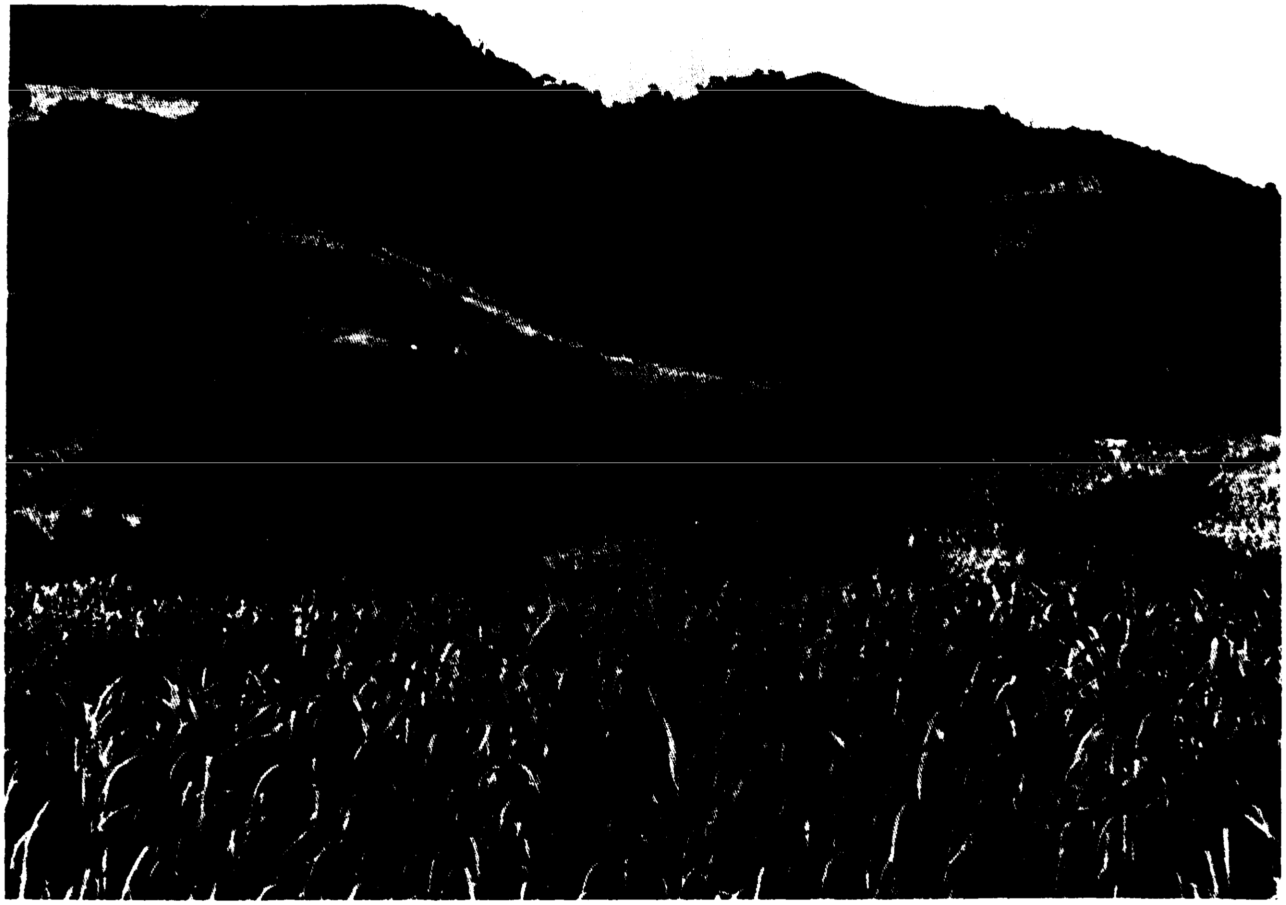


Photo credit: W.C. Lowdermilk

Puerto Rico's agricultural sector developed a substantial smallholder component following the creation of the Puerto Rican Land Authority in 1941.

cultural resources, 2) improvement of capital and credit availability for agricultural producers and industry, 3) development of efficient marketing systems, and 4) reorientation of fiscal policy to achieve these goals (10). Incentives offered to businesses included tax exemptions, technical assistance, labor training programs, and subsidized rental of government buildings (87). The construction industry prospered and government grew. This, and a large exodus of laborers to the U.S. mainland, removed capital and human resources from agriculture (116). Sugar, coffee, and tobacco contributed 64.3 percent of gross farm income in 1950, and only 14 percent in 1985 (9).

Industrial development led to more attractive employment opportunities in industry than in agriculture, lower priority for agricultural programs, and increased abandonment of farm land. The growth of the tourism industry also attracted capital and labor away from agriculture. These two factors contributed to the accelerated urbanization of major Puerto Rican cities.

The Puerto Rican electorate approved the island's newly drafted constitution in 1952 and the Commonwealth of Puerto Rico became a recognized entity. The Commonwealth is an autonomous government in voluntary associa-

Photo credit: William Balmer

The pine plantation in the background shows the timber production potential of these sloping, abandoned agricultural lands in the central highlands of Puerto Rico.

tion with the United States. Internal conflicts over political status have occurred, with factions divided over the issue of statehood, independence, or continuing as a Commonwealth.

U.S. Virgin Islands

The present-day U.S. Virgin Islands (USVI) were first colonized in the 1630s when settlements on St. Croix were established by the Dutch, English, and French. A period of colonial friction followed these early settlements, with the French finally gaining control in 1650. France retained sovereignty until 1695 when its colony was relocated to Hispaniola. The island of St. Croix remained virtually uninhabited until 1733 when France sold it to the Danish West India Company (DWIC), the exclusive Crown agent for settlement and trade in the West Indies (55).

St. Thomas was successfully colonized by the Danes in 1672. The islands represented an opportunity to produce highly valued agricultural commodities to supplement the homeland economy. Early colonial modification of the land included clearing of forests, primarily by slash and burn techniques, for plantation establishment and commercially valuable timber species (72). The early plantations produced a variety of crops, including tobacco, indigo, coffee, cotton, foodstuffs, and sugarcane. Extensive forest clearing for agriculture, as well as introduced predators (e.g., mongoose), probably contributed to extermination of some indigenous fauna (e.g., agouti) (97).

At the close of the 17th century, slave labor (of African extraction) became increasingly important as Danish interest increasingly focused on sugarcane production. The population of St. Thomas rose from about 1,000 in 1691 to nearly 4,000 by 1715 and the proportion of slaves increased from roughly 60 to 85 percent. Agricultural terraces (sugarcane and bench) were constructed on the hillsides through the use of slave labor (97). Danish interests expanded in the early part of the 18th century with the DWIC acquisition of St. John in 1717, and again in 1733 when St. Croix was purchased from France. The company focused heavily on sugarcane production and plantation numbers increased dramatically. On St. Croix, nearly all arable land was under cultivation within a decade of its purchase by the DWIC.

St. Thomas became a free port in 1724 and the DWIC's activities—both in colonial staple exports and European imports—established the island as a major trade center in the Caribbean. Slave trade in particular became a thriving business, attracting buyers from America and other Caribbean plantations (55). However, financial and political difficulties led to DWIC bankruptcy in 1754. The Danish Crown purchased the Danish West Indies and continued control of the islands.

During the 18th century, diversified agriculture gave way to sugarcane monoculture, and the sugarcane plantations progressively enlarged their control over island resources. By the end of the 18th century, these plantations comprised 67 percent of all plantations and sugarcane accounted for nearly 80 percent of all cropland. The majority of pastureland was also held by the plantations (97). Sugarcane was cultivated extensively on all three major islands of the Danish West Indies, and at one time or another nearly all of the land was in sugarcane production (72,100).

s

The sugarcane plantations flourished until the 1830s. Thereafter, falling prices, rising production costs, scarcity of investment capital and labor problems aggravated by slave emancipation in 1848 combined to debilitate the industry (97). Limitations such as contract wage labor and harsh vagrancy laws were instituted and effectively tied many newly freed slaves to the land (56,97).

The postemancipation decline of sugar export in St, Croix was exacerbated by the emergence of intercontinental steamships which could bypass St. Thomas as a fueling station (56). However, the sugar industry struggled on despite declining acreage, primarily by incorporating technological improvements such as steam mills and central factories.

Many St. Thomas and St. John plantations progressively were abandoned after emancipation, and their cleared areas were allowed to revert to brush forest. Nonetheless, on St. Thomas extensive deforestation occurred during the middle of the 19th century, as secondary forests were cleared to supply the growing fuel and construction needs of the Port of Charlotte Amalie (97).

The structure of the plantation system changed significantly after 1848. The emerging system primarily was one of small-scale, less labor-intensive, more diversified agricultural activities (97). Crops such as sea-island cotton, sisal, fruits, coconuts, and foodstuffs were cultivated and livestock (cattle and sheep) production increased. Many large landowners who chose to discontinue agricultural activity nonetheless held onto their properties for speculative purposes (20,97). Thus, while the total number of plantations (units with more than 50 acres) declined only slightly between 1796 and 1915, landuse shifted away from caneland and cropland toward increased pastureland and woodland.

During the second half of the 19th century some control over plantation-land resources was relinquished to ex-slave smallholders. The number of smallholdings (plots under 50 acres) rose from 4 in 1796 to 594 in 1915. This process went furthest on St. John, where by 1915 there was a total of 244 smallholdings covering 1,148 acres, or 9 percent of the land area (98). The St. John smallholders practiced a subsistence economy that combined subsistence farming, animal husbandry, fishing, charcoal production, and part-time labor on the plantations (70,98).

On St. Thomas most of the smallholders were French immigrants from St. Barthelemy (St. Barts), who settled on the north side of the island during the 1860s and either rented garden plots or entered into sharecropping agreements. Some managed to acquire title to their land by the beginning of the 20th century. Like their counterparts on St. John, their subsistence strategy combined farming with fishing and charcoal production (62).

St. Thomas increased its specialization as a point of international commerce and center of regional finance because of its deepwater harbor, free-port status, political neutrality, and strategic location (56). A dual economy developed during this period, with St. Thomas emerging as a trade center and extensive plantation agriculture characterizing St. Croix (56).

Prior to the decimation of St. Thomas' forests in the latter half of the 19th century, Danish colonial authorities showed little concern over deforestation and its impact on soil productivity or freshwater supplies. The only law touching on this subject required Cruzan planters to leave shade trees, or trees bordering the main roads, untouched (97). A Danish resource survey in 1903 indicated that there was no forest on St. Thomas and St. Croix and little forest of commercial value on St. John.

Although fish were an important dietary component, commercial fisheries were slow to develop in the Danish West Indies. More commonly, tropical produce was exchanged for imported saltfish—a preference that continues today. There were, however, some local fishing activities. Early 19th century accounts indicate an abundance of marine life near the Virgin Islands (97).

Archeological excavations uncovered shellfish middens on plantation sites, indicating that some harvest of clams, conch, and mangrove oysters occurred historically (97). While most fishing was undertaken to satisfy plantation consumption needs, descriptions by local visitors during the slave era indicate that slaves and free fishermen were selling some portion of their catch in fish markets near the urban centers (84).

Throughout the colonial period, fishing technology was similar to that of the indigenous islanders. Shellfish and turtles were taken along the shorelines (88). Offshore fishing was done from skiffs and dugouts, Woven fishpots constituted the primary catch technology; however, handlines, nets, seines, and harpoons were also employed (84).

Emancipation marked a decline in the number of fishermen employed by the plantations and corresponding expansion of fishing activity by those persons living outside the plantations. Fishing communities were established on St. Thomas by French emigrants from St. Barts. Fishing was a common component of subsistence strategies in the Danish West Indies.

The Danish Government exhibited some interest in colonial fishery development in the early 1900s. The first fishery law was passed in 1908; it regulated the right to fish; protected fishpots; and prohibited the taking of juvenile fish, lobsters with eggs, and female turtles in certain seasons (28).

Negotiations over the sale of the Danish West Indies to the United States began in 1865 and the islands were finally purchased in 1917. The U.S. Navy assumed initial administrative authority over the newly named Virgin Islands of the United States (USVI). U.S. citizenship was granted to most Virgin Islanders in 1927 and within 2 years universal suffrage was granted (114).

The first 40 years of U.S. administration did little to alter the prevailing patterns of land distribution or land use. Agricultural policy encouraged sugarcane cultivation for export and virtually ignored the subsistence sector. Consequently, land resources were consolidated in the hands of a few plantation owners and land speculators, with an associated decline in the amount of land distributed to smallholders (97).

Most privately owned plantations began to fail in the late 1920s. This led to the formation of the federally run Virgin Islands Co. (later becoming the Virgin Islands Corp., VICORP), which held nearly all the sugarcane land on St. Croix, and operated the only sugar factory. With its focus on sugar and rum production, VICORP did little to encourage alternative crops or the production of foodstuffs for local consumption (97).

Sugar production experienced a slight resurgence with the repeal of U.S. prohibition and concurrently the demand for cane cutters rose, resulting in large-scale immigration from nearby islands (56). Among VICORP's later projects were the development of a small forestry program (118) and the beginnings of the infrastructure necessary to support a tourist industry. Commercial difficulties finally resulted in VICORP's dissolution.

A sector of full-time fishermen existed in 1917, but little was done to promote the local fisheries. The Naval Administration requested a survey of the local fisheries in 1932 (28) which included the numbers of local fishermen, technologies employed, and harvest amount. The survey concluded that the fishery was operating at 50 percent capacity and recommended various government supports to foster development. Except for promotion of cooperatives little seems to have been done. A 1950 economic report noted that local fishermen still relied on primitive technologies and marketing, and little had been done to take advantage of marine resources (72).

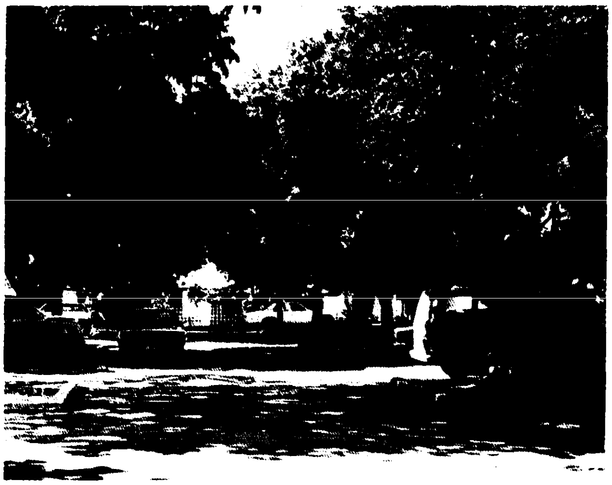
Administration of the islands was transferred to the Department of the Interior in 1931 and a civilian governor was installed. A homesteading program was put into effect. Although many could not afford the initial downpayment, the program met with some success, as evidenced by an increase in small farms (56). Overall, however, activities to promote the viability of a small farmer sector received little attention (97). The self-reliant, subsistence community on St. John declined, many on St. Croix abandoned working their land, and on St. Thomas only the northside agricultural community persevered.

The First Organic Act for the Virgin Islands was passed in 1936. St. Thomas became the capital of the USVI (114). A revised Organic Act was passed in 1954 and contained numerous fiscal and economic provisions of benefit to the USVI.

The Virgin Islands Tourist Board was established in 1952, evidence of the beginning of tourism-focused development. Between 1950 and 1970, the USVI experienced a massive economic boom based on tourism in St. Thomas and St. John, and heavy industry in St. Croix, The islands became the fastest growing tourist haven in the Caribbean and the site of the largest oil refinery in the Western Hemisphere (Hess Oil in St. Croix) and of Martin Marietta aluminum processing. During this period 42,000 acres were absorbed by increasing tourist, residential, and industrial development (56),

This period coincided with the phase-out of commercial sugar production, intense resource competition from the tourism sector, construction and government employment, and export manufacturing. To accommodate rising population densities and immigration from surrounding West Indian islands, the territory experienced a widespread pattern of suburbanization (55).

Tourism has been actively promoted since the 1960s and is currently the most significant economic activity. As a result, the current economy is primarily based on tourism and related enterprises (110). Presently tourism accounts for approximately 40 percent of the gross ter-



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ritorial product and employment while local government absorbs another one-third of territorial activity (56). Historically, the majority of desirable land has not been available for small scale subsistence agriculture. Initially, the majority of highest quality land was in large plantations while currently, with the emergence of the tourism industry, increased real estate prices have made much of the land inaccessible (97).

REPRESENTATIVE RESOURCE PROBLEMS OF THE U.S.-AFFILIATED TROPICAL ISLANDS

introduction

The renewable resources of U.S.-affiliated islands in the Pacific and the Caribbean supply their inhabitants with many important goods and services as they did in the past. Yet, human activities have jeopardized the renewability of some of these island resources. Despite their differing histories and cultures, these islands share some common resource problems, including that of resource overexploitation. Another major problem is related to impacts of human activities when a particular resource is developed or exploited. Such problems and their underlying causes commonly are more apparent on small islands than they are on large continental areas.

Certain naturally occurring hazards, although not unique to islands, often represent a significant problem. The relatively small size of islands often makes them less able to absorb the impact of a natural disaster than a large continental area. Agricultural or fishery capacity may be reduced temporarily, resulting in increased dependence on imports. Cyclonic storms, associated flooding, and landslides occur on many of the islands. In American Samoa, for example, flooding is ranked as a major problem. The majority of development has occurred in the narrow flatlands which lie between the steep volcanic mountains and the shore. The watersheds typically are comprised of steep valleys flanked by sharp ridges with underlying permeable rocks. Although the watershed is heavily vegetated, landslides still occur, posing a clear hazard for villages located in the coastal valleys.

Episodic catastrophes have been related to tidal phenomena. Rainstorms coinciding with spring low tides killed up to 92 percent of reef invertebrates at Enewetak Atoll, Marshall Islands (47). Other natural stresses are less common in the Pacific. Active volcanoes are limited to the Northern Mariana Islands, where eruptions may severely disrupt intertidal and shallow-water habitats **(24).** Many of the U.S.-affiliated islands are in or near seismically active areas and occasionally experience earthquakes (106,107,108,109,110,111). Shoreline erosion is another naturally occurring problem. Well-developed coral reef, seagrass meadows, and littoral vegetation systems provide some protection; however, where these systems have been removed or degraded, natural protection is limited or nonexistent.

Terrestrial Resource Damage and Depletion

Damage to the terrestrial resource base largely has been a function of human activity. Resource depletion is apparent in many of the islands' early colonial histories and continues today, further reducing the islands' productive capacity. Loss of forest area on many islands has adversely affected groundwater resources, wildlife habitat, soil fertility, and has exacerbated soil erosion. Habitat loss, introduced competitors and predators, introduced disease, and overexploitation all have contributed to depletion of many island wildlife populations.

Island freshwater resources are inherently limited and on many islands these resources are threatened by such factors as infiltration of agricultural chemicals and industrial wastes into the aquifer. Further, distribution of existing freshwater resources to inhabitants poses a problem in some island areas. Hazardous waste from military activities remains a problem on some Pacific islands. Islands in both the Pacific and Caribbean still are used as impact areas for military weapons,

Flora and Fauna Resources

Past, poor landuse practices have degraded forest resources in the U.S. Pacific and Caribbean tropical territories and have resulted in significant amounts of degraded and abandoned land and relatively unproductive secondary forest. Island fauna similarly have been threatened by such landuse practices. Related resources (e. g., water supplies and coastal marine resources) in many places are threatened by forest loss. Reliable information on the original extent of forests of the Western Pacific islands does not exist but forests probably covered most of the islands. The Caribbean islands were forest covered at the time of European contact.

Forests.—On many islands, deforestation has resulted in turbid, erratic, and seasonally disappearing streams (99). For example, older inhabitants of northern Babelthaup (Palau) remember when the streams ran year long. Now, the forest cover has been destroyed through repeated burning and the streams flow only when it rains, at which time they often are muddy and flow very fast (99).

At one time Guam was entirely forest-covered, but human disturbances, frequent typhoons, and the adverse impacts during and after World War II have left little undisturbed forest on the southern part of the island. Only scattered patches remain in largely inaccessible areas in ravines and on steep slopes. Savannas on the southern part of the island are believed to be mostly the result of repeated burning. Some of the open land is barren and actively eroding.

Accelerated clearing and burning of forests on old volcanic soils in recent centuries have created a secondary forest in some areas and much secondary savanna. Erosion and soil deterioration have been accelerated in some areas by frequent burning, making natural forest regeneration a slow process (99).

Fire is the biggest technical problem to overcome in rehabilitating grasslands. Fires sweep through grasses to the edge of the forest, destroying forest along the margin. The Guam Division of Forestry estimates as much as 80 percent of the fires on Guam are caused by arson (38).

Most abandoned agricultural land revegetates naturally to savanna or to secondary forest. Little of the secondary forest is suitable for immediate commercial timber exploitation due to poor quality and low volume of commercial tree species (99). Nearly two-thirds of American Samoa's rainforest has been damaged or destroyed by man's activities, leaving undisturbed forests only on steep slopes (106). Man has influenced the vegetation of the Marianas for at least 3,500 years. Observations in Puerto Rico indicate that the forest area is increasing slightly or has stabilized (99).

Vegetation removal during construction activities and the exposure of loosened soil to

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heavy rainfall also leads to soil erosion. For example, the largest part of the erosion problem in the Virgin Islands is attributable to the clearing of large tracts of land, construction of homes and roads on steep slopes, and the filling or destruction of natural water courses (117). After heavy rains on St. Croix, it is common to see a red-brown plume of sediment discoloring the sea at the mouths of streams situated below construction sites (110). Similar sediment discharge may be observed in Puerto Rico (63). A critical problem in American Samoa is the erosion of soils. The sediment is carried to the nearshore waters where it adversely affects water quality as well as marine populations such as corals (106).

Protected Species.—Several species of island flora and fauna are on the verge of extinction or have not been seen in years and thus are presumed to be extinct. This problem is critical on Guam where recovery programs concentrating on birds are carried out in conjunction with the U.S. Fish and Wildlife Service (USFWS) (39). Guam's avian population has declined rapidly since World War II. The Guam Division of Aquatic and Wildlife Resources has identified several causes for this decline including, loss of habitat, pesticides, avian disease, and predation. Predation, particularly by the brown tree snake, appears to be a primary factor. Research on the brown tree snake indicates a correlation between expansion of the snakes' range and decline of avian populations (38). The Philadelphia Zoo, National Zoo, and zoos in Denver, New York, and San Antonio have begun a "bird lift" and breeding programs to save several endangered avian species (39). Cur-

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rently, seven species of Guamanian birds are listed under the Federal Endangered Species Act, An avifauna survey was recently completed by USFWS on Pohnpei and other high islands of Micronesia (26,31).

USFWS, the U.S. Forest Service (USFS), and Yap Institute of Natural Science (YINS) have conducted two censuses of the Mariana fruit bat *(Pteropus mariannus mariannus)* population on Yap. Yap banned the hunting and exportation of fruit bats in the early 1980s because of the decrease of the bat population due to its export to Guam. Fruit bat populations on Guam were severely reduced during the 1960s; among the causes were: increased exploitation, loss of habitat, economic importance of the species, and lack of adequate protection (38). The Mariana fruit bat and the Little Mariana fruit bat (Pteropus *tokudae*[8]) currently are protected under the Federal Endangered Species Act. The Yapese ban on hunting and exportation of fruit bats still is in effect and the fruit bat population is recovering (39).

A high incidence of seabird mortality at Midway is due to air strikes with planes and collisions with radio antennae. The seabird population at Wake Island was severely decimated during the Japanese occupation. During this period the Wake rail became extinct. A potentially rare plant species, *Lepidium wahiense,* from Wake has been proposed for listing by USFWS as an endangered species. The monk seal has been adversely affected by human pres-

[8]The Little Mariana fruit bat *(Pteropus tokudae),* endemic to Guam, is believed to have become extinct recently [122].

ence and populations have declined at Midway and other islands of the Leeward chain (53).

Introduced Species.—Certain introduced species have had unexpected negative impacts on island renewable resources. Harmful insects and plant diseases have been introduced in the Pacific islands over the last 10 to 15 years as travel to and from the islands has become easier. Two of the most harmful introductions have been the Rhinoceros beetle and the Giant African snail which now populate many islands. The Giant African snail inhibits nursery production for horticulture and forestry. The Rhinoceros beetle causes extensive damage to coconut palms in several island groups (99), but does not exist in the Marshall Islands (76), Yap, Truk, Pohnpei, Kosrae, or on atolls (26).

A recent introduction that threatens some young Leucaena forests on Saipan, Guam, Palau, and Yap is the insect Psyllid (39). This insect seems to be controlled on Yap by the native bird, the bridled white eye (26). On some atolls, rats significantly damage young coconuts; control efforts have included trapping, poisoning, and bringing in additional cats to the affected islands (76).

Tilapia is an exotic species of fish that was introduced into the wild in Puerto Rico. The introduced *Oreochromis mossambica* is now considered a pest because it is viewed by the consumer as inferior quality human food and as such has created consumer resistance to the consumption of the cultured species *Tilapia nilotica* (34).

Some introduced animals have become public health problems in the U.S.-affiliated Pacific islands. Foremost among these pests are snails and toads which, in extreme cases, have been linked to some human deaths. Rats, birds, and fish are known to carry human and animal parasites (23].

The Giant African snail *(A. fulica)* hosts organisms which cause human diseases. For example, the rat lungworm *(Angiostrongylus cantonensis),* which parasitizes the African snail, has been recognized as the cause of cerebral angiostrongylosis in humans. The parasite is most commonly found in *A. fulica;* however, it has also been found in some rats, land crabs, coconut crabs, and freshwater prawns. Infection is acquired by ingesting raw or improperly cooked meat containing the parasite. The African snail also carries the gram-negative bacterium *Aeromonas hydrophila* (60).

Toads *(Bufo marinus)* are another introduced nuisance and have poisonous parotid glands behind the head which secrete toxins. The toad has caused numerous cat and dog deaths and human deaths have also been recorded (96). Circumstantial evidence indicates that increased salmonella outbreaks occur in areas of large toad populations. The high incidence of polluted drinking water and dysentery in American Samoa may be connected to the high densities of toads in areas of human habitation (4).

Freshwater Resources

A major health concern on islands is water quality. Islands commonly have a limited supply of freshwater and experience an increase in health problems when water sources are degraded or contaminated. Water quality may be affected by many factors, including infiltration of agricultural chemicals and industrial wastes into aquifers, and insufficient treatment and inadequate disposal of sewage. Islands with extremely porous soils generally are more likely to experience infiltration of undesirable agents, such as chemicals or sewage, into the aquifer.

As human populations have increased on many islands, the demand for increased freshwater supplies has grown. Until relatively recently, the quality of surface water and groundwater in Puerto Rico and the U.S. Virgin Islands was excellent. However, unregulated pumping of water from aquifers underlying the coastal lowlands has led to saltwater intrusion into some parts of the aquifers. The resulting saltwater or brackish water in the wells renders these parts of the aquifer unfit for human consumption, agriculture, and many industrial uses (64,73).

In the U.S. Virgin Islands, every structure must have its own rooftop water-collection system feeding into a cistern. In addition, extensive paved catchments exist on some hillsides leading to large cisterns that feed public water

Photo credit: Office of Technology Assessment

This rooftop water catchment system in Majuro (Marshalls) serves as a supplementary freshwater source. However, few such rainwater collection systems exist in the U. S.-affiliated Pacific islands, but are commonplace in the Caribbean.

mains. Rapid population growth, however, has exceeded the capacity of the public catchments and cisterns and as a consequence, desalination plants have been built to increase freshwater resources (73). In the recent past, St. Thomas Island had to import water by barge from Puerto Rico to supplement local water supplies.

Nearly all of Guam is served by a piped water system. Groundwater resources from the northern half of the island supply as much as 70 percent of the island's potable water. Since 1983 Guam has implemented a comprehensive groundwater management program designed to protect groundwater quality and direct groundwater extraction to avoid salinization. American Samoa, the Commonwealth of the Northern Mariana Islands (CNMI), the Marshall Islands, Federated States of Micronesia (FSM), and Palau are in varying stages of developing similar programs. Salinization is a particularly important problem in the CNMI which relies on groundwater supplies for 90 percent of its potable water. Catchments are used to supplement groundwater in areas where salinization or undependable water service is a problem. Many areas in the former TTPI (FSM, RMI, and Palau) do not have sufficient infrastructure for comprehensive groundwater management (49),

Puerto Rico's principal water-supply problem is the deterioration in service from irrigation districts serving 40,000 acres. Deliveries from the four districts have fallen below half of their pre-1920 design capacity of 4 inches per month to the serviced land. The decline continues because of archaic operating rules that were designed originally to service a sugarcane monoculture no longer in existance; and because of reduced irrigation demand, and continuing reservoir sedimentation. Declining surface water availability has led many farmers to rely exclusively on groundwater. Because deliveries from irrigation district reservoirs constitute the single most important source of groundwater recharge, this trend of changing irrigation water use eventually will cause an unfavorable balance and the intrusion of seawater into the freshwater aquifer (64). No action has been taken yet to manage the surface water system to ensure that adequate amounts of recharge are provided (64). The irrigation practices still in use on a majority of the farms are wasteful, inefficient and costly (73).

Increased population levels or overcrowding may also cause water quality degradation. Treatment systems, sponsored by the Environmental Protection Agency (EPA), have been or are being constructed in population centers in the U.S.-affiliated Pacific islands (49). However, in some areas sewage systems are still under construction, or facilities still need to be extended to all structures (49,53). Overcrowded conditions on Moen, and to a lesser extent on Tel, Dublon, Fefan, and Uman (Truk) have led to unsanitary wastewater disposal practices. Although a sewage treatment plant and outfall on Moen have been in operation for many years, hookups with residences are few (53). Through a series of EPA projects (Rural Sanitation Programs) remote areas are now being provided with basic wastewater and water supply facilities (49).

Coastal Resource Damage

Sand, a renewable resource of beaches, in certain cases has undergone extreme depletion through mining. Some of the calcium carbonate beach sands of St. Croix in the U.S. Virgin Is-

Photo credit: Office of Technology **Assessment**

Hillside mining for construction materials is an alternative to beach sand mining, however, the associated adverse environmental impacts to terrestrial and marine ecosystems may rival those caused by beach sand mining.

lands came under heavy mining for construction purposes in the early 1960s. The sand was mined for government and private use, leading to nearly complete stripping of some beaches. As more seaside hotels were built it became evident that maintaining beaches was more valuable than using the beach sand for construction. Subsequently, dredged sand replaced beach sand for construction (114). Mining or collecting beach sand for personal use has been a practice among Samoans for centuries. Now, however, some beaches are being depleted for commercial construction purposes. On Truk, removal of beach sand for construction fill has led to some shoreline erosion (53). Beach sand mining is a problem in most Pacific areas (49).

Hazardous Waste

Johnston Island has served as a temporary repository for chemical defoliants and chemical munitions since the early 1970s. Agent Orange was stockpiled at Johnston after the U.S. involvement in Vietnam and finally was incinerated at sea away from Johnston in 1976. During years of storage, however, some drums leaked into the ground. The extent of contamination has been analyzed and remedial actions have begun (82). Some chemical munitions deteriorated and started to leak as well. This led the Army to embark on a program to incinerate and destroy the chemical munitions in an explosive-proof facility to be constructed on Johnston (53).

U.S. nuclear testing took place on Bikini Atoll between 1946 and 1954 and weapons testing took place on Enewetak between 1948 and 1958. Blast effects and contamination from radioactive materials severely damaged or destroyed parts of these atolls. Today, plans suggest that the radioactive soil from Bikini may be removed and deposited on another atoll, in a lagoon crater, or used for landfill along the shoreline. Agriculture will not be allowed on Bikini for obvious health and safety reasons (53). Enewetak underwent a similar cleanup during 1976 to 1978. Low-level radioactivity still was present in the soil of several large islands in the atoll after the cleanup. Recent radiological tests indicate that coconuts from trees replanted in the northern islands are not fit to eat due to excessive levels of radiation (53).

American and Japanese military ordnance from the World War II era still litter some Pacific islands. Unexploded bombs and shells still are found on parts of Guam, Saipan, the Marshalls (31), Truk, and Peleliu (Palau). The presence of such explosives inhibits the use of certain lands and provides a lingering hazard to island residents. Recovery of corals in previously blasted or bombed holes that resulted from air raids on Moen (Truk) seems relatively minor (53).

Some U.S.-affiliated islands are still used as impact areas for military weapons. Parts of the island of Vieques just east of Puerto Rico serves as a bombing and gunnery range for the U.S. Navy. In order to offset the negative environmental impacts, the U.S. Navy has recently reforested 100 acres of abandoned/eroded pastureland on Vieques. The U.S. Navy and the Commonwealth of Puerto Rico (Memorandum of Understanding) cooperatively fund projects to enhance employment prospects and create long-term benefits for the inhabitants of Vieques (77). Farallon de Medinilla, a small raised limestone island north of Saipan, is used as a bombing and gunnery target by U.S. Pacific naval forces and by the U.S. Air Force tactical air squadron on Guam. Exercises on this island are said to be sporadic (48,53).

Marine Resource Damage and Depletion

Degradation of the marine resource bases of the U.S.-affiliated islands follows a pattern similar to that of the terrestrial resources. Many human activities, on-island and at sea, have adversely affected the marine resource base of many islands, Some on-island development activities have had adverse impacts on nearshore marine life. Destructive fishing practices and overharvesting of certain marine species has adversely impacted the marine resource base. Despite such damage, however, the marine resource base continues to provide essential products to island inhabitants.

Nearshore Fisheries

Because of past over-optimism as to the commercial potential of nearshore fishing resources, a rather consistent scenario of fisheries development and depletion seems to be emerging. The scenario is in various stages of realization throughout the U.S.-affiliated Pacific and Caribbean islands. Urban center populations grow with rural or outer island migrations (101,102, 103,104,105). As urbanization continues, the reef resources are over-harvested in an ever widening area emanating from the urban center (34,65).

The number of fishermen in Puerto Rico increased from 1,230 to 1,872 between 1976 and 1982 while the number of fishing vessels increased from 865 to 1,449 (8,43). This development pattern has had a striking impact on Puerto Rico's nearshore resources. Because of rising fuel costs, larger "offshore" boats have tended to fish closer to shore. In 1974, the waters of Puerto Rico were characterized as "very nearly overfished" and "heavily exploited" (43,44). The increase in total effort expended within the fishery was accompanied by a nearly 50 percent decline in catch per unit of effort; a classic indication of overfishing (8).

Increases in local population and tourist trade in the USVI has been accompanied by increased demand for fish, conch, lobsters, and other seafoods. Adult fish of the shallow coastal waters have become increasingly scarce resulting in the decreased effectiveness of fish pots as a harvest mechanism. In easily accessible sites, conchs and lobsters are heavily depleted (114). The USVI Government has deployed artificial reefs constructed of old automobile tires in an effort to increase shallow-water fish habitat and thereby enhance fishery potential (34).

Destructive Practices.—The history of coral and mollusk fisheries is one of progressive exploitation leading to chronic depletions (36,37, 51,85,86,121). Conchs and black corals are heavily overfished throughout the Caribbean, including populations among the U.S.-affiliated islands (51,112,120).

Pearl oysters have been important items of commerce for centuries in certain parts of the Pacific. The pearl shell industry had a major impact on some islands as a result of the activities of the foreign traders and fishermen drawn to exploit the stocks of the Golden Lipped and the smaller Black Lipped pearl shell (69). As stocks of pearl oysters were depleted, the top shell, *Trochus niloticus*, came to be used as a source for buttons and other similar items (66,69). Trochus recovered after World War II from its pre-war depletion. However, populations began to decline from over-exploitation again by the mid-1950s, leading to establishment of reef sanctuaries in which no harvest was permitted (53,59,91). Despite closed seasons, however, trochus populations remain low from overharvesting in Pohnpei and Truk (31).

Fishing with explosives was contrived by islanders during World War II with the readily available supply of military ordnance (7). This type of "fishing" still is widespread throughout the South Pacific. Destructive fishing methods such as dynamiting pose a severe problem in Truk lagoon (31). The availability of unexploded ordnance on many of the Japanese sunken ships near some islands and the illegal acquisition of dynamite from local construction activities are factors which may foster this activity. This technique is without question responsible for considerable destruction of reef corals and reef fish habitat (53).

Chlorine bleach and water purification powder have been and are being used by some islanders to kill reef fish and bring them to the surface where they can be collected for sale or for the fisherman's consumption. Bleach sometimes is used on Yap for such purposes (41). The bleach has such severe negative impacts on fish, corals, seagrass beds, and algae that some populations are permanently reduced (7).

The exploitation of nearshore resources by subsistence fisheries of American Samoa is heavy in places and occasionally destructive methods using dynamite and chlorine bleach are employed. As human populations continue to rise, increased fishing pressure and overfishing of preferred species, especially in reef and lagoon waters, are major emerging problems in Pohnpei, Kosrae, Truk, and Yap (31).

Tourism has certain inadvertent but direct negative impacts on marine resources. One study shows that the trampling effect of corals by humans is significant. At one site, 18 traverses by individuals reduced living coral from 41 to 8 percent (117). Certain fragile species like *Acropora* suffered the greatest damage. Shells, used extensively in handicrafts in American Samoa, the eastern Carolines, and the Marshall Islands, have become increasingly scarce. Supplies of shell and coral are being adversely affected not only by the handicraft industry but also by builders and divers (117).

Protected Species.—Natural stocks of giant clam F, Tridacnidae have been seriously depleted in their natural range. *Tridacna gigas* populations are believed to be extirpated from marine habitats of many of the U.S.-affiliated Pacific islands. Two varieties of giant clam, *Tridacna gigas* and *Tridacna derasa,* have been placed on the International Union for the Conservation of Nature and Natural Resources (IUCN) endangered species list (95).

Currently, the harvesting of corals and other sessile or sedentary animals is restricted in the U.S.-affiliated Caribbean islands by various Federal and Commonwealth statutes. Exceptions are made for small-scale collections for scientific, educational, or personal use (29,120). Despite this level of protection, the poaching of corals for the tourist and aquarium trade is ubiquitous throughout the Caribbean region, and seems unlikely to diminish. Mollusks are not protected, with the exception of conchs and species living within the Federal waters and parks (112).

The two most common marine turtles among U.S. insular areas of the Pacific—the green turtle and the hawksbill turtle—have been declared "threatened" and "endangered" respectively and are protected under provisions of the U.S. Endangered Species Act. Harvest of these turtles is prohibited in Guam, the Commonwealth of the Northern Mariana Islands, and American Samoa. Despite protected status, hawksbill turtles are killed in some islands, as evidenced by the large number of well-crafted tortoise shell combs, earrings, and bracelets on the market. Residents of some U.S.-affiliated islands are permitted to harvest marine turtles on a subsistence and traditional basis as a protein resource (91).

Four species of sea turtle occur commonly in the Caribbean: hawksbill, green, leatherback, and loggerhead. All are variously protected from harvesting or molestation by living within Federal waters or by their status as endangered or threatened species (112,113). Moreover, strict import controls apply to the mere possession of turtle products in the United States. Nevertheless, turtles have been hunted intensely in the Caribbean and continue to be poached and sold, even among U.S. islands, for food and fine jewelry (29,112). Turtles are easily caught in nets, by hand, or on the beach while laying eggs. The general availability of outboard motorboats and synthetic netting exacerbates the problem, and the economic value of turtles ensures that low-level poaching likely will continue (120).

In December 1985, a 400-ton ferryboat ran aground on Mona Island Reef off the coast of Puerto Rico, a reef that is a marine preserve and habitat for several protected turtle species and marine birds. The ship was still aground on the reef as of March 1986, breaking up, leaking oil, and crushing the coral (21).

Degradation of Nearshore Resources

Large-scale destruction of coral reef communities from sedimentation is well documented (25,30). Dredging and filling operations in the nearshore environment are significant contributors to marine resource destruction. Dredging and filling associated with the military buildup in Guam before, during, and after World War II resulted in considerable adverse impacts to reefs in Apra Harbor and other coastal resources; battle activities added to these problems. Centuries of slash-and-burn agriculture and intentionally set savanna range-fires have aggravated soil erosion and contributed sediment to riverine, estuarine, and reef systems (53).

Since 1980, excessive dredging and filling related to an airfield-port construction at Okaht on Kosrae has caused major sedimentation damage to coral reefs and seagrass beds. The fishery catch has declined in Okaht's coastal habitats. On Pohnpei, considerable mangrove, lagoon, reef, and perhaps seagrass habitat has been destroyed or degraded by recent dredge and fill operations (26). Sedimentation from upland construction also has contributed to reef degradation, Part of the reef itself has been used as a source of fill material, Some of the shoreline filling is to accommodate immigrants from outer islands because of unavailability of land. Yap has no exposed limestones or other suit-

Photo *credit: Office of Technology Assessment*

Dredge and fill operations often take heavy tolls on nearshore marine ecosystems: heavy machinery may break up the coral reef, associated sedimentation may smother bottom communities, and loss of habitat can adversely affect nearshore fishery potential.

able rock available for fill, roadwork, and other construction activities and, therefore, most material must be dredged from lagoon reefs.

Perhaps the single most significant impact to coral reefs in American Samoa resulted when the commercial airfield was extended out into Pala Lagoon, resulting in severe restriction in tidal circulation, and dredging and quarrying on once important reefs. In addition, the Government relied on filling of reef lagoons in inner Pago Pago Harbor to expand its landholdings (53).

Dredging and shoreline modification associated with tourist developments are a major threat to nearshore resources in Puerto Rico and the U.S. Virgin Islands. Coral reefs in Puerto Rico are seriously threatened by human development activities including dredging, land erosion, oil spills, industrial and thermal pollution, and direct harvest for curios (43). Alteration of the coral reef ecosystem may produce adverse changes that are essentially irreversible (34).

St. Croix Island has not escaped dredging impacts. Prior to 1968, release of dredging spoil to Christiansted Harbor damaged coral communities on nearby reefs. From 1968 at least to 1974, no new dredging permits were issued in the U.S. Virgin Islands largely because of negative public opinion about damage to the marine environment. The retail price of one cubic yard of sand in 1968 was $3.50 but the price has now reached $50.00. Thus, strong economic incentives exist to resume dredging (68).

Waste Management.—Damage of nearshore resources from dumping solid wastes, sewage releases, thermal pollution, and oil spills are common on the islands just as they are in the continental United States. Solid waste management is a serious emerging problem in Pohnpei and the FSM in general and is cited as a serious problem on Majuro in the Marshall Islands. There seems to be little planning to designate sites and landfill operations, and rubbish and solid waste is dumped indiscriminately, commonly at the shoreline environment (53). Guam has recently instituted a litter control program which sets fines for littering; the funds will be used to clean up open dumps (49).

Sewage, oil, and cannery waste pollution has long been a serious problem in Pago Pago Harbor in American Samoa. Sewage treatment plants at Utulei and elsewhere have largely eliminated degradation from domestic wastes. Oil handling and storage facilities also have been improved although the unauthorized dumping of bilge waters into the bay continues to be a problem. Presently, no pumpout facilities exist for ships and yachts calling at the bay (53).

Pala Lagoon on Tutuila has high fecal coliform concentrations presenting a public health hazard. The construction of the airport runway over the opening of the lagoon to the ocean has reduced water exchange with the ocean. This problem is exacerbated by stream runoff, which is high in nutrients and sewage tank overflows (106). A sewage collection system with associated individual dwelling service is currently under construction there to mitigate the adverse environmental impacts (49). Traditional discharge of raw sewage into nearshore waters still occurs in some areas, resulting in severe water degradation.

Similar problems exist in the Caribbean area. Solid waste on St. Croix was pushed into the sea at a site near their airport until 1974. This practice has ceased but the old dump remains a source of nearshore water pollution. A chance exists that wave action from a tropical storm could spread the debris widely. Overflow from the tailings ponds of a bauxite processing plant reached the sea in the past during periods of heavy rainfall. Waste heat and brine are carried into the sea from water used for cooling purposes.

Oil Spill Hazards.—Oil spills and oil discharges by ships adversely affect nearshore resources in many parts of the world. An oil spill damaged a section of mangrove on Guam (91); another in 1971 affected Sandy Point on St. Croix. In addition, oil and tar from tankers floats in from the open ocean to the beaches of Puerto Rico and U.S. Virgin Islands (22,81), Globs of tar floating on the sea in the Caribbean and off Florida mistakenly have been taken for food by hawksbill turtles. Dead and dying tar-laden turtles are reported on the region's beaches (22). Oil spills also are problematic throughout the Pacific. Enforcement of existing laws (e.g., Clean Water Act) is difficult because of the need to observe the incident or prove guilt through relatively complex procedures (49).

THE ISLAND SOCIOECONOMIC CONTEXT

Introduction

Sustainable renewable resource management depends not only on the capability of ecological resources, but also on the availability of skilled labor and desire to engage in resource management and development activities. Human resources are critical to renewable resource management, Indispensable human components include: laborers with special skills; farmers, foresters, fishermen, and aquaculturists with entrepreneurial abilities and a knowledge of modern-technology; technicians who combine scientific training with practical experience; and strong resource management leadership with a sense of mission and background not only in natural sciences but also in cultural and economic areas.

All of the U.S.-affiliated islands have rapidly growing populations and many have high rates of out-migration to the U.S. mainland and immigration of mainlanders and foreign nationals. This has led to heterogeneous island populations with a multiplicity of ethnic groups and cultures. These groups may have different aspirations, different demands for products, different attitudes towards and values for resources, and different techniques for resource use.

The level of development of the U.S.-affiliated islands is considerably behind that of the United States, with Puerto Rico being the most developed of the islands. While gross domestic product (GDP) and per capita incomes are low compared to U.S. levels, they are generally high compared to regional levels.

The public sectors are large in comparison to private sectors on most islands, reflecting a common preference for the security, prestige, and fringe benefits of local government employment. Most private sector development has occurred in service industries; however, industrialization has grown in Puerto Rico and tourism and related enterprises have grown in the U.S. Virgin Islands. On most islands, agriculture and fisheries have nonetheless declined. Many island residents are multi-occupational: they engage in several occupations, part-time or seasonally. Similarly, island institutions tend to be multidisciplinary and general in approach (81].

The common recommendations of economic development plans have aimed at establishing more self-reliant economies primarily by expanding agriculture, fisheries, and tourism (and to a lesser extent light industry), although the order of preference may vary among island areas. The prospects for industrial development in the U.S.-affiliated Pacific islands are almost nonexistent because of small size of domestic economies, high wage levels, the lack of natural resources, and proximity to major Asian competitors. The limited nature of economic development opportunities is illustrated in Palau where, as recently as the late 1950s, the most valuable export was scrap metal, mainly relics of World War II (14).

Import substitution has become increasingly important in light of rising transport costs and desire to encourage private sector development. A number of plans also have called for a reduction in government employment and expenditure to allow the productive components of the economies to catch up with consumption and to reduce the trade gap (11).

Pacific

The U.S.-affiliated Pacific islands are characterized by high population growth rates, increasing emigration to the U.S. mainland and to other Pacific islands, and growing numbers of alien immigrants. The latter group have, to a certain extent, been encouraged to enter islands such as American Samoa and Guam to fill jobs for which local residents lack the necessary skills or which they are unwilling to accept. A combination of these factors has led to the development of bimodal societies, or trimodal societies—in which a significant subsistence sector still exists. The private commercial sector on most of these islands is small or nonexistent.

The private sectors that have developed have been oriented primarily to services supporting the public sector and public sector employees; the productive components of the economies—agriculture, fisheries, and manufacturing—have declined, or failed to develop. For example, government employment and service industries (general merchandising, transportation, food services, and construction) account for at least 90 percent of formal employment in the Federated States of Micronesia while the labor force employed in direct production accounts for only 1.3 percent (11).

In the absence of a significant productive component to their economies, the U.S.-affiliated Pacific islands have become highly dependent on U.S. expenditure to contribute to local economies. For example, Palau's GDP was estimated to be $20 million in 1979, of which $9 million was contributed by the United States in public sector support payments (14). Only 9 percent of the Trust Territory funds for 1980 were derived from tax revenues while U.S. grant and Federal program funds contributed 87 percent (11).

Unemployment is high—estimates range from 16 (Palau) to 22 percent (Majuro)—but accurate data on unemployment levels or trends are unavailable, especially for rural areas.

The skills required to develop the productive sectors of the economies are being lost at a rapid rate, and few young islanders are seeking education or employment in agriculture or fisheries. Rapid population growth in some places has accelerated the move away from local food production. The increased population pressure on limited resources may eventually preclude self-sufficiency and necessitate emigration or family planning (11). This situation has already been reached by most of the U.S.-affiliated islands.

Wages also are sharply bimodal. Wages in the public sector tend to be considerably higher than those available through the private sector. For example, the minimum wage in Palau in 1982 was $1.94 per hour. In the private sector, for which there is no legal minimum wage, some wages were as low as 40 cents per hour (14). This incentive to obtain government employment results in further withdrawal from local production. An associated effect is demand for educational opportunities which may not transfer into employment opportunities, resulting in increased unemployment (11).

Caribbean

Nearly 3.4 million people reside in Puerto Rico (3,417 square miles) and 107,500 reside in the U.S. Virgin Islands [132 square miles), representing some of the world's highest population densities. As a result of improved health care, family planning programs, and general economic affluence, birth rates in Puerto Rico and the U.S. Virgin Islands have declined in the past three decades while death rates have dropped or remained stable (73).

The cultural heritage of the U.S.-affiliated Caribbean islands is largely influenced by prior colonial presence as well as cultural influences from other European, African, and Caribbean nations. This mixing results in a largely heterogeneous society with varying cultural ties (79). Further, the close relationship with the mainland United States strongly affects these island cultures.

The United States is the primary commercial partner of the Caribbean islands. The United States' purchase of major U.S. Virgin Islands exports (i.e., tourism, petroleum, rum, and light industrials) and supply of consumptive goods comprises a large part of island trade[9] (57). The

[9] During the period of 1970 to 1979, U.S. Virgin Islands' exports to the United States averaged 89 percent of total exports, U.S. citizens reached above 85 percent of total tourists and U.S. goods comprised 72 percent of U.S. Virgin Islands imports (56).

United States' investment in the Puerto Rican economy totaled some $15 billion in 1982 (90). North American capital controlled the highest percentage of assets in manufacturing, retail sales, exported industrial production, marine and air transport, labor force, housing construction, and banking and finance[10] [90), Thus, the economies of Puerto Rico and the U.S. Virgin Islands are closely tied with the United States and react to U.S. economic changes. Similarly, associated employment sectors react to economic trends within the United States.

Traditional Cultures and Economic Development

Pacific

Many U.S.-affiliated Pacific islands are shifting from a traditional subsistence economy towards a modern cash economy; in Pohnpei, 70 percent of wages are earned by only 2,120 government employees (no more than 10 percent of the population). Obviously, many people make a living outside the cash economy. In a properly functioning subsistence economy, production equals demand and the agent of both is the family. Family needs in such an economy can be met with about 3 or 4 labor hours per day (89). Cash is neither plentiful nor needed, and consumer goods on the island are limited (although the number, price, and quality of products have increased in recent years).

On Pacific high islands, most family needs for food and shelter can be obtained from the land and surrounding ocean, and available resources seem to be underused. Most farmers produce just enough products to sell to meet their immediate cash needs. Farmers have little incentive to increase cash crop production, such as Pohnpei pepper, even though both land and labor may be available. Pepper has gone unharvested when farmers have not needed or wanted to convert the crop into cash.

In most traditional Pacific cultures, the concept of "borrowing" displaces that of "saving." Those who have are supposed to share with those who have less, particularly within family and clan. One who accumulates savings may have to deal with frequent requests from family and friends and contribute to the lifestyle of less industrious individuals with little likelihood of repayment in cash. This removes personal incentive to earn more than one immediately needs and may be a major deterrent to development (32).

As traditional economies have shifted toward cash economies, the lack of a dependable labor force (in terms of cash economies) has inhibited economic development. Tropical climate characteristics generally prevent agriculture workers from putting in an 8 hour day; more commonly, 4 or 5 hours constitute a day's work.

Acquisition of temporary jobs for an immediate monetary goal is common. This complicates training and supervision, and results in lower than expected productivity. Per capita income is high compared to regional levels, resulting in reluctance on the part of the working-age population to accept low-paying employment and further influencing the use of alien labor.

Caribbean

The structure of U.S.-affiliated Caribbean island economies has changed significantly in the past three decades, from primarily agricultural economies to highly industrialized (Puerto Rico) and tourism [U. S, Virgin Islands) based economies. This change in focus has influenced people to seek employment in fields other than agriculture and fisheries.

The structure of the agricultural industry and profile of the present day farmer have changed[11]

[10] Percent assets controlled: manufacturing—81 percent, retail sales—85 percent, labor force—81 percent, housing construction—65 percent, banking and finance—60 percent, exported industrial production—90 percent, most means of mass communication, and virtually all marine and air transport (90).

[11] Agriculture is still dominated by part-time workers. Total amount of farmland in Puerto Rico increased by 4 percent between 1978 and 1982, but was still only half of 1950 levels. There has also been an increase in the number of farms, largely in the less than 10 acre bracket; 53 percent of farmland is owned by operators. The average age of individuals whose primary activity was agriculture was 56.1 years, secondary was 53,7 years. Puerto Rican agriculture is dominated by small farm units run by an aging population, A small but growing group of educated Puerto Ricans farm as a secondary occupation (116). Similar circumstances exist in the U.S. Virgin Islands, with 45.5 percent of farmers spending 200 days in off-farm employment (57). There has been an increase in the number of small farms, and increase in the education level of farmers.

(73) concurrently with the change in overall economic structure. Puerto Rico has excellent physical resources, well-trained young people, required technology, and entrepreneurial ability to create a modern agriculture (116). Skilled and unskilled labor are available. There are the necessary professionals in Puerto Rico with approximately 1,500 college-trained specialists in various fields (of which 800 are employed by the government); 200 with masters degrees and 80 with doctorates (116).

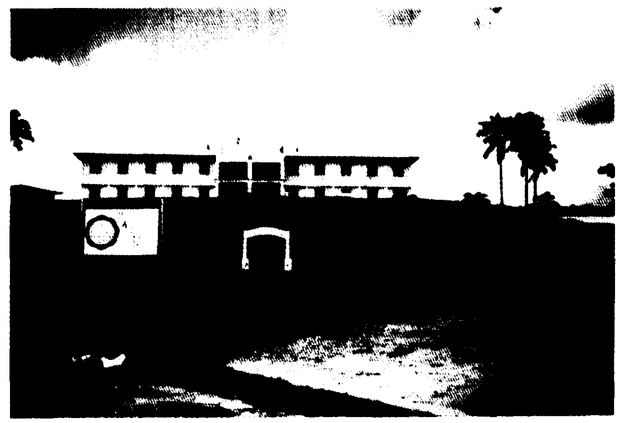
Several sectors within the U.S. Virgin Islands have effectively demonstrated over the past decades the viability of small farm and fishery operations. The French herb farmers on the north side of St. Thomas have successfully grown and marketed specialty herbs and spices. Similarly, the south side communities have been successful in small-scale, semisubsistence fishing operations. Presently, migrants from other Caribbean islands are engaged in successful subsistence agriculture activities, involving small plots of intensively cultivated land and organic inputs. These sectors combine small-scale operations with a multiplicity of occupations to maintain successful operations (e.g., French herb farmers may turn to fishing when crop markets are poor).

In Puerto Rico and the U.S. Virgin Islands, agricultural work generally has a perceived low social status, partly as a result of the plantation and subsistence economies. Early plantation agriculture relied on cheap labor. As economies boomed in the mid-20th century, landholders retained their land for speculation rather than continuing in agriculture and the younger generation generally sought employment in areas other than agriculture. Additional disincentives include the more attractive wages paid in government, manufacturing, tourism, and construction. The effect is compounded by farm operators who remain remote from their workers (116). Consequently, young, well-trained and motivated farmers are scarce.

Education and Out-Migration

Pacific

The scarcity of certain education opportunities on the islands—primarily vocational train-



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ing—in combination with primary and secondary education systems which focus on liberal arts and college preparation have reinforced a tendency to avoid agriculture and fisheries in favor of "bureaucratic employ merit." Currently, however, vocational education opportunities are increasing in the Pacific islands (52).

Westernized school curricula exclude the teaching of many traditional skills and knowledge in many developing countries, amounting to an underlying assumption that such knowledge is unnecessary in today's world (42). The current education system in this way has created a desire for urban life and "nonproductive" (i.e., public sector, tourism) employment.

Students entering college also tend to seek a more general college education. Professionals trained in public administration, economics, physical and natural sciences, and engineering are insufficient for many islands' development needs.

Out-migration from the islands for educational or income purposes is common, and on some islands, extremely high. For example, nearly three-quarters of high school graduates leave Palau for further education (14). Despite these educational pursuits there exists a rift between available employment opportunities and local skills. Public, retail, and skilled private sectors remain the desired employment areas. In many cases, the off-island residence is considered temporary (until education is completed or until job-holders claim retirement benefits or save enough to open a business on the home island). However, many do not return because local employment opportunities that match acquired skills are scarce; starting a new home-island business can be difficult, and standards of living fall below the aspirations developed off-island (14,16).

The public sector/private sector disparity in wage levels, moreover, leads to underemployment in the private sector. This increases the demand for education, encourages the dependence on alien labor, and increases the capital investment requirements for job creation (11).

Attempts to retain skilled islanders may necessitate bonding students to return (perhaps to guaranteed jobs or other fringe benefits) or providing salaries at close to U.S. levels. The former approach requires careful planning of the manpower needs of the economy, considerable administrative cost in scrutiny of curricula, and may require termination of financial support for students choosing alternate educations—a difficult choice when skills are needed in many fields. It may also be necessary to redirect students from U.S. institutions towards regional academic institutions, such as the University of Guam or the University of the South Pacific (Fiji), which may cater more appropriately to the needs of small, tropical islands (13).

On the other hand, bringing salaries more closely in line with U.S. levels may lead to even greater disparities between the incomes of the government employees and those of other Micronesians (11). The remaining alternative is to provide an environment on the home islands favorable to the satisfaction of the desires of returning migrants; this will not be easy at prevailing population growth rates (11,12,13).

Caribbean

The availability and diversity of educational programs have increased; however a shortage of skilled labor still exists at all levels. Generally, local educational and training institution efforts are not directed toward creating a labor force with appropriate skills for the current (or future) direction of the employment market (33,73). The generally inadequate level of education and skills among graduates, as perceived by employers, as well as shortage of personnel in particular specialties (33), in turn, exacerbates unemployment problems.

For example, the Tahal Report commissioned by the Government of Puerto Rico (94) indicated that the existing agricultural production system lacks adequate knowledge of commercialization required to achieve a reliable and high-volume production and delivery to markets. A gap exists between the systems of wholesale marketing and production; while the marketing system has undergone rapid modernization in the past decades, the production system has not developed in a parallel manner. Despite numerous government and private agricultural organizations (including the Agricultural College, Extension Service, and the Agricultural Experiment Station) which possess professional personnel, a need still exists for such specialized training. Research and extension personnel rarely have appropriate prior experience with high yield technology and modern commercialized markets to guide farmers (64).

Rapid development often exceeds the capacity of an education system to supply an appropriately skilled labor force. Efforts to increase profitability in the productive sector often requires specialized skills and training which often are not immediately available. For example, increased mechanization commonly is necessary for farms to be profitable, requiring employees with specialized skills (34). Thus, a need exists to train young, fairly well-educated people for agricultural pursuits; although nearly one-half of the Puerto Rico's work force has a high school education, the approximately 40,000 agricultural laborers average a fourth grade education and one-half are over 40 years of age (116).

Wage Rates and Unemployment

The Fair Labor Standards Act (FLSA), which sets minimum wage and workweek standards, applies to the U.S. Caribbean and some of the

U.S. Pacific islands. Local economies commonly are tied to regional location. Consequently, these labor laws, while improving wage rates, may hinder the regional competitiveness of the island. For example, tourism is more costly in the Caribbean than in neighboring non-U.S. islands; consequently some economy-conscious tourists may avoid the U.S. islands (57,79).

Pacific

In Micronesia, cash and subsistence economies sometimes conflict. In general, the production and distribution of goods in Micronesia and American Samoan subsistence economies are not determined by wages, prices, and profits in the western sense, but by such nonquantifiable factors as satisfaction of fulfilling kinship and other traditional responsibilities, the status and recognition this brings and the inconvenience that work entails. Production ceases when family needs are met. Total production and consumption may grow with the population, but per capita production remains constant for long periods.

Thus, many Pacific islanders are usually not productive in a cash economy unless wages are quite high (i.e., in government and military employment). It is difficult to attract Micronesians to lower paying commercial jobs. Such employment is usually short-term and undertaken to obtain a certain amount of cash for a particular item. Most employers prefer workers who can be relied onto stay long-term and develop the experience and skills needed to improve their productivity; however, the discrepancy between private and public sector wages does not promote long-term private sector employment. Often this results in the private sector turning to alien labor.

The FLSA sets minimum wage rates and workweek standards on Guam, but not on neighboring islands or nearby countries. As a result, Guam cannot offer tourists the prices and values that its neighbors, with lower wage rates, can. Guam's proposed Commonwealth Act suggests that U.S. labor laws be amendable by local legislative action as deemed appropriate.

Caribbean

Evidence exists that the minimum wage increases in Puerto Rico have strongly affected local production and employment. The higher wage rates associated with the FLSA tend to curb employment of unskilled workers particularly in labor-intensive industries. Since many economic activities related to renewable resources are labor-intensive, they are especially affected by minimum wage increases (73). Higher than regional wage levels, combined with the capital-intensive industrial development in Puerto Rico, have been postulated as a factor in the high unemployment on the islands (79,80).

Unemployment increased sharply after 1975 in Puerto Rico; it currently exceeds 20 percent officially (90,116) and may be as high as 25 to 30 percent in rural areas. Unemployment is heavily concentrated in ages from 16 to 34 years (6,35). From 1982 to 1984 the Puerto Rican labor force increased largely as a result of women and young people entering the work force (6). Labor force growth currently has exceeded the local economy's ability to generate new jobs. Alternative employment opportunities for displaced workers have not materialized and unemployment remains a large problem despite out-migration to the U.S. mainland, which continues from Puerto Rico at a fairly rapid pace despite industrial growth (73).

Historically, immigration to the United States from the U.S. Virgin Islands has fluctuated with insular economic changes. During periods of rapid economic growth, such as the 1960s, there was widespread immigration to the U.S. Virgin Islands from both the mainland United States and nearby islands. During the economic slowdowns of the 1970s and early 1980s, however, these inflows were significantly reduced and in some cases reversed. Close ties with the U.S. mainland and easy access to the wide variety of U.S. employment markets has encouraged out-migration, particularly in periods of economic adversity.

Social Support Programs

Pacific

Although Federal subsidies to Micronesia, especially in social services, were carefully controlled in the 1950s so as not to compromise the goal of self-sufficiency, during the latter part of the Trustee period (after 1963) this changed. Federal appropriations rose from almost $7 million in 1963 to at least $60 million in 1971 and continued to rise steadily throughout the 1970s. Most funds were channeled into administration, schools, and health services (89).

Even during a time of rapid economic growth in the early 1970s, the number of welfare recipients steadily increased (14). Nearly one-quarter of Guam's civilian population received food stamps in 1980, although many of these may have been aliens. The decline in FSM agriculture and fisheries production has been attributed, in part, to Federal surplus food distribution programs (11). Cases of condensed milk and cheese were distributed freely in the Commonwealth of the Northern Marianas (CNMI) while a dairy ranch on Tinian exported 80 percent of its milk and 92 percent of its meat to Guam (12). The inhabitants of Agrihan (CNMI) produced papayas, mango, and coconuts but were otherwise entirely dependent on U.S. Department of Agriculture supplies (12).

A Nutrition Assistance Program was established in the CNMI in mid-1982 with about 28 percent of the Mariana citizens participating (819 households). One condition of this program was that 15 percent of all coupons were to be used for the purchase of locally grown food. The ability of local producers to supply the required volume was uncertain at the institution of the program (12) but, while data are unavailable to indicate the program's success in increasing agricultural production, indications suggest that this has been accomplished (74).

Caribbean

Social support programs grew rapidly in the U.S.-affiliated Caribbean islands with the expansion of the "Great Society" programs on the U.S. mainland. However, this has moderated since 1981 as the U.S. administration generally has slowed Federal spending. Federal transfer payments have recently been providing close to 30 percent of Puerto Rico's disposable income and roughly 50 percent of island households have been receiving food stamp payments. A 1980 U.S. Department of Commerce study found that approximately two-thirds of Puerto Rican families lived below U.S. poverty levels (90). Puerto Rico was removed from full coverage under the Food Stamp program in 1983 and placed under a special block grant of $825 million. Puerto Rico administers its own nutrition assistance program with these funds, paying beneficiaries with checks instead of food coupons (73).

Preference for Government Employment

Pacific

On most U.S.-affiliated Pacific islands, jobs with the U.S. Government (e. g., military) are preferred over jobs with the local governments, which in turn are preferred to employment in the private sector. Local government wage and salary levels are nearly twice those of the private sector. (Data from Palau indicate that public and private sector wages and salaries are increasing; while the differential has remained the same, the absolute difference in levels has increased.) Living in more urban centers, in which most infrastructure development has occurred, also is preferred to village living. Government employment absorbs at least than one-half of all wage earners on many islands and a large proportion of the private sector (devoted to services) is dependent on expenditure generated by the public sector (14). The large size of the public sector may, however, reflect hiring because of available funds, irrespective of necessity, and not necessarily an underdeveloped private sector (11).

Attempts by the private sector to match public sector wages places an economy at a comparative disadvantage for many import-substitution activities and export-oriented development strategies (11). However, because government salaries are subject to much redistribution through family ties, public sector employment can be regarded more as a channel through which public money is distributed than as a means of increasing productivity and improving public services (15). This may partly justify low productivity at high wages (15).

Because of U.S. fiscal restraints and the approval of the Compact of Free Association, public sector employment probably will tend to decline in the next few years on many U. S.-affiliated Pacific islands. This will have a similar impact on some parts of the private sector, notably general merchandising, transportation, food services, and construction, which, with government employment, account for most formal employment in the islands.

Caribbean

Public service comprises the largest employment sector in the U.S. Caribbean islands; this sector, however, includes some "productive" services which in other economies maybe provided by the private sector (110,111). Public sector employment in 1977 to 1978 was estimated to be 25 percent in the U.S. Virgin Islands (110) and 23 percent in Puerto Rico (111). Recent figures for the U.S. Virgin Islands indicate that the public sector comprises over 30 percent of the total labor force and 33 percent of all employed workers (55). Employment in the public administration sector alone comprises nearly 33 percent of Puerto Rico's total labor force; this percentage does not include those public employees in health, recreational, transportation, or communication services or public utilities (35). Current fiscal limitations within the U.S. Virgin Islands Government are expected to constrain further employment growth. Consequently, increasing concern exists for training the local labor force for private sector employment (79).

Shortage of Rural labor

Pacific

A major constraint to productive rural development is rural labor shortage, especially of skilled labor. Most rural/outer island residents have relatives in the urban centers, who provide the reason and means to migrate (14). The periodic food supplies once sent from rural islanders to urban relatives are superseded by imports (14). Rural population totals disguise high ratios of dependent population to productive work force. Rural to urban/off-island migration has left many island rural areas with an hour-glass shaped population pyramid–a population heavily biased towards the very old and the very young (14). Moreover, while there may be many islanders with skills relevant to the economy, their aspirations generally are directed towards government and retail employment, resulting in a labor constraint to productive employment.

No shortage exists of people, especially young people, to form a labor pool in U.S.-affiliated Pacific islands; however, agricultural labor shortage is a problem in several areas. In general, there is a low esteem for farm work, and wages and benefits are low compared to other types of employment. Guam has considered importing foreign labor under the Federal H-2 temporary alien program, but the Labor Department apparently blocked this (54). Since the Government of Guam was granted the authority to certify and import alien workers in 1984, they may reconsider this proposal (45). In American Samoa, much of the agriculture depends on aiga family members from Western Samoa, and Taiwanese and Koreans who have jumped ship at Pago Pago (54,83).

Caribbean

Today the social situation has changed significantly in the rural interior of Puerto Rico. Large numbers of the population have migrated from the rural interior to urban centers or off-island. The remaining rural population is employed as seasonal labor for coffee harvest and supplements its income with food stamps and occasional part-time jobs. The "old timers" have rapidly disappeared and the younger generation is usually unskilled labor (78). Although rural unemployment is high (25 to 30 percent in some municipalities), alternative employment opportunities, food stamps, and social security from extended families all contribute to an underground economy, which, in some cases, can provide $2,000 per month in non-taxable family income.

Agricultural development in the U.S. Virgin Islands is constrained by lack of trained personnel and reliable labor and available agricultural labor is generally expensive and unproductive (116]. Perhaps correspondingly, the percentage of farms with hired labor has declined in the U.S. Virgin Islands from 33.9 percent in 1975 to 27.7 percent in 1983 (57).

Despite the high unemployment rates, Puerto Rican farmers have reported it difficult to obtain large numbers of part-time laborers (116). Farmers reportedly locate only 90 percent of the workers they need; 52 percent of farmers report difficulty locating experienced workers and 39 percent say that the shortage of labor forces them to employ inexperienced farm workers (123). No migrant labor is available in Puerto Rico (116).

Alien Labor

Pacific

At the same time islanders are leaving their islands for education, employment, or other enticements, considerable numbers of aliens are entering the island economies. Some of these are U.S. mainlanders or Europeans who enter local government positions while an increasing number are Filipinos and other Asians filling largely unskilled positions, predominantly in construction, fishing, and to a lesser extent, agriculture. For example, alien employees currently comprise at least one-third of the Palauan private sector and some economic sectors are almost entirely dependent on Asian labor (14).

Alien workers offer employers substantial advantages in high productivity and reliability, obtaining overtime work, and in flexibility in discharging unsatisfactory workers (11). However, the cost of employing U.S. expatriates is high and there are large costs, and potential benefits, in the impact of the expatriates on consumption (15). For example, the preference for "western-style" foods may increase imports but it can also signal a potential market for locally grown, non-traditional crops.

The question of whether or not to import foreign labor is a difficult one. Agricultural industries such as Hawaii's were built with cheap foreign labor, but there can be resulting social tension when large numbers of foreigners are imported into a relatively closed society, as in many of the U.S.-affiliated islands. Pohnpei has rejected two development proposals—one to bring in Vietnamese refugees to grow rice—for these reasons (83). On the other hand, importing labor may be better than importing food–the agricultural industry will develop, dependence on imported food is reduced, and foreign workers generate tax revenues through payment of taxes on their wages (45). Alternatively, agriculture might be made more profitable for local producers and workers through increased research, development, and extension (83).

Despite the current lack of economic growth in the U.S.-affiliated Pacific islands, the proportion of aliens in the local work forces probably will not diminish in the near future (11). In the FAS islands, it is increasingly likely that local islanders will seek government employment or move overseas, while all other sectors of the economy will become increasingly dominated by alien workers. Most will come from Asia and work for lower wages than are offered by government employment (14).

Substantial out-migration of the few skilled professionals now in the FSM and their replacement by alien professionals is likely to continue. Adoption of a wage and salary structure commensurate with the U.S. mainland may reverse these trends, but goes directly against United Nations' recommendations and is likely to exacerbate existing income inequalities, The FSM is becoming more like Guam, the Northern Marianas and American Samoa (and also the U.S. Virgin Islands), where government employment is predominantly indigenous, while employment in other sectors is increasingly taken up by lower paid aliens, a situation made possible only with substantial external financial assistance (11).

Caribbean

While the Puerto Rican labor force is almost exclusively comprised of residents, the U.S. Virgin Islands has developed a relatively large alien labor force. Local application of the special Temporary Foreign Worker Program in the U.S. Virgin Islands has created a labor base largely comprised of British West Indians. This labor force generally increases in periods of economic prosperity, and decreases only minimally during periods of recession. The net results are: rise of unemployment, increase in individual's multiplicity of jobs, increased reliance on savings, and reductions in remittances (57). Displacement of local workers by aliens currently does not seem to be a concern in the U.S. Virgin Islands.

Immigrants from neighboring islands are accustomed to rural lifestyles and prefer working in agriculture, but often lack capital and land and generally earn most of their income from industry or tourism (78). Consequently, the aliens generally are employed in a large variety of low-level jobs that U.S. Virgin Islanders have traditionally avoided (79), thereby creating a bimodal society which promotes internal cleavage in U.S. Virgin Islands society (58).

Conclusions

If the islands are not to suffer a decline in living standards, they must either find new sources of aid, reduce government expenditure, or develop greater self-reliance. Increasing self-reliance means reducing dependence on imported goods and expertise, and probably will require some changes in consumption patterns as well as increased local productive capacity (15).

The small size and limited skilled labor force of the polities virtually preclude accelerated socioeconomic development towards a mainland U.S. standard of living without outside inputs of technical assistance and skills (12). Economic development probably cannot be achieved simply by reallocating resources towards improved infrastructure or agricultural investment. It may also require a fundamental change in attitudes, demanding such policies as wage constraints and raised taxation (on imports and income). This may be extremely difficult to achieve on small, democratic islands (14). The combination of relatively high educational standards and aspirations, limited opportunities for formal sector employment, and the possibility of free movement to the United States, suggests that out-migration from the U. S.-affiliated islands is likely to become increasingly important in the future (14).

The application of technologies is many times hindered by the lack of properly trained personnel. Training in some specialties is not available in local academic institutions and students must travel to off-island institutions for such training. Few island residents can afford this. Those students who attend off-island institutions often remain there, enticed by better jobs, opportunities for further training, and career advancement. The lack of trained personnel may have adverse effects on all aspects of renewable resource management, including research, law enforcement, project implementation, and education in academic institutions (19).

Adequately trained, dedicated staff are needed at all levels. Individuals with appropriate attitudes and aptitudes must be identified and given technical or professional training and continuing education, so they may keep abreast of new resource management and development strategies and technologies. Short courses could be organized locally, and key staff encouraged to travel to conferences and summer programs abroad. Where human resources are scarce, they could be directed to the most critical areas or problems (19).

Suitable working conditions must be provided. Flexibility is needed in personnel regulations and incentives programs, especially of the insular governments. Salary scales could be upgraded on a regular basis to remain competitive with the private sector. Public corporations might replace more successful government programs to provide professionals with secure, well-remunerated positions.

The Federal Government could raise the limit for exemption from minimum Federal wage payment for nonmechanizable agricultural operations. It also could assign a specific proportion of the food stamp funds and/or any increases in these funds to increase employment and local food production. Increased income to laborers could reduce payments for food stamps and for unemployment compensation and reduce migration to the mainland (116).

Agriculture and other renewable resource-related enterprises can be an important source of employment, but unless production is increased, greater employment may be accompanied by lower wages, higher prices, more government subsidies, losses to farmers or some combination of these. On the other hand, in Puerto Rico every job in agriculture is estimated to create at least one other job in the island's economy, considerably more than that created by industry or construction (116).

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Chapter 5
Islands As Integrated Systems

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Islands As Integrated Systems

INTRODUCTION

Islands are by definition small areas of land isolated by water, and it is small size and isolation that make them different from continental land areas (3). The small size of islands means that many different ecosystems may exist in close proximity. Thus, the interrelationships among ecosystems are critical to the functioning of the entire island's renewable resource system. The smaller the island, moreover, the higher the ratio of coastline to land area and the more important the land-sea interface in fulfilling human needs.

Renewable natural resources—water, soil, vegetation, fish, and wildlife—by definition have a resiliency to recover from human use. Their ability to renew themselves makes them especially valuable in the support of human life, a fact understood by most people but sometimes forgotten in their continuing process to improve their quality of life and supply the desires of society. Inadvertently, these resources can be abused and can sustain damage that is slow to repair.

The various island ecosystems maintain an equilibrium when in an unmodified state, or when modification is done in such a way as to allow the natural flow of energy, freshwater,

[1]Ecosystem—sum of biotic and abiotic components of a specific environment.

Photo credit: A. Vargo

Intimately interlinked terrestrial and nearshore marine areas comprise the "island ecosystem."

and nutrients through the system. Understanding the linkages between the various parts of the renewable resource base and incorporating them in development activity design is necessary to keep these resources truly renewable and to allow their sustainable use. The integrated management of island renewable resources is a sound way to enhance their long-term renewability and ensure that benefits derived from the resources will be long lasting.

Sometimes resource renewability is sacrificed to accommodate certain other goals. For example, certain islands or parts of islands are set aside for such military uses as practice bombing sites or the impact areas for artillery or naval gunfire. Even if such practices were to cease at these sites and if some renewable resource systems recovered, it is unlikely that such lands could be brought back into productivity for decades. Some islands which were inhabited perhaps 40 years ago no longer exist as a consequence of nuclear bomb testing.

Similarly, colonial authorities of the Pacific island of Nauru decided to mine the island's considerable phosphate deposits quickly, irrespective of effects on the island. Integrated renewable resource management plays no role in such cases.

Conversely, some islands have been established as wildlife refuges, such as Rose Atoll in American Samoa, and Howland, Baker and Jarvis Atolls. Human interaction with the environment is minimized, renewable resources are not exploited and thus the need for management is primarily limited to the protection of the refuge.

The multitude of island resource problems (summarized inch. 4), however, largely are of a different nature. They typify instances where one island resource was exploited without adequate consideration for its impacts on other island resources (cf: 8). In many of these cases, recognition of the interrelationships between resource exploitation in one place and unintentional resource damage elsewhere on or near the island has led to imaginative, sound management approaches that benefit all of the resource users.

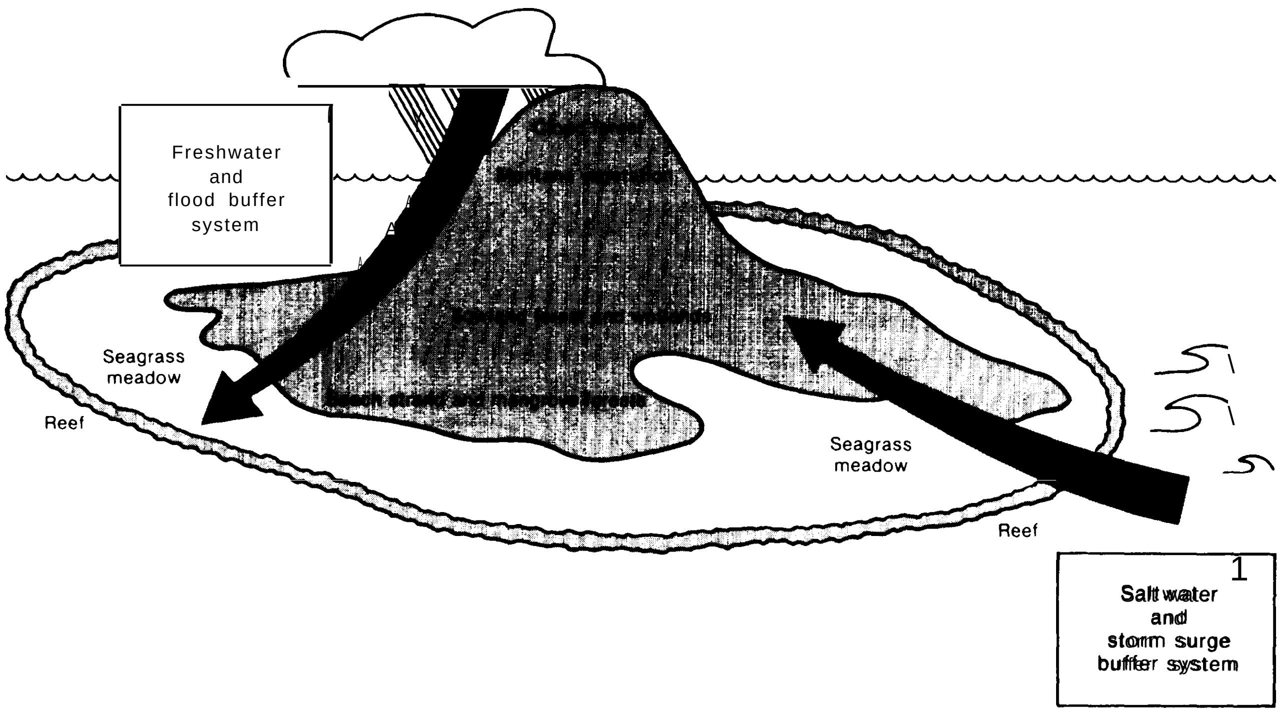
Island resource damages have occurred over long periods of time; many of the corrective actions have taken place relatively recently. These recent encouraging actions seem likely to continue and perhaps expand while certain of the old causes of resource damage probably will fade away. To accelerate this process it seems likely that an increased understanding of the working components of the renewable resource systems of islands, including the integrated nature of different resources, is an important first step. Consequently, technologies and various management practices described in this assessment have been examined to identify unforeseen adverse impacts that they might generate; technologies that are likely to foster numerous serious impacts were omitted. In such analyses, fresh water and its movement seem to provide the common link among different parts of islands and their resources.

EROSIVE ENERGY BUFFER SYSTEMS

Islands have at least two major physical forces acting on them: 1) the flow of water from higher altitudes to the ocean, and 2) ocean wave action moving from the ocean onto land. Both of these forces have strong erosive powers—abilities to denude the land and nearshore ecosystems of biological productivity. Thus, the magnitude of these movements of water, coupled with the island's form, largely determine the technological options available to its residents to improve the long-term production of food and fiber.

Natural island ecosystems, however, are arranged in such a way as to buffer the erosive forces of water movements (figure 5-1). The individual components of the "freshwater/flood buffer" range from highland vegetation to seagrass meadows and each may fill several specific ecological functions. The latter also is

Figure 5-1 .—Erosive Energy Buffer Systems on Islands



SOURCE Off Ice of Technology Assessment 1986

true of the "saltwater/storm surge buffer" which generally is comprised of coral reefs, seagrass meadows, littoral vegetation, and lowland forests.

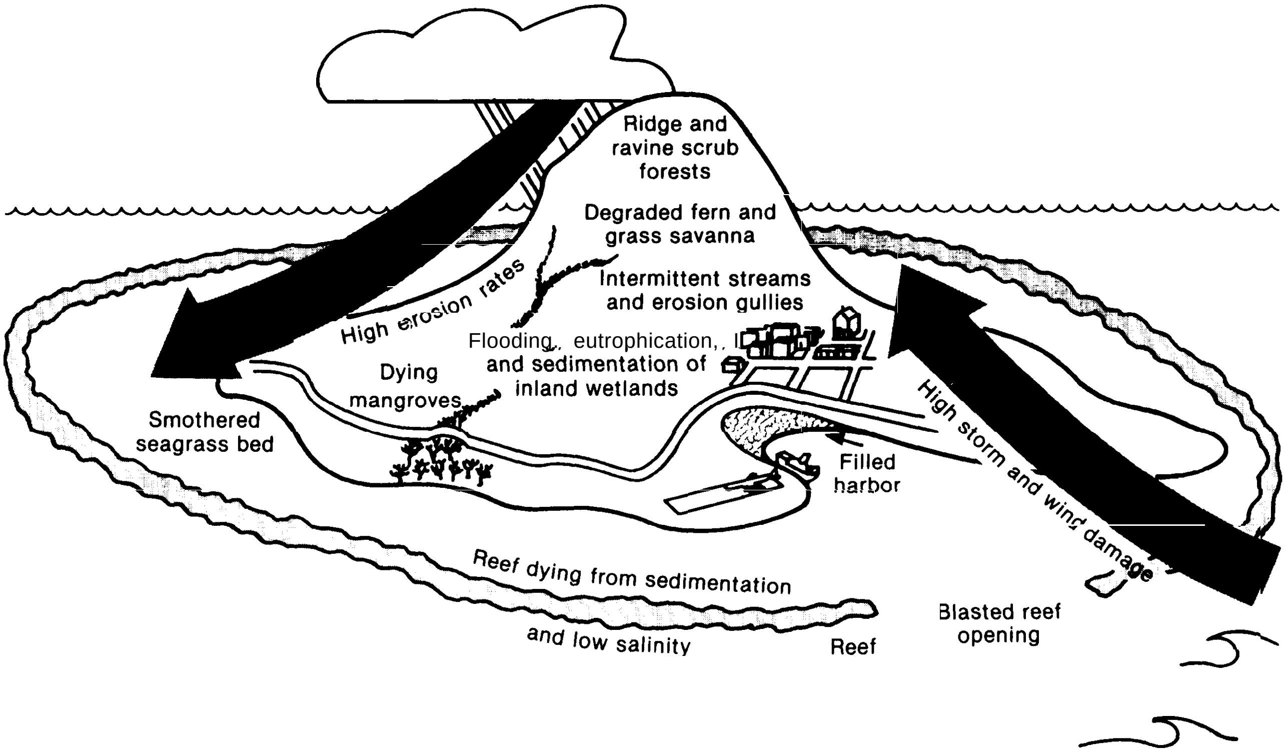
Development activities that modify or degrade parts of these buffer systems may result in repercussive changes to connected ecosystems (figure 5-2). For example, if a part of a reef is mined, the opening which results will allow wave energy to impact directly on the shoreline. The previously quiet environment of the back-reef[2] habitat will be disturbed and shoreline erosion may ensue, as well as increased water turbidity. These changes consequently may affect the biota dependent on the back-reef habitat.

Similarly, if upland vegetation is removed and, thus, terrestrial erosion increases, streams may become sediment-laden and ultimately discharge sediment into the nearshore waters. Excessive sedimentation may adversely affect freshwater communities, smother nearshore marine bottom communities, and kill corals. Thus, damage to one part of an island's renewable resource base easily can adversely affect others. Though such damage may be unintentional, nevertheless, it may result in the loss of valuable resources that do not regenerate quickly.

Island form and composition largely determine the natural communities that develop and also affect the way these natural systems respond to human stress or disturbance; different island types have different environmental vulnerabilities. For example, high volcanic islands may be highly susceptible to erosion because of their steep slopes, whereas raised limestone islands may be particularly sensitive to groundwater pollution and the rapid loss of soil nutrients. A knowledge of island structure should help to predict the environmental impacts of various development possibilities (3).

'Back-reef—the lagoon/shallow bottom side of the reef.

Figure 5-2.—Resource Degradation Due to Modification or Disruption of Isiand Buffer Systems



SOURCE: Office of Technology Assessment, 1986

Freshwater and Flood Buffer System

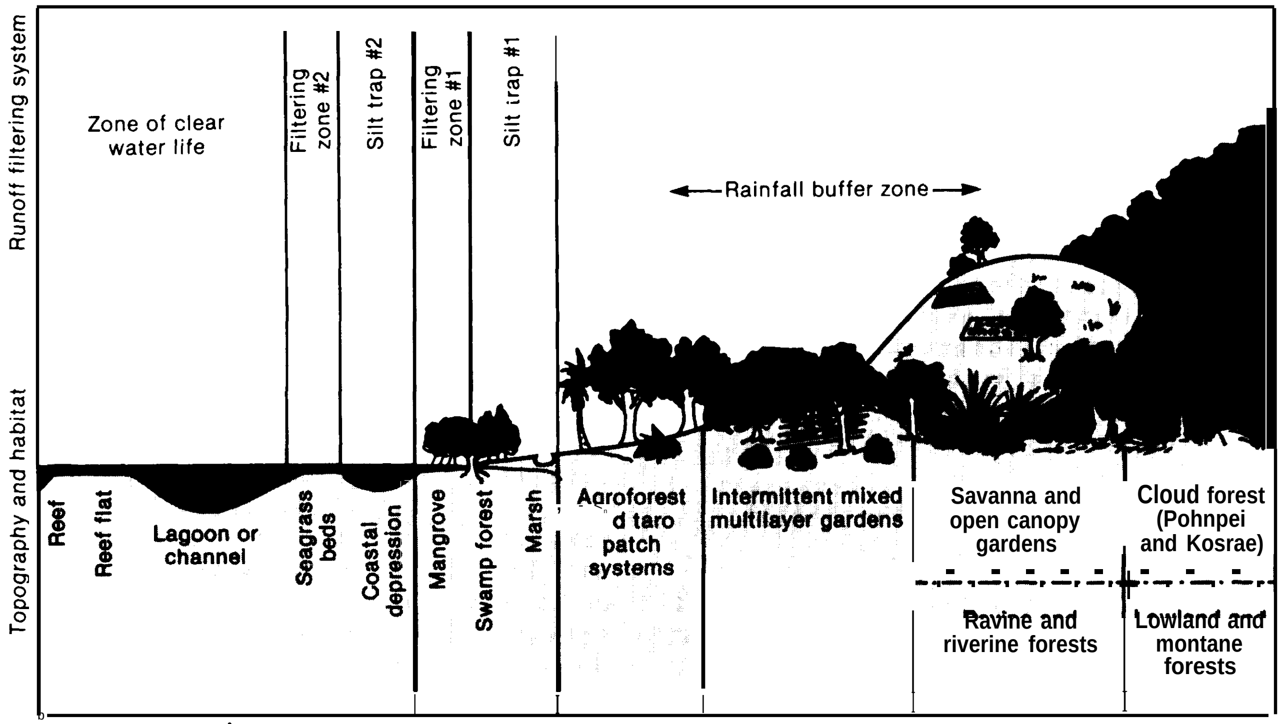
Tropical storms are more violent than those in temperate areas. More water falls per storm, quickly saturating the soil. Consequently, a larger proportion of the rainfall runs off the soil surface. Furthermore, in tropical storms raindrops commonly are larger, thus having great kinetic energy and high erosive power (13).

Tropical forests—the common natural vegetation of upland island areas—protect soil and modulate water flows in several ways. The canopy of trees, undergrowth and litter layer intercept rainfall and provide temporary water storage. Vegetation intercepts rainfall, reducing its energy and allowing it to reach the soil at slower speed and over a longer period of time than precipitation striking unprotected soils. The organic litter in undisturbed, closed tropical forests is typically only several centimeters thick, the majority of organic matter being in vegetation root systems. Water is stored in the organic litter on the soil surface and in the porous topsoil. These mechanisms minimize the impacts of intense rainstorms, reduce peak stormflows, and help mitigate flooding (13).

The steepness of high volcanic islands promotes the rapid flow of rainfall from uplands to the ocean. The rapidly flowing water carries nutrients and sediments through a series of ecosystems that change with elevation. vegetation of the various ecosystems slows runoff, trapping some of the sediment and nutrients. Each topographically lower ecosystem is successively less tolerant of siltation (5).

For example, on a typical high volcanic island, the erosive force of torrential rainfall is first buffered or moderated by highland forests. Surface water, flowing on its way to the ocean, is slowed by and deposits some of its silt in

Figure 5-3.—Relationship Between Topography, Traditional Agriculture, and Rainfall/Runoff Erosion Buffer Systems on High Caroline Islands



SOURCE: M. C. V. Falanruw, "Traditional Agriculture and Resource Management Systems in the High Islands of Micronesia," OTA commissioned paper, 1986

coastal plains. Mangrove forests further remove sediment and seagrass meadows filter out remaining silt. This filtering system serves to maintain the clarity of lagoon waters necessary for marine life (figure 5-3) (5). Many plant and animal species of the intertidal zone are adapted to certain salinity ranges in the water. Without such mechanisms to control the level of fresh water discharged to their habitat, damage easily may occur,

Mangroves are sensitive to changes in salinity balance which may occur from increase or decrease in freshwater input into the mangrove ecosystem. While mangroves can develop in freshwater regimes, they generally are outcompeted by terrestrial vegetation, thus mangrove development primarily occurs in saline environments. Hypersaline environments can be equally detrimental to mangroves, resulting in stunted growth and eventually mortality (2). Development activities which alter the periodicity or amount of freshwater input may cause damage or loss of mangrove forest area with a concomitant loss of the benefits afforded by the ecosystem (i.e., nutrients for nearshore aquatic life, filtration of sediments). Primary productivity of the damaged mangrove ecosystem declines, providing fewer nutrients for associated primary consumers (mollusks, crabs, polychaete worms); the effect continues through the food web to which the mangrove is linked (7).

The composition of the buffer system may vary from island to island depending on geologic structure. However, the system is generally comprised of upland forests (cloud and submontane forests), lowland forests, riverine forests, swamp and mangrove forests, and seagrass meadows. All of the island terrestrial vegetation acts to protect island soils from the impact of rainfall and contributes to soil moisture storage. The highland forests are particularly important in soil moisture recharge, and contribute to flood and erosion control. Riverine and swamp forests also play important roles in flood control and stabilization of water flow to the ocean. Freshwater flora may serve to filter some sediment from streams, however, large sediment levels may degrade the habitat of these plants. While these vegetation formations cannot prevent such natural events as flooding, landslides, and erosion, they comprise a gauntlet of resistance.

The freshwater buffer system provides a range of beneficial effects that enhance and sustain the environmental quality of the island. The individual components are inextricably linked through the flow of fresh water, each modifying the flow and thus creating viable habitats for the components further "downstream."

Saltwater and Storm Surge Buffer System

Wave action may easily erode large areas of beach in the absence of any protection. Most islands possess a natural wave energy buffer composed of several closely interrelated ecosystems—coral reefs, seagrass meadows, and littoral vegetation (mangrove communities and beach strand). These ecosystems are closely interrelated and function not only to reduce wave energy but also to protect areas further inland from salt spray.

The coral reef comprises the first physical barrier to wave energy impacting on the island. The structure is solid and acts to dissipate the bulk of wave energy before it reaches the shoreline. Although waves maintain momentum after breaking over the reef, the energy level has been reduced. An active reef can build islands like the atolls of Micronesia, provide sand for beaches, and repair itself after storm damage. If the reef-building processes are disturbed, however, marine erosion will take over and the reef will deteriorate.

Shallow, back-reef seagrass meadows dotted with individual coral "heads" increase friction, further impeding the wave's progress towards shore. The seagrass meadows capture larger particles of eroded coral sand and act to stabilize bottom sediments, thus helping to prevent coastal erosion.

Still, some wave energy reaches the shore. Here, littoral vegetation acts to stabilize shorelines by holding soils in place through a network of roots. Littoral vegetation, including the specialized formation of mangrove forests, will hold sand and soil particles firmly, eventually allowing for the outward extension of the formation. Mangrove forests are particularly well suited to this type of expansion, advancing seeds that germinate while still attached to the parent tree. Littoral vegetation also acts as a physical barrier to salt spray released by wave action on the shoreline, as well as that carried by wind. Littoral species such as *Pandanus*, coconut, and mangroves typically are highly salt-tolerant.

The wave energy buffer system in its entirety comprises a valuable resource for islands to maintain and stabilize a commonly tenuous shoreline against ocean energy. Where parts of the system are removed, the remaining components of the buffer may not be able to fulfill the entire stabilizing function and shoreline erosion and saltwater damage to inland vegetation may ensue.

Raised Limestone Islands and Atolls

The geologic structure and low surface altitude of atolls obviously makes them extremely vulnerable to wave action, storm surge, wind, and salt spray. Raised limestone islands, in part, have a similar structure although a higher surface altitude. The porous nature of the soils of these islands allow for ready percolation of rainfall directly through the island's surface and through the coralline limestone solution cavities into the freshwater lens or to be discharged through coastal springs. Although raised limestone islands may have freshwater streams, they generally do not empty directly into the ocean. Thus, the freshwater filtration system of high islands does not exist on raised limestone islands or atolls. However, shallow coastal depressions and seagrass meadows may act as filtration mechanisms for sediments discharged by coastal springs.

A wave action buffer system exists, however, and operates similarly on atolls and raised limestone islands: the reef offers protection from wave energy and shoreline vegetation fosters soil-building, shoreline stabilization, and retards shoreline erosion. Vegetative formations also serve as partial barriers to wind and saltwater spray which present major limiting factors to plant growth particularly on atolls, Littoral vegetation on the windward side of atolls often is maintained to serve as a natural barrier to saltwater spray. *Pandanus tectorius, Messerschmidia argentea, Cordia subcordata, Terminalia samoensis, Clerodendrum inerme,* and *Barringtonia asiatica* are some of the more common Pacific trees and shrubs which provide protection from salt spray. The coconut palm Cocos *nucifera,* is a highly salt-tolerant species which thrives in well-drained, saline soils common on atolls. While young palms initially may require protection, older plants do well in areas of high salt spray (11).

BIOLOGICAL INTERACTIONS-NUTRIENT CYCLING AND FAUNAL INTERACTIONS

The U.S.-affiliated islands contain a number of individual ecosystems which in their entirety can be considered an "island ecosystem" (3). Individual ecosystems commonly fill several ecological functions within the island biotic structure. The interaction of all of the biotic components of island ecosystems transport and cycle nutrients and form a food web which is of critical importance to the sustainability of the island fauna and flora and ultimately affects the quality of human life.

Nutrient Transport and Cycling

The vegetation components of the freshwater buffer system, while ultimately maintaining clarity of nearshore waters and protecting marine organisms intolerant of high levels of fresh water, also are integral in maintaining soil fertility. Most tropical ecosystems have little 1ong-term nutrient storage capacity; rather nutrients are cycled through the biomass of the systems. Most nutrients are added to the systems through transport of nutrients in water or by fauna, and through specialized plants which can fix nitrogen from the air. Seabirds bring nutrients from the ocean and deposit them on land (guano), increasing soil fertility; conversely, land-derived nutrients enhance fisheries and the productivity of coastal waters by fertilizing the macro- and micro-algal base of the food web.

Forest Nutrient Cycling Systems

High rainfall in most tropical areas leaches out basic plant nutrients, thus, forest canopy and vegetation is critically important for maintaining soil fertility by returning organic matter and its contained nutrients to the soil through the natural plant lifecycle (9), Undisturbed tropical forests have an efficient nutrient recycling system. As long as the forest is undisturbed, the nutrient supply remains stable. Soil shaded by the closed forest canopy is cool enough for the abundant organic material to decay gradually. Detrital decomposes such as bacteria, fungi, and arthropods are important in nutrient cycling within vegetation formations as well as in soil building; the nutrient value of the detrital layer is increased when it passes through the systems of many of the decomposes. Thus, the humus content of forest soils acts to hold the nutrients released by microorganisms until they are absorbed back into the web of tree roots to be recycled again.

Soils with low humus content hold fewer nutrients and, when rain falls, runoff and leaching deteriorate the soil's fertility. If land is returned to forest fallow soon enough after clearing, a new growth of trees can reestablish the soil's humus, the web of roots, and the nutrient recycling system. The successional sequence from pioneer plant species to mature forest, which helps restore soil fertility in fallow areas, depends on the presence of nearby seed sources, and often on animals for seed transport.

Mangrove forests provide considerable amounts of organic material to adjacent and nearby ecosystems. Although obviously dominated by mangrove trees, these forests actually comprise a complex and diverse association of marine and terrestrial animals and plants whose members range from tiny filamentous algae to epiphytic bromeliads, and from microscopic zooplankton to frigate birds, turtles, and alligators (10,16). Marine plants and invertebrates, in particular, contribute to the nutrient cycling function of the mangrove forests generating significant amounts of particulate and dissolved nutrients which augment growth of adjacent seagrass and coral reef communities (16).

Coral Roof Nutrient Cycling

Reef corals and algae extract calcium from the seawater to make solid calcium carbonate: the *coelenterates* build the hard *theca* or homes in which they live and the algae form a hard lime crust, both of which comprise the solid reef structure. The **waves** and currents on the fore-reef[3] carry nutrients to the reef organisms and thus the reef tends to grow outward (11). Clearly, the interaction of the biotic components with their environment contribute to the maintenance and expansion of an ecosystem.

In an undisturbed coral reef ecosystem the individual components interact to maintain equilibrium. Proper distribution of trophic levels is necessary to the efficient maintenance of the ecosystem. Various species graze on the coral reefs or in nearby seagrass meadows, while larger species feed on the grazers. When activities of one component exceed a sustainable level, the balance of the ecosystem is affected. For example, if primary consumer populations are reduced dramatically the food source for secondary consumers correspondingly is reduced. Similar adverse impacts may arise if secondary consumer populations are reduced, allowing overpopulation of primary consumers.

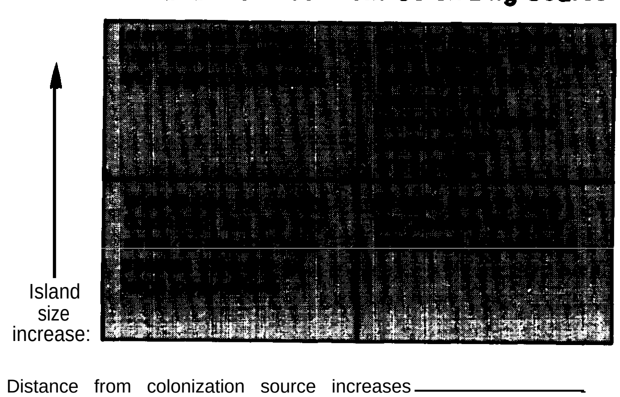
While tropical ecosystems are among the most productive in the world (cf: 1), they are also vulnerable to natural and man-induced disruptions. Because most of the needed and available plant nutrients in the systems are held in the biomass, a high percentage of nutrients can be lost rapidly from exploitation.

Faunal Interactions

The number of species an island can support (species diversity) and species populations both decrease with decreasing island size. Because of low population levels, biota on very small islands are vulnerable to extinction (cf: 4). The equilibrium of island populations depends on rates of immigration and extinction and, hence, indirectly on distance and size (figure 5-4). The likelihood of an extinct species being replaced through immigration from a continent or another island decreases with the distance from such sources.

The interrelated nature of island ecosystems is apparent in island faunal behavior. It is not uncommon for species to migrate among several ecosystems during their ontogeny. For example, the queen conch *Strom bus gigas* spends its larval stage sheltered in mangrove forests and moves to reef environments as an adult (16). Similarly, larvae of spiny lobster commonly set-

Figure 5-4.—Relationship Between Insular Species, Island Size and Distance From Colonizing Source



SOURCE: Office of Technology Assessment, 1986.

[3]Fore-reef—the seaward side of the reef.

tle among the prop roots of mangroves, move onto adjacent seagrass beds or shallow reefs as juveniles and then into deeper reef habitats as they mature (6). Some fish seek shelter on the reef, feed in seagrasses, and breed in mangroves. Spawning habits of some species result in movement between fresh- and seawater environments. The freshwater eel, for example moves downstream to the ocean to spawn. Coconut crabs live on the land but breed in the ocean; turtles live in the ocean but breed on land. The breeding areas of these animals are critical habitats (3).

It seems that movement among ecosystems is the rule and not the exception. Thus, removal or degradation of an ecosystem may affect not only those plants and animals which continually reside within it, but also may block a migration pattern other species depend on to complete their lifecycle—thus compounding the adverse effect.

Interactions of the plant and animal species within each forest community commonly result in a number of beneficial effects such as nutrient cycling, expansion of vegetation through seed dispersal, and biological control of pests. Birds and bats, in particular, are often important for plant pollination and seed dispersal.

CONCLUSIONS

Individual island ecosystems are closely interdependent and, while each component may have unique functions, they are also important as components of the "island ecosystem. " Thus, in many ways, an island is a single system; the degradation of any part of it may affect the productivity of the whole (3).

The closely interconnected nature of island ecosystems can constitute a major advantage or disadvantage. while the interdependency of ecosystems may compensate for deficient operation of one biological aspect (e. g., moving nutrients from an undisturbed to a degraded ecosystem), it may also result in disruption of another to such a degree that damage to the entire system is compounded. Thus, unwise use of a particular resource may result in degradation of larger resource areas.

Damaging a single watershed of a large continental area may not be as devastating as damaging a small island's watershed where negative impacts may quickly affect many parts of the island ecosystem. Additionally, alternate water sources may not be as easily available as on continental areas. Clearly, then, islands cannot be considered scaled-down versions of continents (12). The difference in scale is too great, and their very natures differ considerably (3).

Modification of the environment obviously is necessary to accommodate human populations. However, options exist in the methods and types of modifications to be enacted. Selection of a development approach which mimics or acts in concert with the desired natural process will result in fewer impacts on associated ecosystems. For example, agricultural expansion into previously unused forestland may take the form of gradual replacement of existing trees with fruit trees. Potential exists here not only to improve agricultural productivity but also to maintain the natural functions of the vegetative cover in the process. Observations of the linkages between ecosystems and repercussive impacts are documented in representative management plans. The programs offered by various plans offer mechanisms to manage development activities (cf: 14,15).

Traditional island societies demonstrated a keen sense of the interrelated nature of the island ecosystems. Damaged or degraded areas were allowed a fallow period in which to recover in order to restore productivity. Present population pressures coupled with heightened economic desires preclude most resource uses which rely on time for recovery. Today, efforts to reclaim degraded resource areas still require recovery time. In addition, these efforts often are costly, sometimes requiring research information and adequate protection or regulation. However, sustainable management of a resource area offers an alternative to a lengthy recovery period. Maintaining and protecting resource integrity from the start would allow productivity over the long term without the high-cost inputs of restoring productivity or loss of productivity "during recovery periods.

Island peoples continue to depend on natural communities for many of their needs. Each island ecosystem, natural or modified, provides benefits to the food and fiber production of islands and contributes to the supply and effective sustained use of island renewable resources. Even areas developed for human use depend on natural ecosystems for many essential services. The cycles of water and nutrients, the flows of materials, and the movements of animal populations therefore require careful management for the island as a whole (3). Through application of rational management activities, these benefits may be sustained over the long term.

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Chapter 6

Management of Terrestrial Resources: Agriculture, Agroforestry, and Forestry

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Chapter 6

Management of Terrestrial Resources: Agriculture, Agroforestry, and Forestry

AGRICULTURAL DEVELOPMENT IN THE U.S.-AFFILIATED ISLANDS

Few areas in U.S.-affiliated islands remain unmodified by man. Most are or have been managed to some extent to provide for human needs, and many land areas have been degraded in the process through deforestation, soil erosion, and nutrient depletion. Terrestrial resources and resource systems still supply many subsistence needs on the Pacific islands, but subsistence agriculture has been declining in many areas of the Pacific, and has not been a significant activity on the Caribbean islands in this century.

Semicommercial and/or intensive commercial agriculture (on smallholder or larger scales) can play a significant role in the islands' economic development and progress toward greater self-sufficiency. Development of agriculture or forestry on any scale must, however, be sustainable and commercial operations will require considerable expertise and probably importation of new technologies. Developmental research also may be required. Subsistence systems, where they exist, can be protected and fostered and/or made more productive and de-

Photo credit: C. Hodges

Eighty percent of the American Samoan population provides or supplements family nutrition through subsistence agriculture.

veloped to semicommercial scale. Which strategy is selected as appropriate will depend on the geographic, environmental, economic, and social characteristics of individual islands.

Terrestrial resource sustainability will depend on several supportive technologies for minimizing soil erosion and crop losses and for improving the productivity of nutrient depleted soils. Revegetation programs (including reforestation efforts) could also be considered.

Pacific Agriculture

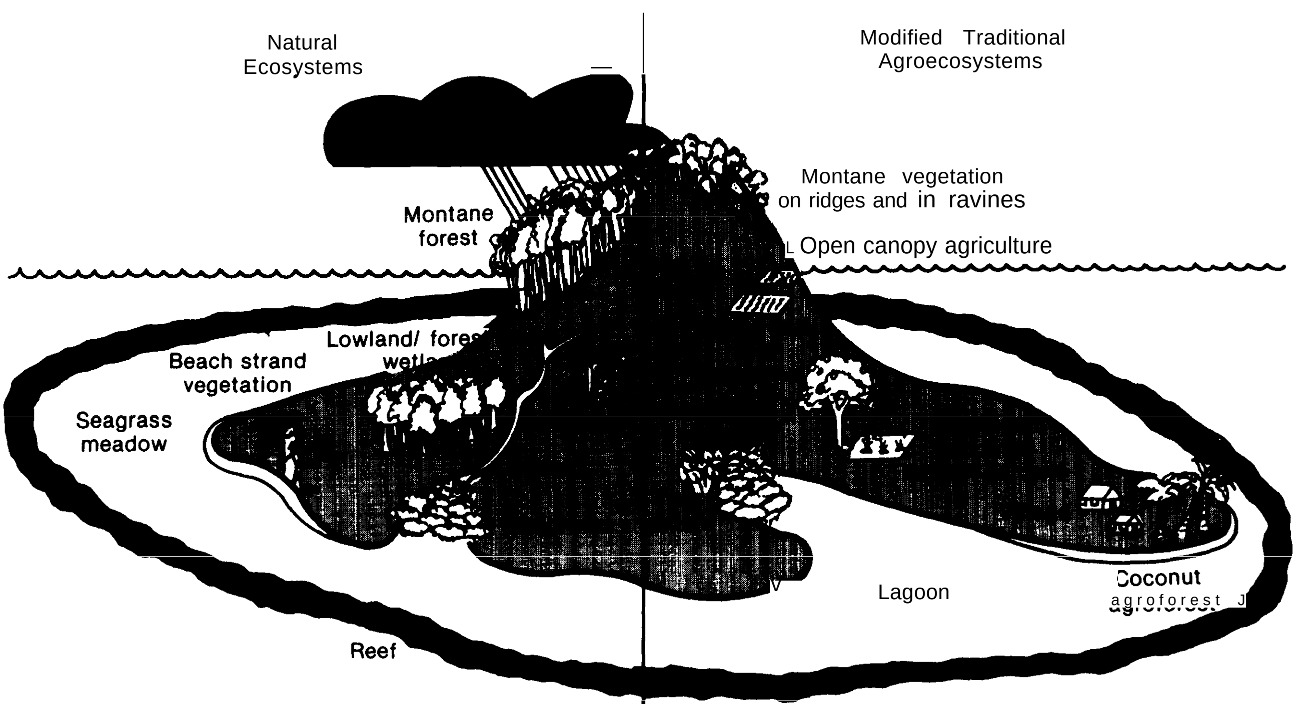
The maintenance of an environment meeting the needs of Pacific islanders involved a complex system of integrated resource management. Rather than rearrange the environment and expend great amounts of energy, people's activities were directed to the most effective use of microhabitat and natural phenomena. This "technology" can be classified as being "nature-intensive," and can be contrasted with what might be classified as "Asian labor-intensive agriculture" and "Western energy- and chemical-intensive agriculture. " Many traditional practices had conservation value resulting from technological limitations of natural materials, taboos and religious beliefs, territoriality, and stratified societies (23).

Traditional Agricuture[1]

The terrestrial activities of early inhabitants of Caroline and Samoan high islands, whether by design, necessity or both, seem to have modified the vegetation of the freshwater runoff filtering systems to meet human needs without altering their basic functions (figure 6-l). For example, swamp forests and low areas inland of mangroves were converted to taro patches which maintained their function as silt traps. Traditional agriculture activities further inland under conditions of low population pressure probably also produced minimal increases in

1 A review of traditional Micronesia high island practices **currently is underway at the University of Guam Water and Energy Resources Institute** (45).

Figure 6=1.—Traditionai Agriculture on a Typicai Micronesia High Voicanic island



SOURCE: Office of Technology Assessment, 1987.

soil erosion *(24).* Atoll agricultural practices were developed to protect crops from salt spray and to place them in proximity to the freshwater lens.

Traditional agriculture systems still can be found throughout the Pacific territories, although some areas have developed these to a greater extent than others. Common systems are:

- culture of wetland tare,
- atoll pit taro culture,
- mixed "tree gardening, "
- intermittent tree gardening,
- "lanchos" and backyard gardens, and
- traditional open canopy culture.

The tree gardens and taro patch systems offer stability and the intermittent gardens offer variety, resilience, and a means of adapting to each year's weather conditions.

Taro Patch Systems.—Species and varieties of food plants in the family Araceae, generally thought of as "tare," can be grown in wet or relatively dry situations. The latter are dealt with in the section on mixed gardening. Culture of wetland taro generally involves preparation of taro patches and management of water and is considered here as a distinct system.

Sites chosen for taro patches are mostly marshy lowland areas such as exist in swamp forests just inland of mangroves. These are deepened as needed and water is generally directed to flow through the patch. *Cyrtosperma* taro is more shade tolerant than *Colocasia* ("true tare"), and is thus more compatible with tree culture, and is an integral part of the agroforestry system of Yap. Taro patches are generally managed on an individual or family basis, the individual taro patch having been handed down from one generation to the next. Where taro patch habitat is extensive, the area is subdivided into separately tended subplots (22).

Palau appears to have the most highly developed cultural methods for *Colocasia* tare. There, the development of a taro patch involves the clearing of a suitable area, in many or perhaps most instances, the site of a previously worked patch. The area may be drained and soil is dug up and leaves, twigs, seagrasses, and other locally available forms of "green manure" are laid down and covered with soil. The patch is then thoroughly mixed and "cultured" to obtain a nutrient-rich muck of desired consistency. planting material consists of small corms or the tops of corms which have previously been harvested. These are planted in depressions and soil is mounded about developing corms to encourage large growth.

A considerable body of expertise exists involving the choice of green manures; choice of cultivar suitable for the site and intended use; management of water; and planting and tending the plant in order to obtain the desired shape, size, and consistency of the corm. Palauan taro patches are divided into sections in which the intensity of management is related to the end product: a fairly intensively worked area to provide for a families' caloric needs, a section with optimal conditions for producing especially high-quality corms for special people or occasions, and sections which are worked less intensively for reserve supplies *(107).*

Colocasia is harvested from 6 months to a year after it is planted depending on the variety and other conditions. The harvested product will not keep long, so only as much as can be consumed is harvested. A continuous supply is provided by successive plantings throughout the year. Once a *Colocasia* patch has been established, it is not necessary to repeat the process of moving soil and adding large amounts of green manure unless the quality of the growing media declines.

Culture of *Cyrtosperma chamissonis* is less labor-intensive than that of *Colocasia* and seems to rely more on the natural transport of nutrients in water directed through the taro patch. Green manure is not commonly added, and cultural methods involve the periodic removal of fallen vegetative material and debris in order to maintain the flow of water through the system. Replanting of *Cyrtosperma* is done at the same time as harvesting, and there is no hiatus required to recondition and replant the patch.

Atoll Pit Taro Culture.–Atoll soils are largely made up of sand and silt-sized particles of limestone and are typically low in organic carbon, nitrogen, and potassium. The soil has a low water-holding capacity because of its coarse texture, and the activity of soil microorganisms is limited *(102)*.

Cultivation of giant taro *(Cyrtosperma chamissonis)* on atolls involves excavating pits down to the level of the freshwater lens, commonly several feet, inserting a bottomless basket made of woven twigs, and filling it with mud mixed with leaves and other organic matter. Then cuttings of giant taro are planted in the muddy substrate in the basket *(41,148)*. Fertilizers are derived from composted leaves, coconut fronds and husks, manures, dried starfish or shark, or rotted sea cucumber *(22,102)*. Thus, taro pit culture is effectively similar to container agriculture, wherein the water and soil management efforts are concentrated in a small area.

Placing the taro plants in pits allows their roots closer access to freshwater and provides some protection from salt spray. Bananas may be planted on the margins of taro pits to take advantage of the higher organic content in nearby soils *(102)*, further protecting taro plants from sea spray.

Tree Gardens.—One special form of Micronesia agriculture is the tree garden, found throughout the high islands of Micronesia, and containing a high proportion of food producing species. In their simplest form, such gardens consist of a mix of coconut (Cocos *nucifera)* and breadfruit *(Artocarpus* spp.) with occasional other trees. Such areas are extensive in Truk.

More complex systems developed on other high islands in the Pacific. Tree gardens on Yap involve about 50 tree species, including betel nut *(Areca catechu)*, a wide variety of bananas Musa spp.), mangoes *(Mangifera indica)*, many varieties of *Citrus* spp., cacao *(Theobroma cacao)*, papayas (Carica papaya), guava *(Psidium guajava)*, and other food trees mixed with timber and wild tree species, and with an understory of shrubs and herbs useful for food, fiber, medicine, condiments, ornamentation, etc. (22). Animals maintained in Yapese village tree gardens include penned or tethered pigs and chickens and feral chickens in the bush. Fruit bats may forage in these areas at night.

Within the crop and tree species that have long been cultivated by Yapese, there are numerous locally recognized varieties. There are, for example, 21 names for coconut varieties, 28 names for breadfruit, and 37 names for varieties of bananas. Such tree gardens represent a considerable collection of genetic diversity.

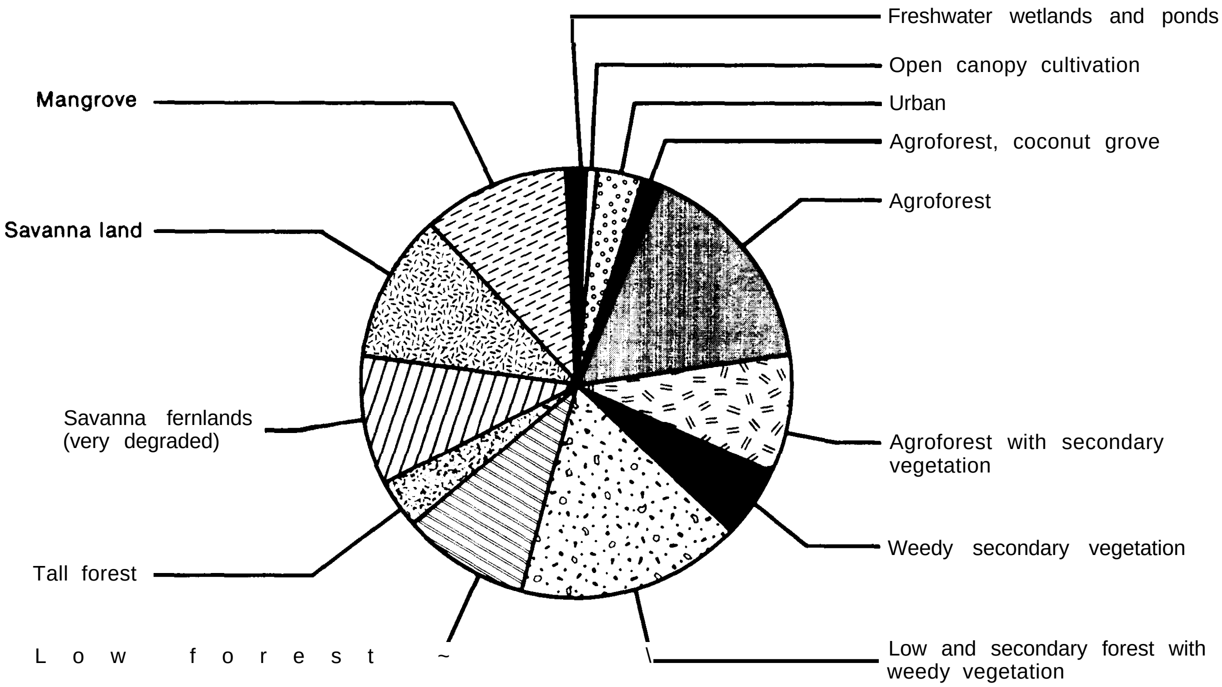
Unlike temperate seasonal agriculture, traditional tree gardens are a permanent fixture and take years to develop. Existing natural vegetation is gradually manipulated into agroforest *(22,94)*. The likely process on Yap was the planting of food trees and other useful trees about homesteads, and in the drained areas created by the excavation of taro patches and construction of paths between homes and villages. Backyard and pathside tree gardens became confluent and today make up about 27 percent of Yap's vegetation (figure *6-2)*.

The objective of traditional tree gardening systems is to achieve a permanent, long-term, stable agroforestry system, primarily on poorer/marginal lands. Tree gardening can be considered a long-term investment, taking up to a lifetime to complete, with large initial labor and energy inputs for planting and maintenance. Once a stable-state tree garden system is established, little labor and energy are expended for activities other than harvesting (99).

Tree gardens recycle nutrients through leaf falls. They are maintained largely by the pruning activities of their owners, who select for desired trees by cutting or girdling those trees that are not desired. Many of the trees propagate themselves by root growth (as with breadfruit), or seed. Fruit bats aid seed dispersal in some cases. People preserve certain volunteer species as well as planting other desired varieties and species.

Intermittent Gardens.—Areas around and generally inland of villages are used for gardens of yams and other crops generally grown in mixed, multilayered culture and alternated with a fallow period in which secondary forest growth develops. Mixed culture of yams and other food crops is practiced on most high Pacific islands, especially on Pohnpei where culture of especially large or old yams can pro-

Figure 6-2.—Main Categories of Land Use and Vegetation on Yap

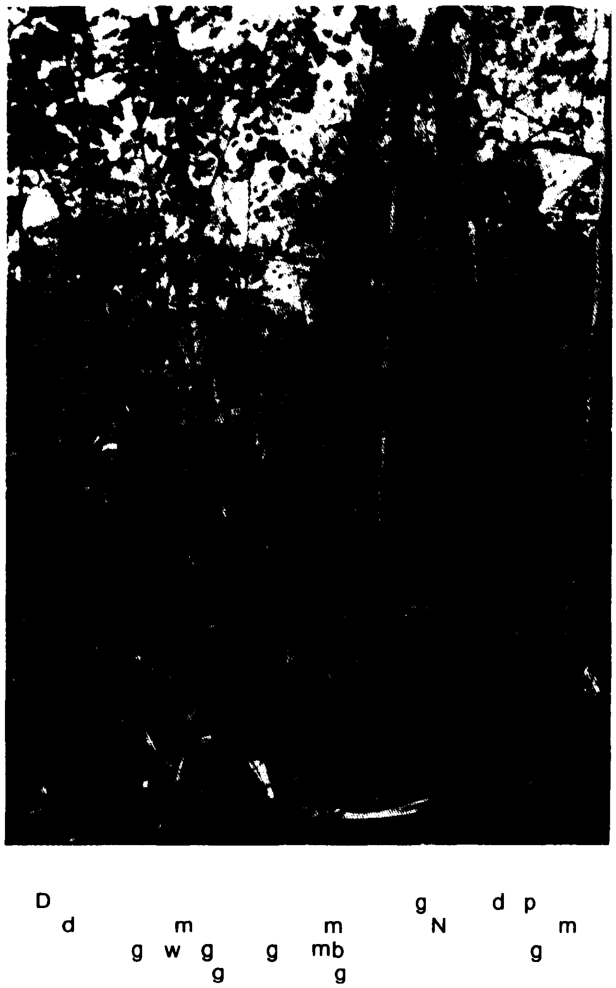


SOURCE: M.C.V. Falanruw, "Traditional Agriculture and Resource Management Systems in the High Islands of Micronesia," OTA commissioned paper, 1986.

vide the grower social status. Four general types of areas are typical:

1. *Early second-growth forest fallow:* Areas on the outskirts of villages which have become covered with a characteristic set of small second-growth trees and often with an understory of ferns. Such areas are generally the site of a previous garden (and are indicated as weedy, replacement vegetation in figure *6-2).*
2. *Advanced second-growth forest fallow:* Areas on the outskirts of villages which are covered with secondary forest consisting of a characteristic set of tree species (indicated as low and secondary forest with weedy vegetation in figure *6-2).*
3. *Bamboo gardens:* Areas on the outskirts of villages which are covered with a mix of secondary vegetation and two species of bamboo. These areas resulted from the planting of bamboo in earlier days when the large and small bamboo were needed in house construction, and the large bamboo was used to build rafts, the most common type of water transport. Now that rafts are used less, other building materials are available, and the style of houses built by young couples is less traditional, areas of bamboo are often burned to be used as gardens.
4. *Special-purpose yam gardens:* Areas within villages where neat raised beds are constructed and bamboo poles brought in to build a series of yam trellises. These areas generally are the work of a group of women growing yams to present on a special occasion. Such gardens are limited in size, more labor-intensive, and do not generally have a variety of other crops planted in the same site.

Sites chosen for intermittent gardens are relatively well-drained areas of secondary vegetation (often the sites of previous gardens) *within* the land available to the family or borrowed for such use. The soil in areas of secondary forest are richest and there is a nearby supply of poles for trellises, so such areas are preferred.



The first step in making a garden is to open a "skylight" in the canopy by clearing herbaceous vegetation. This is piled about trees and burned. Sometimes trees may be girdled before being burned. Standing logs and surrounding vegetation commonly are left to shade young plants, or the canopy may be removed gradually so that young plantings are shaded the first part of their lives.

The major crop grown in such gardens are yams of the genus *Dioscorea*. The tops of tubers which have been previously harvested, as well as small whole yams are planted. A border of fallen logs often is formed about the yam plantings and mulch is piled within this area. Trellises of poles, often of bamboo, provide pathways for yam vines to grow up into the sunlight and produce large tubers. In areas rich in bamboo, trellises may consist of tall "teepees" of three or more poles tied together at the top. In Pohnpei, vines are trained to climb trees along a string, often made of *Hibiscus* bark, which is tied to a stone and thrown up to the first branches of the tree. When the yam vines reach the first branches, additional strings may lead the vine to higher branches. The tree may be injured or killed so that it drops part or all of its leaves as the vine covers the tree. This new vegetation forms a canopy similar to that furnished previously by the tree.

After yams are planted in the choicest microhabitat, the rest of the garden area is filled in with a mix of other crops, generally in a predictable succession: pumpkins *(Cucurbita* spp.) and wax gourds *(Benicasa hispida)* which grow fast in the ash fertilizer and form a protective layer of vegetation over the soil. These often die back by the time the yams and other crops have made their major vegetative growth. Sweet potato vines may be planted in raised mounds although they are more often planted in open areas.

Pineapples and sugarcane maybe planted in suitable areas. Other crops include certain taro species, bush spinach *(Abelmoschus manihot),* and winged beans *(Psophocarpus tetragonolobus).* Banana may be planted and weeds that are cleared from the garden piled about the trees as mulch. Papaya, passionfruit, and luffa vines may grow voluntarily or from old plantings in the area. Sometimes a few fruit trees from nearby agroforests may be present.

These crops grow rapidly so that a multistoried canopy of leaves is formed by the time the rainy season starts. Intermediate crops are harvested as they mature and yams are harvested at the end of the growing season. The garden may then be replanted if the soil remains fertile, otherwise it is only sporadically tended to harvest tree crops and other long-term crops, and gradually is abandoned. Gardens are seldom used for more than 3 consecutive years.

After gardens are abandoned, they go through a series of successional stages as the wild canopy reforms. They are invaded first by herbaceous weeds followed by woody species. Seed dispersal commonly is aided by birds and fruit bats (21).

"Lanchos" and Backyard Gardens.—Traditional agricultural activities in the Marianas are not well documented. However, wild food plants found in the Marianas indicate that the original inhabitants ate the food found on other high islands of Micronesia (22). The neotraditional agriculture system of the Marianas was the development of "lanchos" or "ranches" where food was grown by people who resided in village areas. Lanchos were generally located in rural wooded areas and consisted of a simply built cooking and sleeping house surrounded by food trees, chickens, pigs, and gardens.

Although many lanchos still are in use on Guam (84], they are harder to find in the Marianas where population increases, division of family lands, economic development, and food stamp programs result in competitive uses for land and decrease the need to raise one's own food. Fresh local produce remains important for fiestas, however, and is reflected in poaching of deer and fruit bats and importation of traditional foods from other islands (22).

Traditional Open Canopy Agriculture.—Crops grown in openland areas include sweet potatoes, cassava, and vegetables. Garden beds are reconditioned by clearing or burning unwanted vegetation from the site. Debris is piled on the garden, sometimes with additional mulch such as seagrass. Ditches are dug or deepened around the garden bed and the soil piled on top of the mulch. The result is drainage of the garden, suppression of weeds and development of a "sandwich" of soil, mulch, soil. Cuttings may be planted directly or in raised rows (22).

Commercial Agriculture Developmemt

After western contact, traditional agricultural technologies were modified to varying degrees by voluntary incorporation of methods or implements introduced by settlers, missionaries, and colonial governments. Few wholly subsistence farmers remain.

In Micronesia, numerous attempts have been made to develop commercial agriculture, beginning with the development of the copra trade by the Germans in the late 19th century. Coconut palms were planted on many islands and villagers were organized to process dried coconut meat (copra) for export to Germany (86).

The Japanese expanded commercial agriculture through the cultivation of sugarcane in the Northern Marianas; cassava, sweet potato, coffee, and other crops in Pohnpei; and various other commercial farming and related industries throughout Micronesia. Agricultural colonies were established, generally with imported Asian workers. The Japanese provided support for agriculture through provision of materials, technical advice and assistance, selection of technologies that maximized use of local resources, and a comprehensive marketing program. Both the German and Japanese efforts primarily served the colonial power and natives were used mainly for unskilled labor.

With the advent of the U.S. administration at the end of World War II, the Japanese-supported commercial agriculture development—which had led Micronesia to become a self-supporting part of the Japanese Empire—quickly disappeared. Initially, exploitation of existing island resources was a very low priority with the new U.S. administration; securing military interest was a primary goal. Without expatriate managers, shipping services and markets, most commercial agriculture was soon abandoned and the islands again returned to subsistence food production (94).

Commercial agriculture development in American Samoa, which became a U.S. possession in 1900, has progressed even less than in Micronesia. Although a small copra industry was developed, most agriculture activity is still at a subsistence level (94).

Within the last 30 years, there have been renewed efforts to develop commercial agriculture, but progress has been slow and results disappointing. Several crops have been designated for commercial development in Micronesia, notably cacao in the late 1950s and early 1960s, ramie in Palau, and banana on some high islands. More recently, efforts have been directed to developing a black pepper industry on Pohnpei and introducing vegetables throughout Micronesia *(99,103,105).* Efforts in American Samoa have been mainly directed at increasing local food production with some effort made to introduce commercial vegetable production. All have been introduced as small-scale projects for limited-resource farmers and many have been unsuccessful for reasons including: *1)* lack of markets or low market prices, 2) technologies dependent on imported inputs, 3) lack of management skills among farmers, 4) diseases and pests, and 5) a general lack of commitment by farmers and U.S. and local governments *(94).*

The most persistent efforts of the Pacific island government Departments of Agriculture, at least during American Administration, seems to have been the encouragement of open canopy vegetable gardens involving crops such as Chinese cabbage, green peppers, tomatoes, and corn, and introduction of western techniques of clean-field gardening using fertilizers, pesticides, etc. Several farmers successfully operate enterprises on Guam and in the Commonwealth of the Northern Mariana Islands (CNMI) and the numbers are increasing as farmers become more adept at cultivation practices and techniques *(84).* However, many attempts have been unsuccessful due to high ratio of input cost to output value; soil degradation; and invasion of noxious weeds, such as the spiny *Mimosa invisa*, which are difficult to clear. Nonetheless, outside advisors continue to recommend such technology and outside funding continues to be made available for such efforts (22).

The incidence of soil erosion is probably greatest in clean-cultivated vegetable gardens where the soil must be made friable and vegetative growth does not provide adequate protection against heavy rainfall or invasion by weeds. An increasing number of pests hinder sweet potato culture, and the repeated burning, depletion of soil nutrients, and changes in soil texture associated with cassava culture results in soil degradation (22).

The environmental impact of the multilayered mixed gardens varies with the extensiveness and intensity of burning. Today, more forest and secondary vegetation is burned than is used. Part of this is due to careless gardeners and part to arson. There appears to be little concern for controlling fires that have gotten out of hand, and local fire departments tend to respond only when residences or other infrastructure are threatened (22).

The expected result from too many attempts at open canopy gardening, too frequent burning of garden lands with too short fallow periods is a decrease in forest fallow areas, use of preferred sites to exhaustion and degradation of the soil. The end result of prolonged degradation of soils seems to be swordgrass savannas or *Gleichenia* fernlands. On Yap, extensive areas of degraded soil bear the sign of too-frequent burning and over-intensive use, and the island's genetic heritage of wild endemic species is small compared to surrounding islands (22).

Current Status of Agriculture

The diets of Pacific Islanders, in general, consist mainly of starchy foods, probably reflecting the kinds of crops which have been adapted to the local environments. Principal commodities produced in the U.S.-affiliated Pacific islands are listed in table *6-1*. On most islands, tare, coconut, banana, and breadfruit are grown in large quantities, primarily for home consumption. In American Samoa and the Compact States, the coconut is used for food, drink, and for making tools and utensils important in the household.

In areas such as Guam and CNMI, where western and Japanese influence has been greatest, meat and vegetables have become more important parts of the diet. Pork and chicken are popular throughout the Pacific Islands, and are raised mainly for home consumption. Pigs and chickens are raised in most rural areas *(108).* In most of the territories eggs are produced in small volume for the market, but per capita consumption is small compared with Hawaii and

Table 6-1.—Principal Crop and Livestock Commodities in the U. S.-Affiliated Pacific Islands

	Commodity	
Islands	Crop	Livestock
American Samoa	Banana, breadfruit, coconut, taro	Chicken, eggs, pork
Marshall Islands	Banana, breadfruit, coconut, pandanus	
Federated States of Micronesia	Banana, black pepper, breadfruit, cassava, citrus, coconut, mango, pandanus, papaya, sweet potato, taro, yam	Eggs, pork
Northern Marianas	Avocado, banana, breadfruit, cassava, cucumber, mango, other melons, papaya, sweet potato, tare, yam	Beef, eggs, milk, pork
Guam	Avocado, banana, breadfruit, cassava, chinese cabbage, cucumber, eggplant, green beans, head cabbage, melons, papaya, sweet potato, tare, tomato, watermelon, yam	Chicken, eggs, pork

SOURCE: R. Lucas, "Role of Smallholders in Agricultural Development in the U. S.-Affiliated Islands," OTA commissioned paper, 1986.

continental U.S. consumption. Backyard gardening in urban as well as rural areas is a popular means to supplement the diet and income of wage earners.

No shortage exists of people in Micronesia, especially young people, to form a labor pool. It is likely that the ratio of children to adults has never been as high as today. However, it is difficult for mothers of young children to care for their babies and do the strenuous work of gardening or gathering. With considerable time now spent in school, where traditional agriculture is not taught, and with motherhood coming at an early age, young women sometimes do not learn and experience all that is needed to be effective gardeners. A number of young women work in town, and leave small children with relatives, thus reducing the available work force of experienced food producers (22).

Caribbean Agriculture

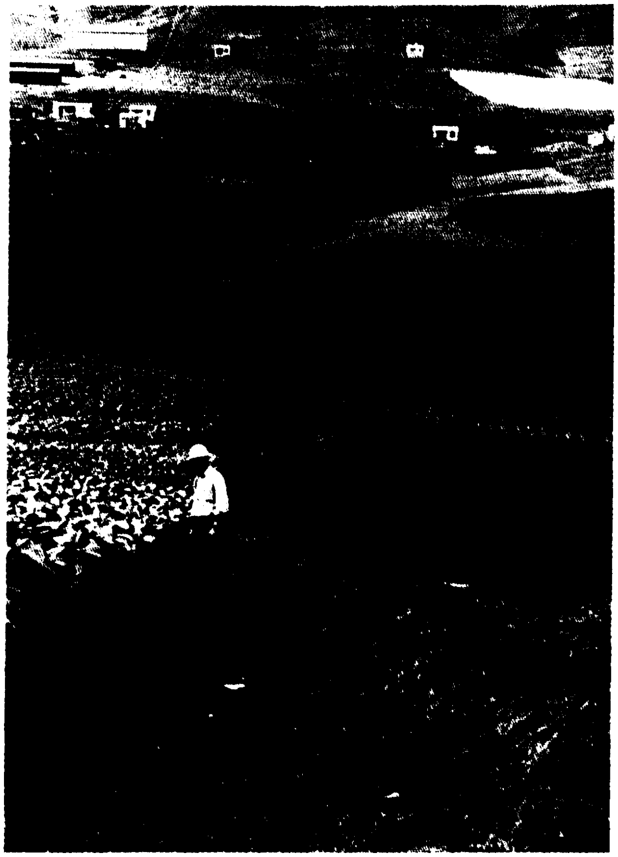
Because of diverse factors, there is relatively little heritage of traditional, subsistence agriculture in the U.S. Caribbean. In Puerto Rico, traditional shifting agriculture was adopted by subsistence farmers of European descent and later by those of African extraction. This subsistence sector continued into the early 20th century, but little remains today. The Virgin Islands were unpopulated at the time of colonization, thus there was no tradition of indigenous agriculture passed onto later inhabitants as occurred in Puerto Rico *(116).* In addition, these areas experienced an extended period of agricultural production for export to colonial powers, continuing well into this century.

Puerto Rico

Early in Puerto Rico's nearly 400-year history of colonization, the forests were cut and up to 90 percent of the plains and mountains were tilled, largely for sugarcane, coffee, tobacco (131) and, to a lesser extent, for bay trees *(Pimenta racemosa) (11).* The island was no longer self-sufficient in wood and paper products as early as *1830 (131).*

Even **50** years ago, Puerto Rico had an agricultural economy based primarily on sugarcane and, to a lesser extent, on coffee, tobacco, and cattle. With the notable exceptions of rice, beans, and codfish (dietary staples), most food was produced locally. Heavy hillside soil erosion severely hindered tobacco cultivation and contributed to reduction in already economically stressed sugar operations. The sediment laden runoff silted water supply facilities; seven major reservoirs lost a total of *32,500* acre-feet of storage capacity and two were totally filled and had become grazing areas (131).

Hillside tobacco and sugar land was abandoned as the profit margin decreased. The land returned to scrub brush and tree cover having little economic value. Sugarcane cultivation on flat coastal lands continued. Substantial reduction in damage to land and water resources has occurred over the last *25* years primarily be-



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cause of natural revegetation of abandoned croplands, and aided by some adoption of conservation practices such as strip and contour cropping, drainage, grazing and brush management, and spring development (131).

Harvested land in Puerto Rico declined from 724,000 acres to 283,851 acres between 1959 and 1978 (157). Abandoned farms commonly belong to persons over 50 years of age who may farm part-time, but who derive much of their income from sources outside farming. The causes of abandonment include lack of working capital, advanced age of the owner, or a preferred course of income outside the farm (10). Economic and sociological studies (8,31, 64) have shown that family-sized farms are rarely profitable due to their limited size; steep, unproductive soils; and lack of credit, entrepreneurial abilities, and technical assistance with production and marketing. Sometimes beef cattle are raised on grass-covered abandoned lands.

In 1950, agriculture provided 215,000 jobs (36 percent of total employment) and contributed 18 percent of the commonwealth product. There are now 40,000 jobs in agriculture, which accounts for 5 percent of the commonwealth product. Production at the farm level is valued at about $580 million with a retail value of about $1.2 billion. Sugarcane production has fallen 90 percent since 1952, and tobacco production has almost disappeared. Coffee producers still provide for three-fourths of local consumption, but they are protected from competition with imported coffee by locally set tariffs (143).

Puerto Rican diets also have changed significantly in recent decades. Despite declining per capita consumption of starchy vegetables, the total amount of food consumed per capita has increased (131). Production of milk, eggs, poultry, and pork has more than doubled since 1952 (table 6-2) (89,90,143). Meat and dairy products now comprise 60 percent of the value of farm output in Puerto Rico. Approximately 600,000 acres are used for pasture, however, approximately 500,000 tons of feed for cattle, pigs, and poultry are imported yearly, mostly from the U.S. mainland; none is produced locally (143).

The Puerto Rican Government has instituted a number of measures to increase and improve local agriculture. Farmers are exempt from 90 percent of local income taxes. Land taxes are low and land used for intensive agricultural production is exempt. Agricultural land also is exempt from inheritance taxes (143). Of the approximately 1,500 college-trained agriculture specialists on the island, 800 are employed by the government in agencies related to agriculture.

The Puerto Rican Government also has made a number of costly and largely unsuccessful efforts to develop modern, large-scale farming in several parts of the island. A local rice industry was developed on government lands on

Table 6-2.—Trends in Production of Selected Commodities in Puerto Rico

Commodity	Product ion 1951-52 (thousands)	Production 1981-82 (thousands)	Consumption[a] 1981-82 (thousands)	Imports (thousands)
Sugar (tons)	1,360	103	140	37
Tobacco (lbs.)	61,949	3,527	—	—
Coffee (lbs.)	52,249	55,115	85,979	30,864
Fresh milk (qts)	48,305	395,318	401,660	6,342[b]
Beef (lbs)	24,700	38,000	114,000	76,000[c]
Pork (lbs)	18,800	40,000	113,000	73,000[d]
Poultry (lbs).	12,600	52,500	195,000	142,000
Eggs (doz)	9,500	21,900	39,400	17,500
Pineapple (tons)	22	42	3	—
Plantains (thousands).	170	330	330	—
Bananas (thousands)	1,120	720	720	—
Tanier (lbs)	95,239	52,910	91,491	38,581
Sweet potatoes (lbs)	61,729	46,297	70,547	22,046
Yams (lbs)	56,438	70,768	70,768	287
Oranges (thousands)	144	162	192	3 1[e]
Grapefruit (thousands)	16	7	9	2
Citron (lbs.)	16,094	19,621	—	—
Pumpkins (lbs)	40,124	100,750	100,750	—
Tomatoes (lbs)	39,683	14,991	77,822	62,831
Pepper (lbs)	17,416	17,637	30,203	13,228
Cabbage (lbs)	14,550	17,637	37,478	23,369
Pigeon peas (lbs)	25,573	24,251	27,558	3,307
Taro (lbs)	25,353	16,535	16,535	—
Cassava (lbs).	28,660	13,228	18,739	5,523
Potatoes (lbs)	—	—	291,669	291,669
Rice (lbs)	—	22,046	683,426	661,380
Beans (lbs)	—	1,764	97,002	94,798
Onions (lbs).	—	—	78,704	81,570
Corn (lbs.). ..,...	—	—	992,070	992,070
Grapes (lbs).	—	—	5,100	5,100
Garlic (lbs)	—	—	3,600	3,600
Cocoa (lbs)	—	—	—	I0,000[f]

[a]Exports from Puerto Rico to the USVI and to others account for some of the discrepancies between imports, local production and consumption
[b]The equivalent of about 158,550,000 quarts are imported in dry or condensed form.
[c]28,000,000 pounds from the U.S. and 48,000,000 pounds from foreign countries.
[d]Plus 28,000,000 pounds of ham.
[e]Plus 4,000,000 gallons of concentrate,
[f]Plus 15,000,000 pounds of chocolate candies,

SOURCE: Vicente-Chandler J., "Assessment of Agricultural Production Technologies for U.S. Caribbean islands;" OTA Commissioned paper 1988.

the north coast in 1978. A rice mill was constructed and the lands were precision-leveled at considerable cost in time and money (143). However, the rice project has not become self sustaining.

Seven years ago, the Government of Puerto Rico started a modern vegetable industry on about 5,000 acres on the south coast by leasing lands and providing credit and facilities to two large Israeli companies and 13 local farmers. Approximately 2,500 acres now have drip irrigation systems and two packing plants were constructed. Crops were grown for both local and export markets with some success. However, in 1986 one project (April-Agro) reportedly was foreclosed by the Puerto Rican Government due to nonpayment of a large government loan although some of its activities are continued. The remaining operation—ISPRAC—continues operation.

Today, Puerto Rico annually imports about 1.2 billion dollars' worth of food (with a retail value of $1.8 billion), and about 400 million dollars' worth of wood products. About 29,840 Puerto Rican farms comprise a total of l,259,700 acres (135). Several large processors of agricultural products exist in Puerto Rico but, with few exceptions, they depend almost exclusively on imported materials and are not interested in processing small periodic agricultural surpluses (143).

Agriculture at present is generally characterized by low yields, high production costs, older farmers (averaging 55 years of age with a fifth grade education), and inefficient marketing systems. Attitudes are generally negative toward farming on the part of technicians, farmers, leaders, and the general public (143).

Young, well-trained, and motivated farmers are scarce in Puerto Rico, probably due to the way agriculture developed on the island. Sugarcane, coffee, and cattle plantations were developed with cheap labor; landholders often delegated responsibilities to poorly trained managers. As the island's economy boomed, many landholders preferred land speculation to learning new techniques and investing in agriculture. Their offspring generally entered other professions; higher wages are paid in manufacturing, tourism, and construction. Children of subsistence farmers went to work elsewhere or migrated to the U.S. mainland. Consequently, agricultural work is considered of low status.

U.S. Virgin Islands

Early colonial land modification in the U.S. Virgin Islands (USVI) included clearing of forests both for the establishment of export crop plantations and for their commercially valuable timber species. Early in this century, St. Thomas and St. Croix were severely deforested and consisted largely of secondary scrub growth characterized by small woody shrubs. The scrub-covered land consisted of thin soil with many rock outcropping. The removal of timber species and subsequent burning damaged the soil further reducing its fertility.

Historically, the majority of desirable land has not been available for small-scale subsistence agriculture. Initially, the majority of the highest quality land was held in large plantations and later, with the emergence of the tourism industry, land speculation and increased real estate prices has made much of the land inaccessible (117,143).

Since 1930 there have been sharp decreases in average farm size, harvested cropland, and agricultural employment and marked increases in the percentage of operators engaged in off-farm work. In the context of waning farm effort and acreage, there have been three major adjustments in the structure of USVI agriculture (80 percent of which is concentrated on St. Croix). First, an increase in mechanization and use of fertilizers; second, the noticeable shift away from cropping toward livestock; and third is a growing bimodal structure in which there are a large number of small farms alongside a few large commercial farms. Over the past century, USVI agriculture has adapted to resource encroachment basically by reducing farm effort and size, replacing capital-intensive inputs, and changing the composition of output from export crops to domestic fruits, nuts, and vegetables. Small-scale holdings largely are secondary income-earners. The largest commercial tracts now specialize in cattle and dairy products (56).

There have been some clear increases in the production of fruits, nuts, rootcrops, sheep, goats, and cattle since 1970, in part because of inflation of the prices of imported goods, slowdowns in tourism growth associated with economic recessions, and new farm efforts by Rastafarians and West Indian migrant workers who have become a permanent component of the local work force. These gains, however, occur in the long-term context of continuing reduction in farm scale and reduction in farm sales (56). Some landowners among the French agriculturists of St. Thomas have begun to sell land for residential development and many young people are looking to alternative livelihoods (117).

COMMON CONSTRAINTS TO AGRICULTURAL DEVELOPMENT IN U.S.-AFFILIATED ISLANDS

Major constraints to agricultural development which apply to all of the U.S.-affiliated islands generally fall into the following categories: biophysical, economic, social and cultural, and infrastructural, Major biophysical constraints are low soil fertility, limited or irregular water resources, and limited arable land of suitable soil types and level topography. Economic constraints include the small size of domestic markets for agricultural products, availability of high-paying government jobs and ready emigration opportunities, high cost of imported livestock feed and other inputs and, in tourism-dominated islands, the relatively low value of agricultural lands vis-a-vis nonrural residential or commercial real estate uses. The arduous nature and declining status of agricultural employment provide social constraints to agricultural development on some islands (13), and land tenure systems characterized by fragmented landholdings and clan influence over use rights can be primary cultural constraints to commercial development. Constraints posed by undeveloped infrastructure include lack of rural farm roads in high islands, scarcity of transportation from rural and outlying areas to central markets, and costly and irregular transportation to overseas markets (43).

The degree to which the above constraints apply to U.S.-affiliated islands varies but, nevertheless, is significant in all of them, For example, cultivable land is sparse on all islands. However, there is more arable land in Pohnpei and Palau relative to population than in the Marshalls, Truk, and American Samoa (table 6-3). In all of these areas, available arable land typically is owned in relatively small parcels, few areas have flat terrain, and contiguous soils of a given type (i.e., soils suitable for a given crop) are not common.

Some constraints tend to apply only to certain of the islands, for example, some islands have significant dry seasons while other islands receive evenly spread rainfall. In areas experiencing dry periods, lack of irrigation capabilities compounds limitations on farm productivity. The incidence of destructive typhoons and other tropical storms, although experienced by the majority of the U.S.-affiliated islands, tends to be much greater in the Marianas and western Caroline Islands (43).

Biophysical Constraints

Biological and physical (biophysical) considerations include availability of land and

Table 6-3.—Comparison of Population Density and Arable Land Acreages in the U.S.-Affiliated Pacific Islands

Islands	1984 Population[a]	Arable area (acres)[b]	Population density per arable acre
American Samoa	35,300	14,000	2.45
Guam	119,800	6,900[c]	16.41
CNMI	18,600	30,000[d]	0.65
Marshalls	34,900	n/a	n/a
FSM:			
Kosrae	6,300	17,900	0.35
Pohnpei	26,900	57,700	0.47
Truk	44,600	13,500	3.30
Yap	10,600	21,500	0.43
Palau	13,000	63,500	0.20

SOURCES:

[a]*Land Use Planning Report,* 13(46):365, November 25, 1985; U.S. Department of State, *1984 Trust Territory of the Pacific Islands,* report to the United Nations on administration of the Trust Territory of the Pacific Islands, 1985; R Lucas, "Role of Smallholders in Agricultural Development in the US.. Affiliated Islands," OTA commissioned paper, 1986

[b]Data derived from U.S. Department of Agriculture, Soil Conservation Service tysoil surveys of American Samoa (1984), Kosrae (1983), Ponape (1962), Truk (1983), Yap (1983), and Palau (1983), except where otherwise noted,

[c]Arable area is based on a soil survey of lands designated as potential agriculture lands (9,920 *acres) by the Guam Bureau* of Planning, and exclude a large portion of Guam controlled by the military, as well as lands designated for urban and conservation use

[d]CNMI arable acreage is based on surveys sponsored by the Trust Territory government and cover only Saipan and Tinian Most of the acreage would need irrigation to be considered good in terms of productivity for agriculture,

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water resources, soils, topography, and climate. In general, land is in short supply on all of the U.S.-affiliated islands, but particularly in the majority of the Pacific islands and the USVI. Additionally, the quality of soils, population density, land tenure, and topographic circumstances determine the degree to which land is a constraint (43).

Tropical soils in the territories have a number of limitations. Natural fertility is low compared to the nutrient needs of high-yielding crops. High rainfall in many areas leaches out basic plant nutrients and erodes the soil. Thus, conservation methods such as terracing, contouring, and conservation tillage practices become critically important. Maintaining forest canopy and vegetative cover stems erosion and maintains soil fertility by returning organic matter to the soil through the natural plant lifecycle. In clean-tilled crop production, soils are more susceptible to loss of fertility through erosion, leaching, and loss of organic matter. To overcome soil fertility problems associated with clean-tilled crop production, use of compost and organic fertilizers, return of crop residue to soil, application of lime, mulching, and crop rotation commonly are required. On coral atolls and single coral islands, soils are very porous, consisting mainly of sand and, while conducive to growing coconut palms, are not suited for most other crops (127).

Annual rainfall is generous in many areas, with a fairly even distribution during the year. However, in the northern Marshalls and, to a lesser extent in Yap, Truk, the Marianas, and the Caribbean, there is a more distinct dry season which can bring drought conditions harmful to crop production. Lack of water is the main physical factor limiting agriculture in the U.S. Virgin Islands; there, evapotranspiration greatly exceeds precipitation (143). The volume of water supplies, while limiting the potential growth of the arid agricultural sector of Puerto Rico, presently does not constrain production in other areas of the island (61).

Storms and torrential rainfall creates problems as well. Watersheds of high islands typically are comprised of steep valleys flanked by sharp ridges. Even if vegetated, flooding and landslides occur posing considerable hazards to agriculture and populations located in the coastal valleys. During the rainy season, cyclonic storms frequently occur in some areas. Atolls and low islands, as well as the coastline areas of high islands, frequently experience flooding and saltwater damage to crops caused by storms and storm surges (43).

The interiors of high volcanic and continental islands are mountainous; much of the land area consists of steep slopes that preclude cultivation of most crops other than tree crops. For example, almost all of the land on St. Thomas and St. John is very steep to strongly sloping, representing problems for agricultural pursuits. Many agricultural areas on these islands have been terraced or planted with fruit trees (143). Land improvement, such as grading of steep slopes, improvement of drainage and irrigation, is generally quite costly.

Social and Cultural Constraints

Social and cultural factors may provide opportunities or constraints to agriculture, depending on the development strategy pursued. Those that are commonly perceived to constrain commercial agricultural development include land tenure and clan value systems, acquired tastes for western foods, and attitudes towards farming as an occupation.

Traditional values of Micronesians and Samoans place great prestige on land and other resource use rights. Within the clan or extended family, the cultivation and gathering of crops such as tare, breadfruit, yams, and coconuts is determined by communal needs rather than by the economic return which could be obtained by marketing production. Decisions on land use are made by the clan or family head, and land use is an integral part of the social system. For example, slaughtering pigs for feasts or social gatherings involving the extended family is part of fulfilling social obligations. The high prestige value placed on land results in increasing fragmentation of parcels over time, as ownership is retained in families that have increased in size (46,47). Acquiring land for commercial use—where the products of the property are not to be used for subsistence and sharing—may be difficult or impossible (22). Alternatives, such as making landowners part-owners, eligible for dividends from earnings from development projects on their lands, may be required.

High social value placed on land is accompanied by clan system values which require the sharing of production with clan members. The sharing extends to individual wage earnings as well. These traditional values toward land and the sharing of wealth and income tend to inhibit individual initiative towards commercial farming. Reluctance to sell or lease land also makes it difficult to consolidate land into larger parcels to enable larger scale farm operations (43).

In areas such as Guam and the CNMI, leasing and selling land has become more prevalent, along with western economic values, as most households have become integrated into the wage economy (43). However, residents no longer have access to one-third of Guam's land, which is controlled by the U.S. military. Considerable amounts of food could be produced if areas suited for farming that are not actively used by the military are opened for short-term leases with rates comparable to those offered by the local government (113).

Land reform has long been a matter of great importance in the Caribbean. The 1940s "Land Law" of Puerto Rico successfully relocated squatters on small plots where they could build homes and cultivate small farms (143). Attempts at land redistribution in the USVI occurred in the 1930s with a "homesteading" program, but the program met with only limited success.

With large increases in public employment and wage income related to U.S. Government expenditures in the Pacific Islands, western consumption standards—particularly for convenience foods—have been increasingly adopted. Rice, flour, canned meat and fish, sugar, and beverages such as soda and beer are large import items. Prestige attached to western foods, convenience in preparation of processed foods, and lack of education on the nutritional value of fresh foods have all been contributing factors in the popularity of imported food. In addition, the influence of U.S. Department of Agriculture (USDA) school lunch and disaster relief food programs, which have distributed large amounts of surplus processed foods to the islands, have contributed to preferences for imported processed foods on most islands. Preferences for some imported foods lessen demand for locally grown crops, and have had a detrimental effect on nutritional status (109).

Farming as an occupation is generally held in low esteem by the younger generation in many of the islands. Availability of secure, high-paying government jobs with career advancement opportunities and fringe benefits (e.g., retirement pensions, low-interest housing loans, medical insurance), and education systems which emphasize white-collar occupations result in little interest by youth in agricultural occupations (43). Well-trained, young, motivated farmers are scarce in Puerto Rico and the USVI; many young people opt for more lucrative or more highly esteemed professions (61,143). In the CNMI, where young farmers consider agriculture a potentially profitable undertaking, alien laborers from the Philippines are hired at $150 per month (80).

Attitudes towards traditional agriculture systems and official and unofficial government policies range from benign approval to benign neglect. In the U.S. Pacific, it is commonly considered good to produce as much of one's food as possible, although in practice no specific programs are designed to help with traditional agriculture, perhaps because it is so much a part of Micronesia lifestyles that it is overlooked (22). Puerto Rico's attempt to encourage a small-farm sector through the establishment of family farms (1940s Land Law) largely was unsuccessful.

Economic Constraints

Small domestic markets, high wage structures, USDA food programs, and lack of appropriate technology are major economic constraints to an expanded agriculture (43). Insufficient economic resources also may seriously constrain sustainable development of renewable resources. They particularly affect research, public education, and project implementation (15).

While development of local food production and markets may be important to local food supply and nutrition, it is limited by the amount of local demand and competition with imported foodstuffs (94). Local markets can absorb relatively little local produce in the Freely Associated States (FAS) and American Samoa as most consumers also are producers; expatriate workers and urbanized locals make up the market on most islands. In some areas, a considerable demand for traditional crops exists, but problems with transport, spoilage, and inconvenience of preparation hinder their marketing (22).

Markets for locally supplied commodities in the U.S.-affiliated Pacific are situated in the capital areas. However, they generally account for a small part of total commodity sales. Inadequate marketing facilities contributes to small volume, but a more basic problem is the lack of steady supply by farmers committed to growing for the market on a regular basis, i.e., lack of commercial and semicommercial farmers, as opposed to subsistence growers (43). Generally, outlets consist of combination retail/wholesale/importer market operations.

Small market size is a major constraint inherent in island economies located at great distance from large population centers (e.g., Honolulu, Tokyo). Territory populations represent a small market demand for any given commodity; commercial farmers using modern technologies can produce all that can be sold on relatively few acres. For example, in Guam it has been estimated that with modern farming practices, including irrigation, only 226 acres would be required to supply almost 11 million pounds of fruits and vegetables (19 different commodities) per annum (14). In Guam, however, where many people buy a large percentage of their food, most prefer the convenience of imported produce and food products to local produce.

In addition, locally grown products also must compete on local markets with products imported from the United States and other developed countries with more efficient agricultural systems, and with imports from nearby developing countries that have lower labor costs. Imports in the USVI offer almost insurmountable competition since they are available in large quantities throughout the year and are generally of good quality although expensive (143). Puerto Rico is similarly constrained by competition from lower wage areas as well as mainland U.S. imports of commodities such as poultry, eggs, dairy products, and meats (98). In Puerto Rico, a tax on imported coffee serves to protect the local industry and increase the incentive for local production. Similar systems may be needed to support development of other agricultural enterprises faced with low-cost import competition (67).

Another disincentive to producing for the local market is the availability of USDA surplus food, which is free and available to many people through the extended family. In the CNMI and Guam, food stamp and school lunch programs distribute large quantities of food. For example, in Guam some 22,600 persons participated in the food stamp program in 1983, and received coupons worth $18 million in food purchasing power, The majority of the food obtained from markets with the food stamps is processed food imported from the United States.

Micronesians are focusing efforts on economic development, including agriculture. The only advice available for development of food and fiber production, however, refers to nonindigenous systems (22). Many recommended projects involve large capital outlays on the part of the farmer or the government, and require outside expertise, imported energy and chemicals, and technology. These systems commonly are suited to parcels of land larger than those generally available to individuals or groups in the islands. The experts, generally on short-term assignments, frequently leave before problems arise from droughts or storms, delay in arrival of inputs, changes in personnel, lack of markets, lack of cooperation, or vandalism, that effectively end the program (22).

Infrastructural Constraints

Constraints to development imposed by lack of infrastructure exist in varying degrees in all of the U.S.-affiliated islands. The main kinds of facility shortfalls are: farm roads, irrigation systems, water storage and distribution, power generation and distribution, transport facilities and service, and storage/refrigeration capacity (43),

In the high islands, such as Palau and Pohnpei, farm roads are needed to enable cultivation of areas which currently are underused. In the CNMI, Palau, Yap and the northern Marshalls, reservoirs, or other sources of water, and distribution systems are needed to increase crop yields (43). In the Virgin Islands, provision for water supply infrastructure is necessary for agricultural development (61).

Transportation infrastructure in the Caribbean islands generally is quite good, with well-developed roads and regular air and sea transportation to the United States and other Caribbean islands. In those Pacific territories with populations dispersed over a number of atolls and islands, however, inter-island surface transportation typically is inadequate to provide farmers with market access and farm inputs such as livestock feed and fertilizers.

In remote U.S. Pacific islands, unreliable shipping has caused shortages of agriculture supplies, forcing producers to ration imported products and to substitute local products for imported supplies, sometimes resulting in reduced production. Because advance orders tie up cash and inventory can be slow to move, some suppliers tend to be unwilling to purchase supplies in advance (80). A combination of the shortages and unwillingness to advance order may cause a "shortage mentality," which results in rationing of these agriculture supplies even when they are available.

Inter-island shipping services and associated harbor docking/storage facilities need to be upgraded to enable an expansion of agriculture in the U.S.-affiliated Pacific islands. Likewise, potential for intra-regional commodity exports and exports to Hawaii and Asian countries may not be realized without improved transportation services—particularly in the FAS and American Samoa. There is little or no regularly scheduled surface shipping between the FAS and Asian-Pacific cities outside Micronesia. The same situation exists in American Samoa (43).

Storage and refrigeration facilities are scarce in all Pacific areas, particularly in the FAS. These facilities are needed to facilitate development by providing for an increased and steady supply of domestic commodities and to improve quality (43).

OPPORTUNITIES FOR AGRICULTURE DEVELOPMENT

The constraints discussed above represent formidable obstacles to agriculture development, but potential opportunities exist for increased crop production. Opportunities available to enhance island economic development include: 1) import substitution, 2) potential for increased local production, and 3) potential for export development for at least a few high-value commodities (43).

Import Substitution

Food imports are substantial in every territory. For example, in American Samoa food imports averaged $18.6 million in the 1981-83 period (4). The CNMI imports more food per capita by value than anywhere else in the Pacific despite its relatively low population density (13); food valued at $23.2 million was imported in 1983 (12). Also in 1983, Federated States of Micronesia (FSM) food imports were $11.2 million (26), and in Palau, $3.4 million (140).

In the Marianas, the USVI, and Puerto Rico, a wide range of fruit and vegetables already are grown commercially (34,43). Although traditional local crops still are favored in the FAS, urban populations are consuming increasing amounts of nontraditional fresh fruits and vegetables. The non-Micronesian population in the urban centers account for part of this demand, but prestige attached to imported foods and greater awareness of nutritional benefits of fresh produce may also be contributing factors (43).

A large proportion of the fresh fruit and vegetable commodities which are imported could be produced on most high islands of the territories. Examples are pineapple, papaya, cucumber, eggplant, bell pepper, citrus, sweet corn, tomatoes, avocados, green onions, Chinese cabbage, and head cabbage in Pohnpei (47). The Soil Conservation Service (SCS) has determined on the basis of its soil surveys that most of these commodities also can be grown in Kosrae (128), Truk (127), Yap (128), Palau (129) and American Samoa (125).

Puerto Rico is self-sufficient in plantain, bananas, pumpkin, and tare, and at least 60 percent of products such as raw sugar, coffee, freshmilk, eggs, taniers (cocoyam taro), sweet potatoes, yams, oranges, and grapefruit are locally produced. Opportunities still exist to substitute some locally grown vegetables for currently imported produce (143), but those that can be imported cheaply from the mainland United States and that require large acreages of land are not good candidates for import substitution (78). The USVI is nearly self-sufficient in egg and milk production (56).

Increased Subsistence and Commercial Production

In addition to increased domestic production for import substitution, there is substantial scope for increasing subsistence and commercial agricultural production of traditional crops, as well as other crops which are not imported but could be grown locally if domestic demand could be developed.

Although semicommercial and commercial farming can be expected to become proportionately larger given a sustained agricultural development program, initially packages of practices for traditional crop and livestock commodities could be developed to raise subsistence productivity. With respect to commercial farming, modern technology already available in other tropical areas can be adapted to selected locally produced commodities.

Export Development

Large export markets potentially are accessible by island producers: primarily Japan for western Pacific islands and the U.S. mainland for U.S. Caribbean islands. In order to penetrate these markets, several hurdles must be overcome. Export marketing requirements include regular, significant volume shipments of high-quality products; prices competitive with similar products—locally produced and imported —in the export market; and, for fresh produce, pest- and disease-free products that can pass the commonly strict animal and plant quarantine regulation of importing countries. Depending on the product exported, reliable and cheap transportation may be a requirement.

Generally, successful export crops are characterized by high value per unit weight, superior quality, low production cost, and low cost and relative ease of transport. Pohnpei black pepper, which is characterized by these qualities, was able to penetrate the U.S. gourmet market (29). Ornamental plants, honeydew melons, and mangoes are exported successfully from Puerto Rico. Other high-value commodities which might be grown in the U.S. high islands include coffee, cacao, nuts, spices, and essential and perfume oils (94,126,127,128, 129,130).

Opportunities for intra-regional trade also are possible for certain commodities such as sweet corn, bananas, pineapple, papaya, and selected vegetables. Coordinated agricultural development planning among Pacific and Caribbean islands would enable some degree of specialization for areas with a comparative advantage for particular commodities (43).

AGRICULTURAL DEVELOPMENT STRATEGIES

Commercial agriculture development continues to be emphasized as desirable for the U.S.-affiliated islands. Goals of such development include increasing employment opportunities in the rural and outlying areas, stemming migration to over crowded urban centers, building the private sector through development of local renewable resources, increasing local food production, replacing imported food items and build self-reliance, and generating cash for the island economies (94).

A basic premise underlying commercial agricultural development is that, in every territory, the private sector must be made more productive to support standards of living to which residents have become accustomed. Further, that economic development options other than agriculture are sufficiently limited so that territorial governments cannot ignore agriculture's development potential. Since imports constitute the bulk of island consumption, for territories to improve economic self-sufficiency they must either produce the goods they consume locally or generate overseas earnings (through commodity or services exports) to pay for the imports. Given the currently large food imports in most of the territories, domestic agriculture can contribute to the ultimate goal of overall economic self-sufficiency by producing for import substitution or for export—in either case, agriculture would have to become increasingly commercialized (43).

However, in view of the pervasive nature and severity of the constraints to agricultural development, and the present levels of standards of living, consumption, and expectations, total self-sufficiency or even near self-sufficiency in domestic food production is unlikely on most islands. An alternative goal might be optimal use of lands best suited to crop production taking into account other land use requirements; large amounts of arable lands may not be farmed where other uses are deemed more socially important (43).

Characteristics of Sustainable Tropical Island Agriculture

Successful tropical island agricultural systems generally exhibit ecological characteristics which mimic and extend natural processes by providing for water and nutrient flow, and maintaining a canopy to protect and enhance soil quality at critical periods, especially during times of heavy rainfall. An agricultural system which incorporates a diversity of crop species and varieties strengthens the system's resilience to disruption from pests and disease outbreaks and, further, provides the farmer with a variety of products throughout the year even where erratic weather patterns exist. For such systems to be readily adopted, they may need to be based on traditionally used systems and should require minimal exotic nonrenewable inputs such as fossil fuel energy or derived chemicals (22), Sustainable agricultural systems commonly:

- mimic natural tropical systems;
- emphasize or incorporate perennial crops;
- emphasize optimization of components rather than maximization of yield;
- emphasize recycling of locally available nutrients;
- emphasize incremental changes from extant systems; and
- provide farmer and consumer security in areas prone to natural disasters.

Mimic Natural Tropical Systems

The major mechanism through which sustainable tropical agricultural systems mimic natural tropical systems is through maintaining a multistoried vegetative soil cover. The vegetation protects the soil from erosion and provides soil organic matter in the form of leaf fall and roots. The growth and recycling of organic matter is similar to that occurring in tropical forests. In agroecosystems, these benefits can be generated through polyculture systems, planting a polyculture—a diversity of plant species and varieties—can increase yields by reducing plant competition, by taking advantage of differences in microhabitat, by reducing the intensity of pest and disease infestations, and through beneficial plant interactions. Thus, sustainable tropical agriculture emphasizes managing biotic interactions within the agroecosystem rather than divorcing the agroecosystem from natural factors and replacing them with imported nonrenewable resources.

Monoculture. —The cultivation of a single crop on a unit of land has been the main commercial cropping technology introduced to the islands to date. Historically, colonial powers in the Pacific and the Caribbean have favored the monoculture approach (e.g., in the Pacific: the Germans with coconut plantations, the Japanese with sugarcane, rice, cassava, sweet potato, etc. and the Americans with cacao, rice, banana, ramie, black pepper; in the Caribbean: the Danes and Spaniards with sugarcane). Traditionally, however, very few cases of monoculture existed originally in local agriculture practices *(94).*

Benefits of monoculture are many and, thus, large agricultural systems have been built around this technology. The main advantage of monoculture is uniformity—in planting, fertilizing, cultivating, and harvest—thus favoring intensive use of inputs such as improved and hybrid cultivar varieties, chemical fertilizers and pesticides, and mechanization (94). This uniformity in product and harvest period also simplifies large-scale processing. Monoculture systems also are simpler to research and develop than polycultures, whose permutations can appear infinite.

These advantages do not translate easily to small-scale farming systems with limited available resources. Capital often is not available to invest in the improved inputs needed to sustain successful monoculture. Labor, needed for tillage, planting, and harvesting, which tend to be concentrated into peak periods, rarely is available to farmers who must depend mainly on family labor. The uniform harvest and greater yield requires adequate storage, processing, and marketing facilities which currently are lacking on some U.S.-affiliated islands. Monoculture also encourages the spread of pests and diseases in the absence of natural barriers found in more diverse ecosystems. Also, in monoculture, as in any cropping system that needs total land-clearing and regular tillage, erosion can be a serious problem, even when terraces and contour-farming are practiced.

All of these factors can add up to a generally unlikely and risky prospect for many island farmers. Few small-scale, limited-resource farmers, who must depend on their farm for their family's food, are willing to take such risks. Another factor, which planners and agriculturists tend to overlook, is that a small farmer, faced with decisions on how best to use his extremely limited land resource, is likely to avoid any technology that will entail tying up a large percentage of land to grow a single crop (94). Thus, monoculture are likely to be undertaken only when markets are guaranteed, when competition is restrained (e.g., if farmers agree to specialize on certain crops) or if crop harvests are staggered *(80).*

Monoculture does, however, hold some possibilities for further development in Micronesia, especially in those areas where landholdings are relatively large (e. g., on government leased lands). Ponape Agriculture and Trade School on Pohnpei has been running a 20-acre mechanized commercial farm for nearly 10 years based on monoculture of sweet potato, corn, cassava, banana, and beans (94). Farmers in Guam and the Northern Marianas also have developed successful vegetable monoculture systems. Each of these systems depends on excellent tillage and cultivation (generally mechanized), well-planned crop rotation schemes, and imported commercial fertilizer and pesticides. Also, markets in these areas are fairly well developed.

New methods of monoculture have been developed in Africa and the United States designed to reduce erosion and/or capital investment by replacing tillage with herbicides. Proponents of these systems claim that the dead mulch left after herbicide treatment helps keep soils cool, suppresses weed growth, encourages water retention and growth of soil building organisms, as well as reducing erosion to as little as 2 percent of that of clean-tilled fields (151). However, with the extremely high cost and irregular availability of herbicides imported into Micronesia, dangers of pesticide misuse and the general reluctance of farmers to practice monoculture technologies, it is unlikely that any of these systems will support commercial agriculture in Micronesia (94).

Polyculture.—Concurrent mixed cropping of two or more crops on a unit of land is the form of most traditional agriculture in the U.S.-affiliated islands. A common form of polyculture is intercropping, the planting of two or more crops together at the same time by row, strip, or in a seemingly random mixture. Another form is relay cropping, with a second crop being planted into the original crop before the latter's harvest. This allows growth of a second crop without tillage.

Agroforestry–a mixture of annual and woody perennial species, sometimes including animals —is the basis of traditional agriculture in the Pacific. Agroforestry systems depend on creation and maintenance of a multistoried, semipermanent stable system. The productivity of the system is based on the positive interactions between the plants (and between plants and animals) giving the farmer a continuous food supply over the long term (94).

Alley or avenue cropping is another form of agroforestry which consists of planting trees, usually a fast-growing, nitrogen-fixing legume species in rows, with annual crops planted in the alleys or avenues. The deep-rooted trees, which act as nutrient pumps and erosion barriers, are pruned at short intervals and the prunings are plowed into the alleys as green manure.

A complex form of polyculture is "Energy Integrated Farming" or "Biogenic Farming." These systems incorporate livestock production with algae and fish ponds, annual and tree crop production, and a biogas digester, the effluent of which is used as fertilizer and irrigation water (see ch. 8). These systems are highly energy efficient. Systems have been operational on an experimental level in the Northern Marianas and Yap, but have not been widely adopted on the U.S. Pacific islands (94). Such systems are in operation in Puerto Rico (2).

Polyculture systems offer a number of benefits, particularly important in the tropics, that are not available from monoculture systems. The mixture of crops and animals tends to discourage the spread of pest and disease infestations, and the multi-story plant canopy decreases erosion, increases capture of solar energy for photosynthesis, and shades and cools the soil. The varied geometry of root systems exploits the soil profile and nutrients more fully than monoculture systems. Overall production per unit of land often is higher than in monoculture systems, although the yield of individual crops per land unit may be lower (30,115).

The increased variety of crops and livestock, as well as beneficial interactions between different species result in a more sustainable agricultural system than monoculture (94). Also, because polyculture outputs closely approximate local consumption requirements, there also is inherent stability in the market or pattern of demand, in contrast to the instability characteristic of internationally sensitive monoculture markets (e.g., sugar, copra) (56). Finally, some farmers may practice polycultures not only because they are traditional in the islands but because the farmers are willing to sacrifice some amount of product yield and quality to save in expenditures on fertilizers and pesticides (80).

Polyculture has not been developed for large-scale commercial agriculture mainly because it does not lend itself well to mechanization or increased fertilizer and pesticide inputs. Polyculture systems also require more research, planning, and management than monoculture if they are to become fully competitive with monoculture in the short-term, since several different crops must be cared for on the same land unit (94).

Emphasizes or Incorporates Perennial Crops

In addition to incorporating a number of crop species and varieties, traditional agricultural systems commonly are comprised of crops with staggered planting and harvest periods. Perennial crops, usually shrub or tree crop species, are typical members of traditional polyculture systems. Although developing a traditional Yapese agroforest or "tree garden" may take years, once established relatively little input is required for their maintenance and food and other products can be harvested essentially in perpetuity. Developing a modern agroforest, in which species' spacing is carefully planned and individuals are planted rather than allowed to volunteer, can take considerably less time.

Most major tropical "plantation crops" also are perennial crops, such as coconuts, coffee, and cacao. Permanent crops are estimated to occupy at least 8 percent of the total arable area in developing countries *(69)*. One of the most widely grown tropical tree crops is the coconut palm, covering some 15 million acres, although it is mostly grown on smallholdings in densely populated areas *(69)*. Smallholders commonly intercrop coconuts with annual crops during the early stages of plantation establishment, but modern plantations generally maintain their traditional characteristics: "monocultural production of an export crop, extensive and, in some cases, underutilization of land, and a high manual labour input" *(69)*. With increasing populations and the need for intensification of land uses, planners and policymakers are increasing their attention to the potential of integrating plantation crops, annual crops, livestock raising, and forestry *(69)*.

Emphasizes Optimization of Components Rather Than Maximization of Yield

A sustainable tropical agricultural system places primary emphasis on maximizing agroecosystem stability through managing biotic interactions and minimizing demand for human and industrial inputs *(42)*. For example, intercropping and crop and field rotations are commonly practiced in tropical subsistence farming systems to minimize weeds and pest infestation and to maintain soil fertility. This is not to say that crop yield per land unit cannot be as high as those in temperate systems, in fact biomass yields may be higher due to the year-round growing season. However, the primary goal of these systems is to derive as many benefits as possible from natural actions and interactions, thus reducing input and labor costs of managing the systems to produce goods for human consumption or sale.

Emphasizes Recycling of Locally Available Nutrients

Traditional agriculture in the islands relied heavily on infusions of green manures to provide plant nutrients to infertile soils. Agricultural inputs are derived from composted leaves and other organic materials and manures, or even from dried starfish or rotted sea cucumber (22,102). On resource-poor islands such as atolls, the ubiquitous coconut fronds and husks are used to supplement the meager organic matter content of soils for crop cultivation *(102)*. In recent years, introduced agriculture implements and chemicals (fertilizers and pesticides) also have been incorporated into the traditional cultivation systems.

Reliable information on the types, amounts, and availability of various organic wastes useful for improving the productivity of agricultural soils is lacking on many islands. Successful planning and implementation of organic recycling programs requires such information as a first step. Several common types of waste that can be used are: 1) animal manure; 2) crop residues and cut vegetation; 3) algae, seagrasses and marine animal products (e.g., starfish, sea cucumber); 4) sewage sludge; 5) food processing wastes (e.g., rum brewery byproducts); 6) organic industrial wastes (e.g., some pharmaceutical wastes); 7) logging and wood manufacturing wastes; and 8) municipal refuse. Information is needed on the quantity currently generated, present and potentially competitive uses, value as fertilizer, and problems and constraints affecting use.

Emphasizes Incremental Changes From Extant Systems

Although farm size, type of technologies applied, and farming goals are not directly related, agriculture in the U.S.-affiliated islands can be classified into four general types that make up a continuum of farming systems:

1. Subsistence *smallholder:* Family (or clan) member(s) producing solely for family consumption, although "surplus" commodities may be sold. Traditional cropping or gathering techniques commonly are used, and the number of crops produced is usual1y greater than in commercial smallholding systems.
2. *Semicommercial smallholder:* Individual or family members regularly producing commodities for the market, but only on a part-time basis. Farming mayor may not be regularly directed to home consumption (farmer may have a full-time wage job in the money economy). Commodities may or may not be produced using modern[2] technology.
3. *Commercial smallholder:* Individual or family member(s) producing solely or substantially for the market. Commercial smallholders typically are full-time producers who derive their principal livelihood from farming. Commodities are normally produced using modern technology. The range of crops is much narrower than for the subsistence smallholder. The commercial smallholder may have a few wage employees, but most would rely solely on unpaid family labor.
4. *Large-scale commercial farming:* Usually is characterized by significant investment in operation, and use of paid wage and salary workers. Ownership commonly would be corporate in form, with production using modern, high-input technology. Output per unit of land or labor would tend to be much higher than for smallholder agriculture.

"Large-scale" commercial farming on the islands is not large by U.S. standards (tables *6-4* and *6-5).* In the United States, farms average *416* acres acres *(132),* whereas in the U.S.-affiliated islands large farms can be considered those with more than *50* acres in the Caribbean and more than *20* acres in the Pacific. Small farms in the United States can be defined as those selling less than *$20,000* worth of agricultural products in one year *(119).* While **8.5** percent of Puerto Rican farms exceed this, under this definition, virtually all farms in the USVI and the Pacific islands can be considered small.

[2]Modern technology is defined to be the package of practices (agronomic methods and procedures, as well as use of labor and material inputs) developed by scientifically based institutions [experiment stations, agriculture departments, specialized institutes) for use in tropical and semitropical areas. A package of practices relates to a given farm commodity or enterprise, and tends to be unique to a particular region. Packages of practices based on modern technology enable a farmer to obtain yields maximized with respect to the scarcest resource (e.g., per acre per crop, if land is scarce; per manhour, if labor is scarce) (43).

Table 6-4.—Comparison of U.S. Mainland and Island Farm Sizes by Acreages

Farm size (acres)	United States[a]	Puerto Rico[b]	USVI[c]	Guam[d]	American Samoa[e]	CNMI[f]
Less than 10.	8.3% (187,643)	45.5% (9,837)	62.4% (189)	93.8% (1,868)	94.7% (1,260)	66.9% (200)
10-19	(included below)	21.1% (4,554)	10.6% (32)	3.2% (63)	3.6% (48)	18.4% (55)
20-49	20.0% (449,184)	18.2% (3,937)	11.2% (34)	1.8% (36)	1.3% (17)	8.0% (24)
50-99	15.3% (343,715)	7.2% (1,549)	5.9% (18)	1.3% (25)[g]	0.5% (6)[g]	6.7% (20)[g]
100-174	16.4% (367,734)[h]	3.0% (658)	4.0% (12)			
175-259	9.4% (211,384)[i]	1.7% (372)	1.7% (5)			
260 and more	30.3% (679,640)	3.3% (712)	4.3% (13)			

SOURCES:
[a]U.S. Department of Commerce, Bureau of the Census, 1982 Census of *Agriculture:* Summary, vol. 1, part 51, (Washington DC: U.S. Government Printing Office, 1984).
[b]U.S. Department of Commerce, Bureau of the Census, 1982 Census *of Agrculture; Puerto* Rico, vol. 1, part 52, (Washington DC: U.S. Government Printing Office, 1984).
[c]U.S. Department of Commerce, Bureau of the Census, 1982 Census *of Agriculture: U.S. Virgin Islands,* vol. 1, part 54, (Washington DC: U.S. Government Printing Office, 1983).
[d]U.S. Department of Commerce, Bureau of the Censis 1982 Census of Agriculture: Guam, vol. 1, part 53, (Washington DC: US. Government Printing Office, 1983).
[e]U.S. Department of Commerce, Bureau of the Census, 1978 Census of Agriculture: American Samoa, vol. 1, part 55, (Washington DC: U.S. Government Printing Office, 1981).
[f]U.S. Department of Commerce, Bureau of the Census, 1978 Census *of Agriculture: Northern* Mariana *Islands,* vol. 1, part 58, (Washington DC: U.S. Government Printing Office, 1981).
[g]Data include farms with 100 to 179 acres.
[h]Data include farms with 50 acres or more.
[i]Data include farms with 180 to 259 acreSs

Table 6-5.—Comparison of Farm Sizes by Sales Class

Value of sales	United States[a]	Puerto Rico[b]	USVI[c]	Guam[d]	American Samoa	CNMI
$1 to $99	(included below)	n/a	2.3% (6)	13.2% (45)	n/a	n/a
$100 to $499	(included below)	9.0 "/0 (1,964)"	25.7% (68)	31.9% (109)		
$500 to $1,199	(included below)	33.2% (7,236)	26.0% (69)	15.5% (53)		
$1,200 to $2,499	23.9% (536,437)	20.5% (4,474)	20.4% (54)	12.9% (44)		
$2,500 to $4,999	12.4% (278,208)	15.1% (3,293)	10.2% (27)	26.9% (92)[f]		
$5,000 to $7,499	7.50/0 (168,483)	6.0% (1,302)	3.0% (8)			
$7,500 to $9,999	5.0% (1 13,319)	3.0% (651)	1.5% (4)			
$10,000 to $19,999	11.5% (259,007)	4.8% (1,043)	10.9% (29)[g]			
$20,000 to $39,999	11.1% (248,825)	2.4% (529)				
$40,000 to $59,999	6.6% (148,272)	0.9% (190)				
$60,00 or more	21.6% (484,859)	5.2% (1,138)				

SOURCES:
[a]U.S. Department of Commerce, Bureau of the Census, 1982 *Census of Agriculture: Summary,* vol. 1, part 51 (Washington, DC: U.S. Government Printing Office, 1984).
[b]U.S. Department of Commerce, Bureau of the Census, 1982 *Census of Agriculture; Puerto Rico,* vol. 2, part 52 (Washington, DC: U.S. Government Printing Office, 1984).
[c]U.S. Department of Commerce, Bureau of the Census, 1982 Census *of Agriculture; U.S. Virgin Islands,* vol. 1, part 54 (Washington, DC: U.S. Government Printing Office, 1983).
[d]U.S. Department of Commerce, Bureau of the Census, 1982 *Census of Agriculture: Guam, vol.* 1, part 53 (Washington, DC: U.S. Government Printing Office, 1983).
[e]Includes all farms in sales class less than $499.
[f]Includes all farms with sales of $2,500 or more.
[g]Includes all farms with sales of $10,000 or more.

Even the definitions used by the U.S. Bureau of the Census reflect the wide disparity in farm sizes between the United States mainland and the islands. Farms in the States are defined as a place that produces and sells, or normally would have sold, at least $1,000 worth of agricultural products per year (132). Enumeration in Puerto Rico covers:

> . . . all places from which $500 or more of agricultural products were sold, or normally would have been sold, during the 12-month period, . . [and] places of 10 cuerdas (9.7 acres) or more from which $100 or more of agricultural products were sold, or normally would have been sold (135).

Farms in the USVI include all those with 3 acres or more on which any field or forage crops or vegetables were harvested, livestock managed or having 10 or more poultry, and places of less than 3 acres if agricultural sales amounted to at least $100 (133). In Guam, a farm is:

> a place on which any crop, vegetable, or fruit was harvested or gathered during 1982, or on which there was any livestock or 15 or more poultry at the time of enumeration (134).

The amount of marketed agricultural produce is small relative to total food consumption in all the U.S.-affiliated Pacific islands; most farming is of subsistence and semicommercial scale. Approximately 3,000 persons in the Marshall Islands were estimated to be active in subsistence agriculture, forestry and fisheries in 1980 (49), and 38 percent of gross domestic product in the FSM was attributable to the subsistence sector in 1983. In Palau, an estimated 20 percent of the 1976 work force was in subsistence agriculture and fishing, and many in the wage economy farmed on a part-time basis for home consumption (43].

Truly sustainable agriculture probably should represent an integration of traditional techniques with modern scientific theory and with modern technologies. Progress will ultimately depend on the development of technology and understanding of the fundamental processes underlying soil fertility (42).

POTENTIAL STRATEGY: Support Nonmarket Agriculture

Traditional cultural practices are labor- and nature-intensive, maximizing the use of local resources and mimicking the local natural environment. In the U.S. Pacific islands, a variety of subsistence crop cultivation systems are practiced including root crop cultivation, agroforestry, and backyard or home garden agriculture. These systems have been adapted to varying island environmental conditions.

Traditional cropping practices in many U.S. Pacific islands are strongly rooted in the sociocultural practices of the communities. Some crops and animals play an important role in traditional exchanges. In Micronesia, specially cultivated taro and yams, and pigs are prepared for significant social and cultural events such as births, marriages, funerals, dedication ceremonies, and for traditional feasts (22,94,108). In urban centers these traditional practices are gradually disappearing.

Although subsistence farming sometimes may not result in highly uniform yield, it provides a number of benefits:

- stable system producing on a sustainable basis;
- ecologic compatibility with the local environment;
- beneficial environmental services (e.g., soil stabilization, habitat protection);
- compatibility with local culture and land tenure systems;
- high crop diversity and phased harvest enhance nutrition; and
- generally does not depend on costly and often unreliable imported resources a-rid inputs (e.g., agrichemicals, feed, spare parts, equipment, experts).

Subsistence farming systems are gradually abandoned and generally neglected by young farmers because these systems are considered inferior and may involve excessive manual work, However, much can be learned from these time-tested traditional systems because they incorporate certain resource conservation practices and operate on a sustainable basis suitable for islands (22).

On the other hand, although these practices are well suited to island conditions, crop yields may not meet the needs of increasing populations on some islands. Traditional root crop cultivation has been gradually abandoned in recent years because it is labor-intensive and relatively low returns are no longer compatible with social and cultural aspirations among young farmers. Because most modern agricultural systems are heavily dependent on imported agrichemicals and have been economically unstable and ecologically unsustainable, in the long run, subsistence agriculture systems probably will not disappear on the islands. They are likely to persist to the greatest extent in situations in which capital is not readily available to farmers or where islanders consider subsistence agriculture practices a manifestation of their cultural identity.

No consistent measure of nonmarket production has been derived for the separate territories. Indicators of agricultural production both entering and not entering the money economies of U.S.-affiliated Pacific islands, are listed in table 6-6. The terms subsistence and commercial (or market) agriculture are used in a gen-

Table 6“6.—Indicators of Subsistence and Commercial Agricultural Production in the U.S.-Affiliated Pacific Islands

Islands	Measures of subsistence production	Measures of production for the market
American Samoa	1,405 acres (81%) in subsistence crops	330 acres in commercial crops
Guam	More than 1,000 family gardens, usually <5 acres	85 commercial farms <5 acres
Northern Marianas	Approximately 20°/0 of total production is for home consumption	Approximately 80°/0 of total production is for market
Marshall Islands	n/a	n/a
Federated States of Micronesia	$40.59 million is imputed value of subsistence agriculture and fisheries	Market production valued at $4.32 million
Palau	n/a	n/a

SOURCE: R. Lucas, “Role of Smallholders in Agricultural Development in the U.S.-Affiliated Pacific Islands,” OTA commissioned paper, 1986 eral sense, but the specific island context is important. For example, in Guam, nonmarket production is largely of the home garden variety but, except for scale and use of machinery, the technology for producing commodities does not differ substantially from the commercial grower whose output is marketed. Virtually all Guamanian households area part of the money economy, and few depend on farming for the food they eat. In contrast, in an area such as Palau, subsistence farming typically not only means use of a different technology but also, for many families, is the main source of the family's food (43).

Little true subsistence agriculture exists in the U.S. Caribbean. However, rural and urban backyard gardens are common in Puerto Rico and the U.S. Virgin Islands, and several groups practice a sophisticated combination of subsistence and semicommercial agriculture.

Opportunity: Project Currently Functioning Traditional Agriculture Systems

Without a conscious effort to retain existing food producing systems, it is likely some traditional practices and varieties will become rare or disappear. Because present-day Micronesians have inherited relatively self-sustaining food production systems developed by more dense populations of their ancestors, complacency about continued maintenance presents a danger; without inputs, even relatively stable systems will run down. For example, the productive lifespan of a coconut tree is about 60 years; under good conditions, breadfruit trees produce for about 50 years (103). These plant lifespans are close to the productive years of each human generation. If present-day island populations do not do their part to maintain the systems, the next generation may not realize what it had until it's gone (22).

Many traditional systems already are declining. On Guam, for example, the percentage of persons involved in fishing and farming declined from 90 percent in 1941 to 6 percent in 1950 to less than 1 percent in 1970. The traditional lancho system has declined precipitously. This was accompanied by a concurrent increase in dependence on food stamps (22).

Without conscious efforts to protect currently functioning traditional agriculture systems, local production of food can be expected to decrease. With increases in prices and population, nutritional problems may be expected to result (110,111). Another byproduct would be the loss of Micronesia's genetic heritage: the wealth of adapted varieties of food plants and other species developed over a great many years by ancestors of the present generation. Further, the collective body of traditional knowledge relating to the use of island resources could be lost (22).

Consideration of development project impacts on currently functioning agricultural systems could be made prior to investment, followed by actions to mitigate adverse impacts. For example, road construction has altered drainage patterns and affected water circulation in some taro patches. In some cases the impact is obvious: the taro becomes buried in silt. In other cases the microbiology of the substrate is changed, generally towards more anaerobic conditions (22). This is particularly important on islands where government economic development strategies favor nonagricultural sectors which will eventually lead to competition for and encroachment on agricultural lands (56).

Opportunity Support and Increase Backyard Agriculture

Backyard or home gardens, as the name indicates, are located immediately adjacent to permanent dwellings. Backyard agriculture is widely practiced in Pacific and Caribbean islands and it maybe considered as an adjunct to subsistence and semicommercial agriculture. Except for scale, many characteristics of subsistence agriculture systems apply to backyard gardening. Generally it is characterized by mixed cropping of a variety of trees and short-term crops, high crop diversity, and labor-intensive cultivation of a small plot of ground (commonly less than 1 acre). In general, produce from backyard gardening is for subsis-

Photo credit: *Office of Technology Assessment*

Although more intensive than other traditional cultivation methods, backyard gardens also commonly rely on minimal soil disturbance and locally available materials such as these bamboo trellises.

tence use, although surplus crops or certain cash crops (e. g., spices and herbs) sometimes are sold. As in subsistence field cropping, backyard gardening activities have few market constraints. However, in cultures based on extended family sharing, backyard subsistence gardens may effectively reduce the market for commercial farmers' products (63,80).

Backyard gardening in rural areas commonly is an extension of subsistence cropping and backyard gardens may serve as a convenient recycling site for organic wastes. They also may serve as trial plots of wild plants or new crop varieties grown under reasonably controlled conditions (22,110,152). Where space is limited or when the soil is extremely poor, crops can be cultivated in containers. When good soil is not available, chopped up fibers from coconut husks and fronds mixed with fertilizer, compost, or animal wastes can be used as substrate in container cultivation for vegetables (46).

Backyard gardening in urban areas may contribute significantly to supplementing diets of wage earners. It also may improve the nutritional and economic well-being of increasing numbers of urban dwellers (110). In recent years, primarily in urban areas, backyard gardens are becoming commercialized. Some backyard gardeners use drip irrigation systems, greenhouses, shadehouses, or even hydroponics (10).

On some islands where agricultural production costs or land values are high, backyard gardening is popular for part-time, semicommercial cultivation of vegetables and fruits. Backyard gardening is popular in the USVI because it requires low capital investment, is suitable for small parcels of land, affords little economic risk, and provides flexibility in choice of crops or cultivation methods to meet changing local market conditions (16).

Backyard gardening, in general, is highly adaptable and can be implemented under varying environmental conditions and social settings (51). Backyard gardening has a number of characteristics making it suitable for the U. S.-affiliated islands including:

- flexible technology adaptable to varying physical, social, and environmental conditions;
- useful for subsistence, semicommercial, and some intensive commercial ventures;
- generally little capital outlay required;
- generally little economic risk;
- could be applied in rural and urban settings;
- little land area needed;
- simple agricultural methods are applicable;
- varied choices in use of agriculture inputs (e.g., organic composts, agrichemicals);
- variety of crops can be grown; and
- provides flexibility in switching crops or cultivation methods to meet changing demands or market conditions.

Opportunity: Enhance Game Wildlife Management Practices

Proper management of game may enhance supplemental food supply and nutrition of island inhabitants. Depending on the island, wild game may include feral pigs, goats, and deer, pigeons, fruitbats, and land crabs. Apart from regulating the harvesting of game, appropriate resource management such as setting aside hunting preserves is essential in order to manage and maintain game species populations. In addition to allowing management and harvest of game populations, restriction of some of these animals, particularly feral goats and deer, to carefully defined areas can protect indigenous vegetation from overgrazing.

Other methods, such as introduction of certain species to uninhabited islands or wildlife ranching of certain species, are ways of supplementing local food supplies. Traditional practices, still adhered to on some Pacific islands, commonly include rules and restrictions that conserve resources. For example, small uninhabited islands are set aside as sanctuaries where turtles and sea birds, and their eggs, can be harvested at certain times and in certain quantities. However, these practices are declining in effectiveness as traditional values and authorities are disappearing (40).

Today, on most islands, local governments regulate the harvesting and management of game species. Generally, they cover three areas: endangered species, hunting laws, and protected habitats. Endangered species protection laws commonly involve a fine for violation. For example, the CNMI Endangered Species Code, based on the U.S. Endangered Species Act of 1973, carries a fine of $2,000 or imprisonment for a maximum of 30 days or both for illegal taking of species listed under the act. Hunting laws may establish harvest quota limits, restrictions based on size or sex for certain species, and provide for exemptions if it is determined that curtailment of harvest of restricted fish and game may result in hardship or malnutrition to the taker or his/her immediate family. However, such regulations are generally difficult to enforce. In some cases, especially on small islands where extended family ties remain strong, violations carry little sanction.[3]

POTENTIAL STRATEGY: Develop Smallholder Agriculture

Development of smallholder agriculture would take advantage of the already existing subsistence, semicommercial and part-time farmers in the U.S.-affiliated islands, and is likely to be more compatible with the present land tenure systems than would be a policy of promoting large-scale farming. Smallholders also tend to produce a large range of commodities which may mitigate some marketing constraints in small size markets. If increased market supply were in import substitution commodities that could be profitably sold at lower prices than the competing products, commodity prices would be reduced.

Semicommercial farming could provide opportunities to increase income for part-time farmers or to generate cash incomes for subsistence farmers. Introduction of new technologies or new crops to extant semicommercial agriculture systems could increase income, yield, and make more efficient use of islands' scarce resources. Furthermore, introduction of semicommercial farming systems may become an effective method for relatively unsophisticated subsistence farmers to gradually learn the operation of commercial farming systems.

Among the three types of smallholder agriculture (subsistence, semicommercial and commercial), competition for resources is not likely to be a concern. Moreover, the three types of agriculture have many characteristics in common, such as relatively modest acreage requirements per operation, generally heavy reliance on family labor, and significantly less capital requirements per operation compared with large-scale agriculture.

Smallholder development policies could seek to achieve a gradual transition from nonmarket production to semicommercial and, ultimately, to commercial agriculture. For example, policies could seek to raise productivity in the subsistence sector, particularly in outlying areas which have arable land but lack transport and other infrastructure needed for market access. Concurrently, efforts could be initiated to strengthen urban markets for the products of semicommercial farmers, and to develop more productive packages of practices for selected import substitution commodities (43).

[3]For example, on one United Nations Day celebration on Yap, a Palauan fisherman whose catch included a turtle won first prize in the spear-fishing contest, even though it was against the law to kill turtles at that time of year (20).

Opportunity: Enhance Existing Nonmarket and Semicommercial Systems

Many constraints to resource management and development do not limit production to provide for personal needs and sharing, while they do limit commercial development. This suggests an initial strategy of encouraging production to meet family needs and, once these are met, surplus production may be marketed. Of course, should employment in nonagricultural sectors remain stagnant, then satisfying extended family needs would effectively satisfy the market (63).

The primary goal of enhancing existing nonmarket agricultural systems would be to increase productivity so that surplus could be marketed. In this way, the farmer would earn income and learn the skills needed for commercial agriculture. Methods of increasing nonmarket agricultural productivity include introducing improved cultivars of traditional crops and assisting women gardeners. In addition to these, a number of methods and crops have been introduced successfully on some islands for semicommercial operations. Methods of enhancing extant semicommercial systems include: improving cultural practices for cash cropping, promoting underutilized crops and animals, introducing suitable new crops, and introducing new technologies.

Introduce Suitable Improved Cultivars Into Extant Systems.—Specialization in agricultural systems and in culture of various crops is found within Micronesia islands and in other tropical areas. Information exchanges among these groups could provide much useful information (22). Similarly, although little is known about ethnobotanical crops or cultivation practices in the U.S. Caribbean, identification of local cultivars and information exchange with non-U.S. Caribbean islands could prove beneficial.

In Micronesia, a number of local crop varieties have been introduced from island to island. For example, varieties of coconut are recognized from the size, shape, and color of the nut; number of nuts per bunch; flavor of the coconut milk and meat; and tree sizes (86). At least seven tall and four dwarf coconut varieties are recognized in the Marshall Islands (104), One high-yielding, tall coconut (“thifow”), originally from Yap, produces twice as much copra as the commonly grown variety. This variety has been successfully introduced to other Micronesia islands including the Marshalls (86).

Prior to introduction of varieties from outside Micronesia, an effort could be made to collect and maintain existing varieties.[4] These varieties may be directly transferable among Micronesia islands and can provide germplasm for cultivar improvement programs. Screening systems and facilities for tissue culture probably are needed to ensure provision of disease-free planting material (22).

New cultivars could be developed that effectively extend the growing season of seasonal crops. In addition, unusual climatological events, such as the 1982-83 El Niño, have been related to gaps in yearly food production on some islands. With improved predictability of weather patterns, new cultivars and new technologies might be developed to fill some of these gaps.

Assist Women Farmers.—Women are the agriculturists on many Pacific islands. Extension services directed to collecting and disseminating information to these women could complement more traditional technology transfer systems. Women extension agents might speed this process. Methods of assisting these women with childcare also could increase time available for production and for passing on their experience to other women (22).

Improve Culture of Current Cash Crops.—Most cash crops currently grown on tropical islands are perennial: coconut, coffee, cacao, and sugarcane, Research efforts for many of these tropical “plantation crops” have resulted in considerable yield increases (e. g., rubber, “the average yield of which has increased over seventeenfold in a century”). On the other hand, the yield of crops like the coconut palm has re-

[4]Mechanisms to maintain crop and livestock varieties and wild plants and animals are assessed in an OTA report on *Technologies To Maintain Biological Diversify*, OTA-F-330 (Washington, DC: U.S. Government Printing Office, March 1987) (118).

mained low (69). This is due to a lack of research attention and, in part, to lack of maintenance by island smallholders.

For example, although copra production represents the only major cash crop for most Pacific islands, very little regular maintenance and replanting is practiced. In the Marshalls, brush growing between coconut palms occasionally is cleared and burned along with fallen coconut fronds and accumulated husks, although commonly they remain on the ground for considerable periods of time. These provide breeding sites for the Rhinoceros beetle, rats, and mosquitos. Fertilizers are not used, and old trees are not thinned. New trees are planted only in conjunction with government programs which subsidize the planting by providing seednuts and mechanized equipment (86). Inadequate maintenance of coconut palms and replanting programs results in reduced yields.

Since coconut palms have a very long economic life (60 years), understory cover management is critical. Manual clearing or control using herbicides generally are expensive or impractical. An alternative would be to keep livestock under coconut palms to graze understory vegetation or to intercrop coconut with other crops. Well-managed intercropping increases the productivity of the land, improves income distribution over time, increases return on investment, and thus may increase farm income (100). It could also increase employment. In some instances, pastures under coconuts can be improved by fertilization or planting nitrogen-fixing plants such as *Centrosema pubescens, Desmodium trifolium,* and shade-tolerant grasses.

Although no accurate copra production figures are available for U.S.-affiliated islands, it generally is lower than yields in Asian countries. For example, about 6,000 nuts are required to produce one short ton of copra in the Marshall Islands (86) as compared to only 4,000 nuts in the Philippines (35). Low yield is partly due to improper maintenance or lack of maintenance, and partly due to the use of low-yielding coconut varieties.

Many stands of coconuts in the U.S.-affiliated Pacific islands, and particularly in the Marshalls, were planted during the German administration of the islands and are now senescent. Little planned replanting is occurring. Although technologies to improve coconut production are available, people are reluctant to replant for several reasons:

1. the substantial investment of time and effort required,
2. the length of time before trees bear fruit (5 to 7 years),
3. unattended nuts will sprout and grow by themselves,
4. the government is likely to provide superior seednuts and replanting assistance (86),
5. in some cases it is more lucrative to plant short-term crops than to plant coconuts (63), and
6. substantial migration from outer islands makes it uncertain whether planters will be able to collect benefits of replanting (13).

Yet, techniques as simple as changing spacing from a rectangular to a triangular arrangement may substantially increase yield per acre (86).

Promote Underutilized Crops and Animals.–Every island has indigenous or naturalized species, either gathered from the wild or raised in small farms, that have been used traditionally for food, fuel, medicine, livestock feed, construction, fiber, and other purposes. These potentially marketable resources may be ignored by some planners in favor of introduced “western” crops, livestock breeds, and methods (121). In recent years, however, there is renewed interest in the potential for developing such resources (22,40,76,94).

Many crops and animals now found on U. S.-affiliated islands were introduced after western contact. Many have adapted to the local environment and are now considered local resources, including crops such as sweet potato, cassava, papaya, mango, and soursop; and animals such as goat, deer, water buffalo, and rabbit.

Systematic introduction of crops reached its peak during the Japanese administration in

Micronesia. A total of 157 varieties of plants producing food, medicinal, and fiber crops were field-tested in Palau; 88 varieties remained after World War 11 (53). Crops include cassava, pineapple, jackfruit, limes, oranges, groundnut, soybean, coffee, cacao, clove, nutmeg, cinnamon, teak, mahogany, ebony, and others, some of which are still present today. Mahogany planted during the Japanese period has largely replaced native hardwood *(ifil)* used in traditional woodcarvings (storyboards). Other crops have potential to provide marketable products

Benefits are obtained from using indigenous or naturalized plants and animals because they are adapted to the local environment conditions and stresses. For example, indigenous crops have adapted to local soil types, climate, and terrain and animals have adapted to local food sources. These indigenous species are efficient users of minimal available resources, and also tend to be resistant to local diseases and pests. Thus, using indigenous crop and animal species adapted to suit the local environment can effectively replace some inputs (e.g., pesticides) which are designed to change the environment to suit the crops or animals (121).

Some indigenous plants offer opportunities for commercial-scale development if markets are available. For these, improved cultivation methods to increase production may be economically justified. However, to develop the potential of native plants, more effort needs to be devoted to identifying potentially valuable species (121).

Introduce Suitable New Cash Crops.—Cash crops (i. e., crops usually providing raw materials for processed products and grown primarily to generate income) can be cultivated on islands for either local or export markets. Local crop varieties generally are preferable to supply local markets, because they are palatable to the local taste and have a number of advantages over introduced crops (22). However, introduced cash crops can provide the means to develop export products.

Characteristics of crops providing products suitable for export markets include: 1) high value of product per unit weight, 2) ease of cultivation and harvest, and 3) ease of processing and transport (43). Pohnpei black pepper, which has these characteristics has been successfully exported in small quantities to the U.S. gourmet market; potential exists for increased production. Other high-value crops that appear suitable to the Micronesia high islands include clove, cacao, cinnamon, nutmeg, vanilla, cashew nuts, and coffee (126,127,128,129,130). All are present in the islands (25).

Introduction of new crops and animals must be carefully weighed against potential undesirable effects on the local environment. For example, introduction of nitrogen-fixing plants generally is considered favorable because they provide an essential nutrient usable by other plants, are fast growing, and can grow on marginal lands. However, giant *Leucaena,* because it grows so rapidly, can effectively outcompete and shade out other, desirable species (22).

POTENTIAL STRATEGY: Integrate Characteristics of Traditional Agriculture Into More Productive Systems

“Neotraditions” of resource use may, in some cases, be suitable for fulfilling local and extended family needs, thus allowing sale of surplus production in local markets. These would involve technologies adapted, via a combination of traditional knowledge and experience and modern science, to today’s conditions (22). This would require evaluation of existing systems to determine which characteristics enhance their productivity and sustainability. Few data currently are available on the productivity or even extent of traditional agriculture systems. One attempt was made to census traditional agriculture production in Micronesia (116), but the results are unreliable (22).[5]

Once existing production systems have been evaluated, they can be compared with other systems and enhanced as needed. Comparisons of caloric and other inputs and production by

[5]Planning for Micronesia agroforestry and subsistence agricultural systems research is underway at the University of Guam (45).

extant and introduced technologies could indicate technologies which could be improved and evaluate needs for new technology. Concurrently, guidelines for development that would assure at least sustainability of a subsistence base of resource uses and foster sustainability of economic development projects are needed (22).

Several common characteristics of traditional systems might be integrated with modern practices to arrive at more productive, sustainable systems. Two of these are interplanting trees with crops and incorporating animals in cropping systems.

Opportunity: Incorporate Trees in Cropping Systems

Agroforestry is a collective name for land-use systems and technologies where woody perennials (trees, shrubs, etc.) are used on the same land management unit as nonwoody crops or animals. In agroforestry systems there are both ecological and economic interactions between the different components. The goal is to achieve an efficient use of space, to optimize crop combinations so as to maximize overall productivity, to optimize the ecological balance of the system and, at the same time, to achieve a sustainable yield (121). In addition to products derived from agroforests, agroforestry systems serve as sanctuaries for wild plants and animals and provide recreation areas. Agroforestry also can retain much of the flood and erosion control services provided by forested watersheds, thereby protecting the productivity of the land.

Traditional Pacific agriculture largely is based on tree crops and on preserving the environmental services of trees in cropping systems. Commonly, only small areas of land are cleared at any one time, forest trees and shrubs are selectively cut, and useful plants (producing food, medicines, or building materials) are mulched with leaves and twigs of unwanted species.

In the Caribbean, Puerto Rico's shade-coffee system can be categorized as an intermediate agroforestry system (121). Several plantings in western Puerto Rico, sampled in 1959, contained shade, fruit, and valuable timber species (114). Charcoal, prepared from annual shade tree prunings had a value of $3 million and accounted for over half of the total charcoal produced on the island in 1949 (106). The coffee "forest" production system was probably the start of modern agroforestry practices in Puerto Rico. Other agroforestry technologies practiced in Puerto Rico include coconut/pasture in coastal regions, mangoes/papaya, plantains and bananas intercropped with rootcrops and citron (87).

In the Virgin Islands, with the exception of bay tree plantations, traditional subsistence agroforestry incorporated root crops; vegetables; fruit trees; livestock; and forest species for charcoal, firewood, and construction. The most prevalent type of subsistence agroforestry is found in backyard gardens, which typically have a mixture of perennial fruit tree crops interplanted with short-term food crops. A more specialized agroforestry system is practiced by French farmers who grow herbs and spices along with fruit trees that serve as windbreaks and mark field (87).

Opportunity: Incorporate Animals in Cropping Systems

A primary means of increasing and enhancing local food production is by incorporating livestock in small-scale cropping systems. Island livestock generally are of mixed breed, resistant to diseases and parasites, and suited to island environments.

On some islands, particularly in the FAS, chickens, pigs and, more rarely, goats may be allowed to roam and forage in or near villages. On more developed islands such as in Puerto Rico, Guam, Saipan, and the USVI, free-roaming husbandry of animals other than chickens generally is not practiced (9,app. F).

Free-roaming livestock require minimal care and feeding and, thus, cost little to raise. However, productivity of free-roaming livestock is low compared to yield from more intensively raised livestock. Free-roaming livestock also may present a health hazard, by carrying and spreading diseases.

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Moreover, free-roaming animals can seriously threaten endemic flora and gardens. They also can denude island watersheds, causing serious degradation of "downstream" habitats and structures. Most Pacific island vegetation did not evolve with herbivore pressure and does not contain defenses such as thorns, bad taste, or protective alkaloids. Introduced herbivores may thus feed preferentially on native species and provide inroads for the loss of native species and spread of exotic vegetation (7).

Penning these animals would permit greater control of their diets, can provide an easily accessible supply of manures for comporting or direct application to soils, and would protect valuable endemic species and natural ecosystems. Considerable labor is required to care for penned animals (e.g., feed procurement, feeding, and waste disposal), which may hinder adoption of this technique. Penned animals currently are fed with leftover food, crop wastes, and forage such as *Leucaena* leaves *(108),* which might otherwise be used as soil amendments and conditioners. However, because manures are more decomposed than food and crop wastes, their nutrients are more readily available to plants.

In addition to penning, the yield and efficiency of livestock production can be increased by using improved breeds, better feeds, and more intensive husbandry. Although imported, improved breeds may increase production, most Micronesians prefer local livestock over imported breeds (93). The high costs of both imported and locally produced feed concentrates hamper widespread adoption of this technique. Since most livestock raised in the U. S.-affiliated Pacific islands are for subsistence use, farmers generally will not invest in processed commercial feed. Little research has been conducted on improving livestock productivity on those islands and much is unknown about its performance under intensive management.

Grazing of livestock on pastures grown under coconuts is a major land use activity in many parts of the tropics, especially the Pacific islands (69). Cattle or goats can be raised on natural or managed grasses and legumes. The carrying capacity of both improved and unimproved pastures varies widely depending on the type of forage plants, climate, age and density of the coconut stand, etc. The effects of grazing under coconuts has been studied by the Coconut Research Station in Sri Lanka, indicating that grazing will have no depressive effects on nut yields if fertilizers are applied to both palms and intercrops (69). Primarily because coconut palms are shallow rooting, the potential competition for nutrients with other, interplanted forage crops is considerable, requiring careful management to maintain high productivity of both. However, where enough land is available to rotate the animals among "fields," goats, in particular, can help to reduce weeds that also compete with coconut palms for nutrients.

POTENTIAL STRATEGY: Develop Intensive Commercial Farming

Conditions in the U.S. Pacific and, to a lesser extent, in the U.S. Caribbean islands generally are not favorable for large-scale commercial agriculture development. Constraints include relatively poor resource bases, small land areas, poor and/or expensive transportation services, and relatively high wages compared to labor productivity. In addition, land tenure systems in U.S. Pacific islands and high land prices in the U.S. Caribbean islands are not conducive to large-scale commercial development (43,61, 87,143).

Despite these hindrances to commercial agriculture, some opportunities for development exist. Profitable commercial agriculture development is generally accomplished through the use of modern technologies and careful selection of crops. Technologies range from intensive field farming to containment of crops in hydroponics and greenhouse systems. More specifically, some techniques used in intensive, large-scale farming can be adapted to the U. S.-affiliated islands, including mechanization, irrigation, and agricultural drainage.

Photo credit: A. Vargo

Increased mechanization appropriate to small-plot semicommercial and commercial farms, such as roto-tillers, is a goal of agricultural development on most U.S.-affiliated islands.

Mechanization. —Increased mechanization gives the farmer the ability to prepare farmland with less labor or to farm larger amounts of land. Given islanders' relatively high wage rates and the difficulties of hard physical labor in tropical areas, mechanization probably will be an agricultural goal in the U.S. Pacific (94) and Caribbean (10). Guam has large areas of flat, well-drained, cleared, and accessible land, as do Saipan, Tinian, and Rota, which can support large-scale mechanization. Pohnpei and Palau and, to some extent, American Samoa also have such areas.

Primary tillage—loosening the soil surface to disrupt weed growth–by hand is extremely labor-intensive and arduous, and is not a common practice in the U.S.-affiliated Pacific islands. Animal power has been, for the most part, bypassed in the U.S. Pacific except for carabao (a Southeast Asian water buffalo introduced during Spanish administration) which are used mainly for transport. A project to breed and train carabao in Palau by the TTPI government did not meet with success despite determination that carabao seemed to be the only sensible farm power for hilly, shallow soils and capital-poor farmers (94).

Small-scale rototillers and tractors have met with some success in the U.S. Pacific islands, although few farmers own farm machinery. Several farmers on Guam and Saipan own tractors, discs, and boom-sprayers (84). On some islands, rototillers and other small machinery are loaned to farmers. Some FSM State Agriculture Divisions till land for a nominal fee using government equipment. A Pohnpei State program provides farm clearing and bed preparation at subsidized rates of $10 and $6 per hour respectively. This program has been responsible for an estimated 152 farms cleared and 10 miles of farm roads completed in 1984 alone. Demand is such that farmers may wait 6 months before they receive machine service (94).

A 12-horsepower rototiller should be able to handle up to 5 acres of crops per year, more than sufficient for the average farmer in the U.S. Pacific, Capital investment in this type of tillage machinery is not prohibitive (about $2,000-$3,000) and machinery could be purchased cooperatively.

Secondary mechanization—seeders, sprayers, harvesting equipment, processing equipment, chainsaws, grass-cutters, pumps for irrigation, etc.—may need to be tested and made provisionally available as agriculture develops. Private business could eventually be encouraged to import and sell farm machinery, but the local government could do the initial evaluation and selection of suitable equipment. Cooperative ownership, as with the black pepper processing machinery on Pohnpei, may increase the availability of equipment to local farmers (94).

Irrigation.—Irrigation services are needed for commercial production on islands experiencing a dry season, such as Puerto Rico, the USVI, Guam, Yap, and the CNMI. In traditional agriculture, planting usually coincides with the rainy season, while harvest coincides with the dry period. Only Guam, the Northern Marianas, Puerto Rico, and the USVI have developed notable irrigation systems (61,94). In the U. S.-affiliated Pacific islands most irrigation systems are multiple-user, government-subsidized systems (94), while small-scale irrigation systems are common in the Caribbean (59).

Major irrigation technologies are flood, furrow, sprinkler, and drip irrigation systems. Flood irrigation is practiced in level areas and is well suited to rice and taro production. This type of system was practiced by the Japanese in some areas. Of all the systems however, flood irrigation requires the greatest amount of water, and is relatively ineffective on rolling lands.

Furrow irrigation involves planting on raised beds on level or leveled land and irrigating in furrows on each side of the beds. Furrow irrigation seems applicable to the CNMI with large level areas of land where sufficient water storage can be developed (94). Furrow irrigation has two main drawbacks: high operation costs because more water is pumped than is necessary and low crop yield because water cannot be applied evenly and at optimum frequency. However, in southern Puerto Rico, furrow irrigation helps maintain a stable groundwater balance because excess irrigation water reinfiltrates the aquifer; the only net loss of water caused by irrigation is due to evapotranspiration (61). Interestingly, infiltration of irrigation water has provided a greater volume of groundwater recharge than rainfall along most of Puerto Rico's south coast (28,59).

Sprinkler irrigation is more suited to sloping and hilly lands. The system also is suited to annual, perennial, or polyculture systems. This technology requires a water source, a pumping system and movable pipes with sprinklers. This system is used to some extent in Guam and the CNMI, especially where water is available through government irrigation projects (94).

Drip or trickle irrigation is the most versatile system in that it can be applied to all kinds of crops or crop mixtures, on sloping or flat

Pboto credit: Office of Technology Assessment

Rainwater is collected from outbuilding rooftops and pumped to a water tower on this Taiwan-sponsored agricultural research station on Majuro (Marshall Islands), using gravity flow to distribute it to the crops during dry periods.

lands, and even in greenhouses. This system requires a water source under some pressure (gravity can be sufficient in some cases) fed into a series of hoses or pipes that have small openings or drip nozzles feeding water near the base of the crop plants. Drip irrigation uses much smaller amounts of water than the other systems, and waters only the crop plants, thus reducing weed infestations between crop plants. Fertilizer and other nutrients can easily be fed into the system. No energy or labor is required to move the system once in place, and a biodegradable drip hose has been developed in Hawaii that can be plowed into the field after crop harvest. However, drip irrigation systems are costly, and water flow must be continually monitored to ensure effectiveness (94).

Construction of irrigation systems in the U. S.-affiliated Pacific islands seems limited to large-scale farm development projects primarily due to the high cost of underlying water storage and distribution systems (94). There are 72 irrigated acres on government land on Tinian made available for farmers during the dry season; Rota has a water system that 20 farmers are using and Kagman Station on Saipan provides irrigation to nearly 35 farmers from a well on the Station grounds. In Guam, municipal water is available to farmers for irrigation at 25 percent of cost, but supplies are insufficient. No other areas have irrigation systems operating at present, although infrastructure—canals and ditches—are still left from the Japanese occupation on some Micronesia islands. Considering the existing situation in U.S.-affiliated islands—lack of water storage and distribution systems, limited capital, and sloping land—drip irrigation seems to hold the greatest possibility for future development (94).

Agricultural Drainage.—Although a less common problem than arid lands, some agricultural lands on the high islands, particularly in the Carolines, are constrained by water saturation. Because the roots of most cultivated crops will not penetrate saturated soil and oxygen uptake is hindered, poor drainage can result in a shallow root spread and a commensurate reduction in plant size, stability, and yield. Water-saturated lands also promote surface runoff of rainwater, inducing erosion and increasing the problem of flooding on downslope land (123).

Surface drainage can channel water through shallow-grassed ditches and into outlets, reducing erosion on sloping soils and surface ponding on flat soils. To lower the water table, subsurface conduits, or tiles, must also be used. Drained soils allow surface water to infiltrate the soil, reducing erosion and can help control health hazards to man and livestock such as mosquito and fly-borne diseases. Drainage of wet cropland also can enhance crop production significantly; wet soils often have high potential productivity because they contain more organic matter than soils that are not as wet (123). However, drainage has been specifically exempted from most USDA cost-sharing programs, primarily because of its adverse impacts on mainland wetland wildlife. Adverse impacts also could accrue to island endangered species such as the Guam Gallinule and migratory waterfowl (113).

Opportunity: Intensive Smallholder Commercial Agriculture

Commercial small-scale farms outnumber large-scale farms in both the U.S. Pacific and U.S. Caribbean islands. In Puerto Rico, the average farm size is 33 acres with an average of 16 acres for each farm worker (37). Commercial farm size on Puerto Rico's south coast varies from 25 to 2,000 acres, but only 10 percent are more than 50 acres (135). In the USVI, commercial farm sizes average less than 1 acre per farm, and only three commercial farms in St. Croix consist of more than 100 acres (61).

To be competitive in the market place, small-scale commercial agriculture has to be made highly productive, This can be achieved in several ways:

- increased agricultural inputs in field farming and improved pasture systems;
- increased efficiency in methods for delivering agriculture inputs (e. g., irrigation, hydroponics); and
- cultivation in controlled environments (e.g., greenhouses, shadehouses, soil-less agriculture).

These technologies also are ways to overcome constraints posed by land scarcity, high land prices, scarcity of fresh water, unpredictable weather, and pest and disease outbreaks. The technologies have several things in common: capital outlays can be considerable, most require mechanization, and nutrients and energy have to be continuously supplied or replenished from outside the system. In addition, to implement the systems successfully, the operator must have both technical and business skills, and access to skilled labor and market outlets.

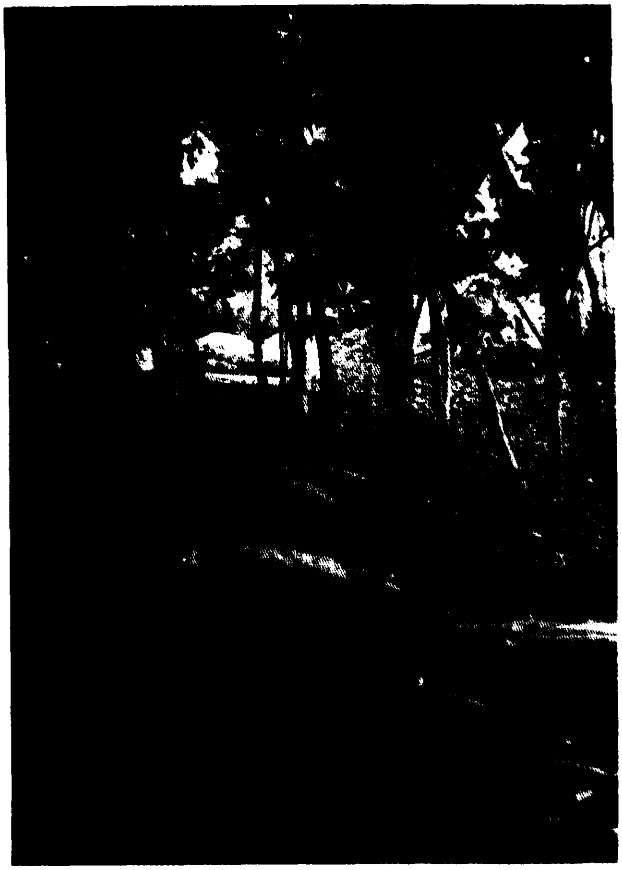
Although increased agricultural inputs commonly increases yields, they may not be sustainable. Yields may suffer if agricultural chemicals are not applied properly or in sufficient quantities. Furthermore, supply shortages, sudden price increases, changes in credit policies, or unreliable transportation services may also contribute to economic instability. High levels of agricultural chemicals applied to fields also may contribute to degradation of nearby environments.

Agriculture development may be constrained by the availability and the willingness of people to work in agriculture. The number and skill requirements of agriculture workers required for intensive small-scale commercial agriculture technologies vary and, thus, different systems have different employment-generating effects. Generally, small-scale farming requires more labor per acre than large-scale farm operations.

Several small-scale commercial agriculture ventures have been implemented on U.S.-affiliated islands with varying degrees of success. Technologies tried include high-input, intensive field cropping systems, hydroponics, cultivation in greenhouse or shadehouse, and intensive backyard gardening.

Intensive Field Farming Systems.—A number of improved agricultural practices have been proven profitable, have increased productivity, have exhibited reduced soil erosion rates as compared to clean-tilled fields, and have been successfully implemented on islands. Examples include intensive "sun-coffee" and plantain cultivation systems in the humid mountain regions of Puerto Rico.

In the past, coffee was cultivated under shade trees. However, research has shown that high density plantings of heavily fertilized coffee, grown without shade, produces higher yields per acre, and is economically profitable (144). A government-sponsored rehabilitation program for the coffee industry, based on intensive cultivation and providing financial assistance for new plantings, fertilizer, and hurricane insurance has met with some success. About 10,000 acres of intensively managed sun-coffee now yield 1,200 to 1,500 pounds/acre. On about 20 farms, harvesting is done with plastic nets rather than by hand; this reduces costs and loss



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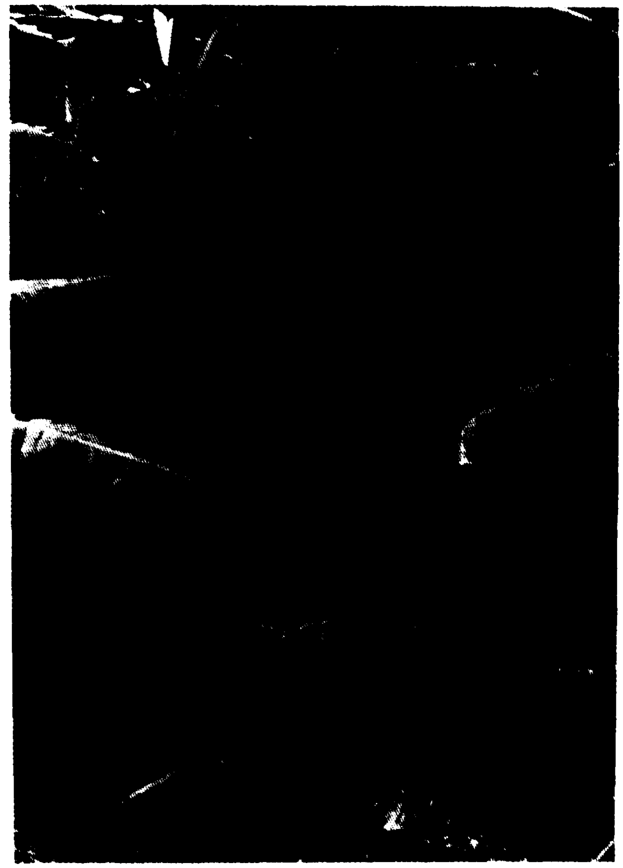

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of berries and effectively increases production. Intensive cultivation methods apply to semi-commercial as well as commercial development. In recent years, small-scale growing of coffee on a part-time basis has become popular among public servants in Puerto Rico.

As is the case for sun-coffee, plantain can be grown in high-density, intensive cultivation, even on relatively steep slopes, using heavy fertilization and intercropping *(143).* In the semi-arid areas of Puerto Rico, plantains can be grown commercially year round by employing drip irrigation systems.

Plantain can also be interplanted as a temporary shade tree and a source of income while permanent crops, such as sun-coffee and cacao, are being established (143). Vegetables can also be interplanted between plantain rows, at least for the first few months after plantain planting. Using appropriate techniques, plantain cultivation can be compatible with conservation *(147).*

Plantains are suitable for family-size commercial farms in the humid mountain regions of Puerto Rico since they provide a high return, do not require mechanization and are drought tolerant. About 3.3 million plantains are produced on *15,000* acres, mostly in small farms in the mountain regions of Puerto Rico, all of which are marketed and consumed locally *(143).*

While increased yields are achieved in both sun-coffee and high-density plantain systems, the high levels of agricultural chemicals required may have adverse effects on island water supplies. The cumulative effect of this is not known. It is likely that nutrients levels in rivers and streams will increase due to fertilizer runoff, increasing eutrophication in ponds and streams and, possibly, adversely accelerating spread of aquatic weeds such as the water hyacinth. Increased water hyacinth growth has been associated with such adverse effects as hindering fishing and fish culture, clogging rivers and canals, and increased schistosomiasis infestations, resulting in increased flood and disease control expenditures (72).

Container Agriculture. -Among the most intensive systems of commercial crop production are greenhouse, hydroponics, and container cropping. These production technologies hold the greatest promise in areas where soils are not productive, as in urban areas or on atolls where high alkalinity and saline conditions preclude standard cultivation practices. These technologies also hold promise for cultivation of some high-value crops that are limited by pests and disease.

When yields are calculated on a per-acre basis, yields from container agriculture are commonly very high and sometimes sensational. A yield of only 3.5 ounces of edible produce from a 0.1-square-yard pot is approximately equal to a yield of 4 tons/acre, a good yield in conventional agriculture. Container agriculture can be used for subsistence or commercial production of salads, herbs, cooked greens, and other vegetables for variety in the diet (50).

Small containers suitable for use in urban areas or on atolls, can be derived from old milk cartons, plastic garbage bags, cans, tires, and other receptacles as long as containers are 1 gallon or larger. Containers made from porous materials lose water through evaporation and thus, although they may require more frequent watering, are more suitable for plant growth in the tropics than nonporous materials (50). Large, permanently located containers allow use of more conventional techniques for plants grown in the ground.

Photo credit" Office of Technology Assessment

Containers for intensive agriculture can take nearly any form and size, although use of abandoned boats for container agriculture, such as on Ulithi Atoll (Yap), can be considered rather unusual.

Soil fertility must be maintained and as much of the plant as possible must be used to make commercial container cropping worthwhile (94). Greenhouses are a special site for container agriculture. Plants in greenhouses are protected from wind and driving rain, but may be exposed to high temperatures, high humidities, and infestations by insects that find greenhouse conditions comfortable (50). If care is taken to ensure that enough water is available in the soil, excess heat radiated from nearby walls or other structures can be reduced by shielding the plants with screen or shade covers.

A friable soil is best for container agriculture it has good aeration and drainage, may have a high organic content and is likely to relatively free of pests and diseases. Coconut husk fiber can improve aeration and peat and sphagnum moss will increase moisture-holding capacity. Crushed shells (including eggshells), coral or limestone, and coral beach sand can be added to neutralize acid soils.

Because relatively small amounts of soil must furnish the nutrients needed in container agriculture, soil fertility must be enhanced by adding commercial fertilizers, liquid fertilizers, or compost. Composted organic material is preferable to raw organic material such as garbage or fresh manure because the latter must deteriorate before they are useful to plants. If the organic content of the soil is high, it will contain a wide variety of micro-organisms, most of which are beneficial (50). When plants have been harvested and removed from their containers, the soil should also be removed and refertilized. Large containers will be needed to store soil to be used in pots, soil to be recycled, and finished compost.

Container agriculture's main requirement is water. Plant size, container size, location, and weather all affect the amount of water needed. Watering devices can be purchased that can water a pot continuously for as much as 1 or 2 weeks; or ropes can be used to absorb and transport water from a basin below the container to any part of the container (50).

plants most suitable to commercial container agriculture are those that can be harvested frequently over along period of time. Some plants, such as leaf vegetables, can be crowded and, thus, profitably planted several to a container. These tend to produce large quantities of edible materials over a long period of time and some act as perennials in the tropics. Many spices and herbs tested also grow well with one to five plants per container. Others, such as tomatoes, produce better when planted only one per pot (and commonly do better outdoors where they have access to greater root areas). Weeds should be removed as soon as they are noticed, before they produce seed or otherwise spread (50).

Greenhouse and Shadehouse Cultivation Systems.—Greenhouse systems were developed in temperate zones to produce fruits, vegetables, and flowers during the cold winter season. In the tropics the greenhouse allows farmers to control irrigation and disease. Crops are cultivated in flats or containers to which water is delivered. Irrigation systems include sprinklers, automatic drip irrigation systems and, for certain ornamental plants, "plant misting" devices. Many crops cannot be grown under heavy rainfall typical of the tropics. By growing these crops in a greenhouse, foliage can be kept dry and soil sterilized.

Greenhouses in the tropics usually have only roofs which are vented to emit excess heat. Materials such as fiberglass, plastic, or polyethylene netting, or saran "shade-cloth" are used for walls and roofs (10). It also is possible, by using canvas dark cloth, to simulate short day lengths, making it possible to grow crops that are day-length sensitive (94).

Shadehouses also are used throughout Micronesia, especially for tree and perennial crop propagation. A shadehouse consists of a wooden or metal frame covered with wood slats or fine netting or commercially available "shade cloth" to allow part of the sunlight to enter. Shadehouses have the dual advantage of subdued light, important for rooting of perennials, and lower temperatures. Shade houses also may be used to grow cool-season crops sensitive to high temperatures and day-length (94).

Although cultivation in greenhouses and shadehouses requires high initial capital outlays, it has a number of advantages over conventional field cultivation methods. It overcomes the need for large tracts of lands, scarcity of fresh water, and can ameliorate seasonal and climatic fluctuations. Types and size of crops that can be cultivated commercially are dependent on the size of greenhouse. And, as in any other commercial venture, business and marketing skills are critical for success.

Insular government agricultural experiment stations in the U.S. Pacific all have greenhouses, mainly for seedling propagation. At Ponape Agriculture and Trade School (PATS), a greenhouse was used for growing tomatoes for a number of years. The project was eventually terminated because of the high labor requirements (the entire soil of the greenhouse had to be sterilized after every production run) and the relatively low demand for tomatoes (94). The high capital costs of building a greenhouse probably limits its use to only high-value vegetable crops.

In Puerto Rico, growing ornamental plants in greenhouses or shadehouses can offer a high investment return, depending on the building design, the type of ornamental plant grown, and the cultural practices used. However, the initial capital outlay for such an enterprise is relatively high, and growing ornamental plants in greenhouses or shadehouses is labor-intensive (lo).

Hydroponic Culture Systems.–Hydroponics are totally controlled systems where plants are grown in a sterile, artificial media—commonly sand, perlite, or gravel—with a premixed nutrient solution continually pumped throughout the system, usually inside of a greenhouse type structure. Crops are grown in containers which, for commercial cultivation, commonly are either long troughs covered with wire meshing or plastic (PVC) pipes with perforations on the top side. Crops are placed in the holes of the perforated PVC pipes or held in place by wire netting that is placed over the containers. Water, plant nutrients, and other agrichemicals are circulated throughout the grow-out containers. Foliage and stems above the water may be treated by spraying.

Most advantages of greenhouse/shadehouse cultivation methods also apply to hydroponic cultivation methods. Hydroponically grown crops commonly are of high quality and crop yields are higher than conventional field cropping methods. For example, yield of hydroponically grown tomatoes is about 10 times greater than tomatoes grown under drip irrigation, and 25 times greater than tomatoes grown using conventional field cultivation methods (10).

Within limits, hydroponic systems are flexible. Varying types and qualities of water may be used as the substrate for growing crops. For example, water that was used for aquiculture can be recirculated and reused for hydroponic cultivation. Research on such an integrated hydroponic-aquiculture system is being conducted at the College of the Virgin Islands (CVI) (92,141).

Photo credit: A. Vargo

A highly specialized form of container agriculture is the hydroponic greenhouse. While greenhouses and hydroponic systems provide a number of benefits individually and in combination, the high capital outlays required largely restrict them to production of high-value crops unsuitable to field agriculture.

The CVI system, based on tilapia and tomatoes or lettuce (92) recirculates water collected on a one-quarter-acre plastic rainwater catchment. The water is directed into freshwater tilapia grow-out tanks, channeled through the hydroponics system, and any surplus is used to irrigate a nearby garden, Combined fish culture with hydroponics systems probably is more economically viable than either hydroponics *or* fish culture alone (5,91). Because of marketing constraints, however, this technology may not be applicable outside of high-demand urban areas.

Hydroponic systems are technically suitable for atolls and high islands in the U.S.-affiliated Pacific, as long as adequate water supplies are available. Hydroponics were used to produce food for soldiers stationed on atolls during World War II (33). Currently, six hydroponic farms produce vegetables, mostly tomatoes, in Guam; one hydroponic farm grows tomatoes on American Samoa and The Gardens Hydroponic Farm on Majuro (Marshalls) grows cucumbers, tomatoes, and peppers commercially (94).

Because of high capital outlay and operation costs, choice of crops is critical for profitability of commercial operations (10). As a result, hydroponically-grown produce typically is more expensive than field-grown produce. Thus, crop choice commonly focuses on a few very specialized crops and is directed toward upper-income specialty markets, such as English cucumbers in Puerto Rico (60). In the U. S.-affiliated islands, crops grown in hydroponic systems largely are restricted to high-value vegetables and herbs. While hydroponics probably will not have a significant impact on the overall produce market, especially in view of the yield-increasing technologies being applied to field-grown crops (e.g., drip irrigation), it has potential for satisfying some specialty market demands currently fulfilled by imported products.

Opportunity: Develop Spices, Essential Oils, and Other Specialty Crops for Export

Historically, spices, perfume and flavoring oils, and specialty crops such as tea and coffee have been highly sought after crops worldwide and evidence exists that markets are growing. For example, the American Spice Trade Association estimates that U.S. annual per capita spice consumption has risen from 10 ounces in 1932 to 36 ounces today, growing 33 percent in the last 10 years (88). Most species are native to warm tropical regions similar to the U. S.-affiliated Pacific and Caribbean islands. Yet, few of these islands grow spices for commercial sale.

With the small size of Micronesia landholdings (usually less than 5 acres), relatively high labor costs compared to the rest of the Pacific, and general high expectations of farm financial returns, spices, essential oils, and other specialty crops seem to hold potential for future commercial development. Numerous spice and specialty crops have been introduced into Micronesia, among them allspice, nutmeg, pepper, vanilla, ginger, and coffee. Moreover, several local and introduced plants can undergo extraction to produce high-priced oils which can be used in soaps, perfumes, etc. (94).

Black pepper was introduced to Pohnpei in 1959 and has become an increasingly important crop for the island's farmers with nearly 70 farmers growing from one-quarter to 1 acre or more. Nutmeg also is produced from six trees growing at the Kolonia Agricultural Station. Ginger is grown commercially at the Protestant Mission at Ohwa. Coffee is grown in the Sokehs area, propagated from the remainder of a Japanese plantation, and the Agriculture Division is investigating the possibility of introducing high-yielding coffee varieties from Costa Rica. Japanese and Fijians have expressed interest in importing sakau (a drink made from *Piper methysticum)* from Pohnpei in the near future. Other local beverages are being investigated for commercialization (94).

A perfume oil from a tree that grows wild on Pohnpei, Ylang-ylang *(Cananga odorata),* has been successfully processed at Ponape Coconut Products at PATS and samples of the oil have received favorable reception in Paris and New York (97). Other crops such as *Fragraea sair* and citrus oils also could provide high-value, low-volume products. In areas with a considerable expatriate or urban population, crops such as ornamental plants or Norfolk Island pines (for Christmas trees) may provide a potential local specialty crop (94).

All of these specialty crops give a high return to labor and management and can be profitable in small plantings. However, because of the small volumes each island could produce, development of spices, essential oils, and specialty crops probably should aim for the gourmet or health food markets where small quantities of product can demand high prices.

While there are little or no duties on dried spices imports into the United States, spice company quality specifications are among the highest in the world (88). The U.S. gourmet spice market is almost entirely controlled by large spice companies such as Spice Islands and McCormick & Co. (36). Even through these companies, however, "gourmet-quality" spices can sell for as much as five times the price of standard spices (57).

Production of gourmet-quality spices depends partly on site conditions and cultivation practices (box 6-A), and partly on handling, processing, and packaging. Some spices are collected from the wild, others are semicultivated and still others, like pepper, take careful cultivation and tending. Those spices harvested in the wild commonly pass through several parties before being sold at the port to a spice company representative. The spice sold at the port, therefore, is a blend of the harvests of many smallholder farmers (57). The more a spice is handled the greater the chance of its contamination with dirt and insects. The final seller must clean the spice before sale to rid it of foreign matter and pests. The harvests of larger producers pass through fewer hands and therefore, are likely to be cleaner and more desirable to the final buyer.

Penetration of the gourmet-quality spice market, then, entails strict quality control and processing standards, which may require farmer cooperative, private joint venture or government oversight during startup. Spice industries also are especially well suited to vertically integrated contract farming (see ch. 8).

For example, black pepper exports from Pohnpei have declined in recent years, partly due to sale of poor quality product; the Pohn-

Photo credit: Office of Technology Assessment

Black pepper has become an increasingly important crop for the farmers and economy of Pohnpei (FSM). Because of its special characteristics, it is estimated that Pohnpei pepper could capture as much as 5 percent of the U.S. gourmet-quality pepper market, even though it currently is grown on plots of 2 acres or less. Other spices may have similar potential.

Box 6-A—Spice Cultivation Research

The quality of a spice (its taste) is believed to be related to a variety of characteristics of the natural site where the spice grows. Rainfall amounts and its timing, soil fertility or lack of it, and cloud cover to mention a few, probably play a role in the taste of a particular spice, but little more is known. Research into the effects of the ecological setting on spice quality is woefully lacking. In addition, improved research on the disease-resistance of spice-bearing plants is needed to offset significant crop losses that occur in the tropics. The U.S. spice industry is only now beginning to conduct the necessary research to help answer such questions (57).

Further, there is little ability to predict the properties a spice will exhibit when it is milled. For instance, nutmeg from one locality will grind to a fine particle size easily and will be easy to handle whereas nutmeg from another site may agglomerate into large particles when ground. Such characteristics play an important role in whether a given spice can find a market. Again, appropriate research could help solve such problems.

While spice companies buy, process, and sell spices, they conduct little research for the use of the grower. The grower or potential grower must seek this information elsewhere or pay for it themselves. Small farmers of the U.S.-affiliated islands are not likely to be able to afford this research. Further, trees that produce many spices can take 6 to 8 years before producing a crop; there is no assurance that the product will be of the quality required to compete in the spice market. Few farmers can take such risks.

In addition, careful market research must precede investment in spice production. For instance, the cinnamon preferred by Europeans is not the same cinnamon preferred in the United States. The first is *Cinnamomum zeylanicum*, whereas the U.S. favorite is *C. cassia* (57). Were a farmer to raise the European favored cinnamon for a U.S. market without knowing of the differences in taste preference the results could be disastrous.

USDA has only general information on growing tropical spices because this is not seen as a major research area. Although some research related to disease resistance, ecological controls, and agronomic practice goes on at certain international and foreign tropical agriculture research centers (e.g., FAO, Spice Research Center in India), little of the information seems to reach insular spice farmers. Extension of this information is a weak link in improving spice farmer's production and the spice's quality.

Research on certain spice, oil, and specialty crops (e.g., pepper, ylang-ylang) is underway at the Ponape Agriculture and Trade School in the FSM. Preliminary results from this research indicate a significant potential from development of spice and essential oil crops. However, further research and strong farmer extension programs will be necessary to develop insular spice, oil, and specialty crop industries fully (95).

pei State government has plans to repossess the government-purchased processing equipment so that it can be more closely supervised (94). To date, the centralized dryer on Pohnpei has provided a check point for quality control but also has proved to be an impediment to farmers in outlying regions; research is underway on solar dryers which would allow initial processing to occur on the farm (38).

Despite the relatively small quantities of product that might be produced on U.S.-affiliated islands, this could have a significant impact on the livelihood of the islands' smallholder farmers. Under current cultivation practices, Pohnpei pepper could capture as much as 5 percent of the U.S. gourmet-quality pepper market with product grown on only 80 acres of land (36), or eight times the acreage currently devoted to pepper on Pohnpei. At present an estimated 70 farms ranging from 0.1 to 2 acres produce pepper (38); growth of this industry could support, at least partially, numerous other smallholder farmers,

Opportunity: Develop New Products From Extant Crops

Local processing of crops can provide higher returns to growers, compared to exporting raw materials, and can provide import substitution opportunities. Major opportunities for development of new products from locally available crops are coconut oil products, fruit juices, and animal feeds.

The major commercial crop in the U.S. Pacific is the coconut, from which copra is made. Copra oil processing plants exist on Majuro, Moen (Truk), Palau, and Pohnpei. Yap is in process of building a plant, The Pohnpei Coconuts Products plant has developed a line of products—laundry and bath soap, dish soap, cooking oil, body oils, and shampoo—for the local and tourist markets, Plants on Truk and Yap will offer similar products, mainly for import substitution. Copra oil is a potential substitute for diesel oil, but its cost ($4.00/gallon) compared to imported diesel oil ($1.50/gallon) is prohibitive at present (94).

Surplus fruit crops can be made into jams and jellies, juiced and bottled, or used in production of fruit ices, currently popular in areas having refrigeration, Small-scale juicing machinery, suitable for small quantities, are available and are employed on other Pacific islands. Through a successful Yap government sponsored radio campaign, coconut milk has replaced large amounts of imported canned beverages; similar campaigns could promote locally produced juices (94).

Opportunity: Support Large-Scale Farming Systems

Large-scale field farming operations need large tracts of uniform soils suitable for the chosen crop. For row-cropping, soil topography should be fairly level to accommodate mechanization and other farm management practices necessary for high uniform productivity. Large parcels of land of uniform type soil are scarce in most of the Pacific territories. While relatively large parcels of uniform lands are available in the U.S. Caribbean islands, land prices are exorbitantly high *(87,143).*

Conventional, mechanized, clean-tilled field farming that characterizes most large-scale commercial farming generally requires considerable levels of agricultural chemical inputs, such as fertilizers and pesticides, to maintain crop yields. In addition, large-scale conventional field-cropping of short-term crops generally entails greater risks of soil erosion and other ecological damage than other systems such as smallholder farming *(22,43,94).*

Finally, large-scale commercial farming requires large markets to absorb production volume. Since local markets on islands are small or the local buying power is low, large-scale producers generally export the products. While export potential exists, it is difficult to achieve *(43).*

Despite these constraints, opportunities for large-scale commercial farm development exist, particularly in Puerto Rico. Careful selection of technologies and crops is crucial for profitable large-scale commercial operations. Business and operational skills, marketing skills and careful timing (e. g., to supply fruits and vegetables to the U.S. mainland "winter market") also are essential.

Increased agriculture yields in field farming generally is achieved by intensifying agriculture inputs or using highly efficient input delivery systems, such as drip irrigation. However, under certain circumstances, improved management of crop production alone will increase yields. For example, low yield of sugarcane in Puerto Rico is primarily due to inefficient drainage and irrigation systems, inadequate pest control, and poorly timed and inefficient harvesting operations (143). In other cases, new technologies may be needed to increase productivity and product quality *(61,143).* In addition to the intensive cultivation of sun-coffee and high-density plantain, large-scale intensive pasture improvement for commercial cattle rais-

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ing has been successfully accomplished in Puerto Rico (9,143).

Conventional Field Farming Systems.–Conventional field cultivation systems are characterized by mechanized operations, clean-tilled fields, and monocultural crop cultivation. To maintain high crop yields, chemical fertilizers and pesticides are used. Gravity (furrow) or sprinkler irrigation systems are common. In Puerto Rico, principle crops cultivated this way include sugarcane, plantains, pumpkin, pigeon peas, pineapple, and some vegetables (61).

Due to high production costs, conventional field cropping for most crops is not economical. High production costs are related to high energy cost, relatively high labor cost (compared to neighboring non-U.S. islands and countries), low labor productivity, and the application of inefficient agricultural technologies. For example, gravity irrigation is considered inefficient compared to the sprinkler or drip irrigation systems, in terms of the amount of water used for irrigation. Although mechanized, clean-tilled agriculture systems have several advantages, given the vulnerability of most tropical soils to erosion from heavy rainfall, the overall effect can be long-term soil impoverishment.

High-Input, Improved Pasture Technologies. —Large-scale, high-input improved pastures have been used in cattle ranching in Puerto Rico. Pasture improvement is instrumental in increasing beef and dairy milk production.

Cattle can be raised on unimproved or improved pastures. Ranching on unimproved pastures is practiced in areas where few alternative land uses exist, such as the semiarid areas of southern Puerto Rico and the USVI (9). Raising cattle on unimproved pastures requires little capital investment and labor. Some landowners in the USVI raise beef cattle on unimproved pastures for investment and tax purposes until these lands can be developed for other uses and sold at a profit (9).

However, raising dairy or beef cattle on improved pastures is considered by some to be the best land use of idle lands in Puerto Rico's mountain regions. Well-managed tropical pastures in steep mountain regions helps protect soil against erosion (145). Soil losses on intensively managed pastures amounted to only 1 ton/acre/year; the lowest for any current mountain agricultural practices in Puerto Rico (101,146).

In Puerto Rico, as much as 100,000 acres of mechanizable land are in intensively managed pastures—primarily for dairy cattle—and an additional 500,000 acres are in less-intensively managed pastures for beef cattle production. Five thousand acres of improved pastures are reportedly being used for dairy in the USVI, 8,000 acres for beef production, and 12,000 acres are in unimproved grassland (9,81,82, 143). However, only part of this pasturage is truly productive; many smallholders apparently graze a small number of animals on their few acres in order to receive tax reduction accorded to "farms"; when the price of land rises high enough such land may be sold for condominium development (56).

Cattle pastures occupy about 22,500 acres in the Northern Marianas (primarily on Tinian), about 170 acres on Guam, 350 acres on American Samoa, and less then 1,000 acres in various other Pacific islands (12,46,134,135,137). Considerable opportunity exists to expand livestock production in the CNMI (84).

Drip Irrigation on Semiarid Lands.–Semiarid lands comprise about 20 percent of the land area of the U.S. Pacific islands (primarily on atolls) and about 40 percent of the land area of the U.S. Caribbean islands, including 60,000 acres in southern Puerto Rico (61,143,150). Semiarid lands are generally associated with high salt and alkali levels in soils, brackish water intrusion into groundwater and, on atolls, salt spray. These undesirable conditions make conventional agricultural practices difficult.

One way to make these lands more productive is through irrigation. Drip irrigation is a particularly efficient and water-thrifty method of water use for crop production; it is 13 percent more efficient than the sprinkler irrigation, 31 percent more efficient than pipe irrigation, and 56 percent more efficient than conventional furrow irrigation systems (10). In some cases, drip irrigation systems can reduce fertilizer costs by about 25 percent. Although total water purchase costs can be reduced from 30 to 50 percent (154), the cost per unit of water delivered to each plant (which includes preapplication filtration, higher pumping costs to provide higher pressure and equipment amortization, as well as water purchase costs) typically is higher in drip irrigation than other irrigation systems (59). The systems can be applied on small or large scales and in manual or automated operations, with varying complexity of hardware, capital investments, and severity of freshwater constraints.

Crop yield is higher under drip irrigation than under conventional rainfed field cropping. In semiarid lands of southern Puerto Rico, drip irrigated crops produced two to three times higher yields than conventional small-scale commercial field cropping (table 6-7) (61). However, the total net value of products is basically the same due to the high initial capital investment and high operation costs for drip irrigation systems.

Installation of drip irrigation systems in Puerto Rico costs between $1,500 to $2,000 per acre for a typical farm (32) compared to $1,000 to $1,400 in the Western United States (6). Sophisticated and costly filtering and backflushing systems commonly are required to keep the systems from clogging due to suspended particles in the water. Because of the high costs, only crops with assured markets can be grown economically.

Opportunity: Develop Commercial Forestry

Reliable information on the original extent of island forests does not exist, but forests probably covered most of the islands. Most of the islands have been largely deforested at some time during their colonial histories, and some are naturally regenerating second-growth forest on abandoned lands. Today, at least one-third of Puerto Rico is again under forest cover; much of this land is too steep for other uses (121).

Some wood products are harvested on most U.S.-affiliated islands, such as fuelwood, wood for charcoal production, poles, and home construction materials. However, most wood products are imported. For example, American Samoa imports nearly all wood products except fuelwood from nearby independent Western Samoa and from the United States and New Zealand. In 1981, Puerto Rico produced about 100,000 board feet of hardwood timber with a

Table 6-7.—Comparison of Yields under Drip and Conventional Irrigation Systems in Semiarid Zones of Puerto Rico

	Drip irrigation				Conventional irrigation	
	Agricultural experiment station		Private growers		Private growers	
Crop	(Box/Ac)	(Tons/Ac)	(Box/Ac)	(Tons/Ac)	(Box/Ac)	(Tons/Ac)
Vegetables:						
Tomatoes	669	10.0	1,000-2,000	15-18.7	600	7.5
Peppers	528	10.5	800-1,000	20-30	400	8.0
Eggplant	668	13.3	1,000	20	400	8.0
Cucumbers	921	18.4	500-1,000	12-25	250	6.0
Squash	—	20.0	—	10	—	6.0
Watermelon	—	12.7	—	2-3	—	3.0
Cabbage	—	15.6	—	10	—	5.0
Onion	—	10.4	—	10	—	5.0
Tree crops:						
Plantain [a]	35,000	21.0	40,000	24	30,000	18.0
Bananas	1,200	24.0	1,000-1,300	20-26	700	14.0
Papaya	—	—	—	40	—	25.0
Avocado	—	3.5-5.0	—	4-5	—	3.0-4.0

[a]Yield computed based on 0.6 lb/fruit *average* weight since this crop is normally sold on a count basis rather than by weight.

SOURCE: G. L. Morris, and D J. Pool, "Assessment of Semiarid Agricultural Production Technologies for the U, S.-Affiliated Caribbean Islands," OTA commissioned paper, 1966

Photo credit: Office **of Technology Assessment**

Although forestry research is being conducted on most U.S.-affiliated islands, including this experimental plot at an Agricultural Experiment Station on Pohnpei (FSM), most wood products continue to be imported to the islands.

retail value of about $200,000, while the island's imports of forest products totaled $410 million (121).

Until recently, the forests in the U.S.-affiliated islands have not been managed actively. In fact, while overexploitation is not now a problem in most areas, poor land uses in the past have left the islands with significant amounts of abandoned agricultural land and relatively unproductive secondary forests. Development and implementation of appropriate forestry technologies could help alleviate rural unemployment, provide local substitutes for some imported products, and help protect land and nearshore resources against erosion, floods, sedimentation, and similar environmental damage.

One method to derive economic benefits from forest resources without disrupting their environmental services is to promote the profitable and sustainable use of animals and plant products other than wood. The potential to develop such products is not large in Puerto Rico and the USVI, but some opportunities exist, such as small-scale production of honey, bamboo products, and eucalyptus leaves and oil (121). Because gathering activities are a normal part of subsistence life on the Pacific islands, this sort of development has considerable potential. With careful management to avert the threats posed by gathering activities to indigenous animal and plant life, harvest of products such as essential oils and mangrove aquatic organisms can continue on a subsistence and semicommercial scale without causing forest degradation.

Relatively little potential for full-scale industrial logging exists in the U.S.-affiliated islands due to limited acreages, topographical factors, competing land uses, small landholdings, high land prices, and uncertain land tenure. Significant potential for commercial forest plantations exists only for the larger islands of Puerto Rico, American Samoa, Guam, Pohnpei, and Palau. However, standard timber stand improvement techniques, such as enrichment planting (wherein higher value species are underplanted in natural second-growth forests) could result in valuable future timber stands on these islands (121). Some of these techniques are being used in the Puerto Rican National and Commonwealth forests. Subsequent harvest provide income for the Puerto Rican Division of Forestry and supports further management of the Caribbean National Forest.

Considerable potential does exist for small-scale industries that can serve domestic markets (121). For example, portable sawmills were introduced to Puerto Rico in 1982. Teak, mahogany, and Caribbean pine have been successfully and economically thinned, milled, and marketed by the Puerto Rico Forest Service. portable sawmills, combined with regulation

Photo credit C. Whitesell

Small portable or stationary sawmills (shown here on Pohnpei, FSM), combined with reforestation and regulation of exploitation, probably are the best-suited timber harvesting systems for the U.S.-affiliated islands because they can support rural industries and yet can be temporarily retired without significant economic disadvantage.

of exploitation; are probably the best-suited harvesting systems for the western Pacific as well, because they can be used as needed and temporarily retired without significant economic disadvantages. Because they can be pulled to the harvest site behind small vehicles, they cause less harm to thin soils than larger systems. They do not require an extensive road system and they leave bark and branches on the site, thus reducing nutrient loss.

Moreover, small-scale sawmills in rural areas can stimulate development of local workshops with corresponding effects on rural employment. These effects could be expanded by introducing facilities such as simple and inexpensive solar kilns or wood preservation equipment. This type of forest industry can be upgraded as workers improve their skills, local management masters the task, and local markets grow to absorb the increased production.

Even though managed second-growth forest is not likely to become a major land use in the U.S. insular areas, it merits consideration as an improvement over unmanaged, low-quality brush or forest land unsuitable for agriculture (121). In Puerto Rico, managed second-growth forests can provide a first harvest before conversion to plantation forestry or increase the value of land deliberately held out of intensive production (e.g., recreation sites).

The most pronounced impacts of forest degradation in the U.S. tropical territories are on island streams and coastal resources. Deforestation has caused permanent streams on some islands to disappear and contributes to increased runoff, flooding, water shortages, and erosion. Siltation has harmful effects on lagoons and reefs, affecting fish and other marine resources important to island people. Increased financial and political support for insular forestry programs could foster reforestation, development of plantation and second-growth forest management, and build local forest industries. Further, science and environmental education in primary schools could direct students towards an understanding of the importance of forests to quality of island life and encourage them to enter relevant fields of study.

TECHNOL0GIES SUPPORTING AGRICULTURAL SUSTAINABILITY

Agriculture cannot be a productive sector of island economies if soils become too nutrient-depleted or if erosion cannot be controlled. Thus, many technologies supportive of agricultural sustainability are aimed at restoring or improving soil quality, or at minimizing soil loss through erosion. Terracing and contour farming, cultural practices and crop choice, conservation tillage, and revegetation can all be used to control erosion. This will have the additional beneficial impact of reducing sedimentation in shallow coastal waters—probably the single greatest cause of coral reef degradation around high Pacific islands (40). Soil amendments and composts, use of nitrogen-fixing intercrops, and salt-resistant crops can increase productivity on infertile soils. Lengthened fallow periods allow natural soil organic matter recovery and growth of regenerated vegetation helps prevent erosion. Finally, reducing crop losses from pests can reduce the extent of land and intensity of use required to meet a production goal.

POTENTIAL STRATEGY: Minimize Soil Erosion and Degradation

Before human intervention, most lands in the U.S.-affiliated islands were forest-covered. Although tropical soils are diverse and variable, in general, few tropical forest soils can sustain productive agriculture over the long term. The presence of either heavily leached soils of low fertility, thin erosion-prone soils, or dry soils makes the establishment of permanent sites extremely difficult. Although soils on certain deltas, young volcanic materials, and flood plains may be fertile, most soils in hot, wetlands have significant fertility problems caused primarily by leaching of nutrients from rock and soil mineral particles. Often, such soils have a poor ability to hold common plant nutrients; if such nutrients are added to the soil as fertilizer they can be expected to be leached away rapidly (121)

In arid/semiarid areas, such as Puerto Rico's southern coastal plain and the USVI, nutrients needed by many plants commonly are in the soil, but become available to the plants only if sufficient water is available. If most of the water evaporates rather than percolating through the soil, dissolved solids or salts can accumulate at or near the land surface in concentrations that few plants can tolerate (121).

Tropical mountainous soils are, in general, rocky, thin, and easily eroded (121). U. S.-affiliated tropical high islands tend to have substantial areas of steep ridges and deep valleys; mountain slopes are extremely steep. For example, about half of Puerto Rico consists of slopes of 450 or more (137), and only 30 percent of American Samoa has slopes less than 30° (138). Thus, minimization of soil erosion and degradation are integral to maintain productive agriculture in the U.S.-affiliated islands.

Soil erosion is greatest in conventional row-cropping, where soil is loosened and exposed to weathering. For example, studies of test plots in Puerto Rico indicate that, on sloping lands, improved pastures suffer the least (1 ton/acre/year) and clean-tilled cultivated crops the most (17 tons/acre/year) soil losses (101,146). Row crops grown under clean-tilled agriculture commonly do not provide soils with adequate protection against heavy rainfall. Depletion of soil

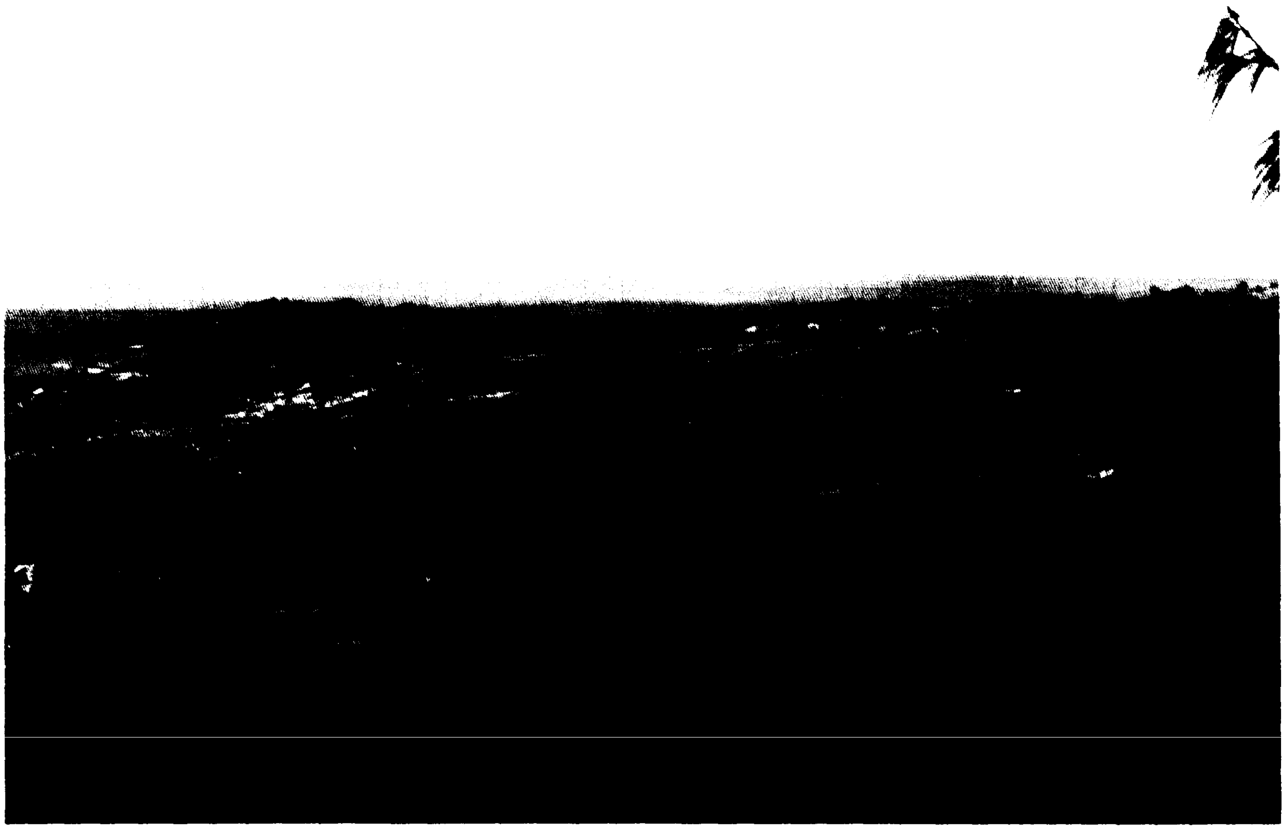


Photo credit: Office of Technology Assessment

These degraded volcanic soils on southern Guam illustrate the potential for reduction in development options caused by uncontrolled soil erosion; few species can survive under these conditions. Revegetation of these lands with more desirable species will be a difficult, costly, and lengthy process.

nutrients through erosion and leaching and changes in soil texture associated with clean-tilled cultivation methods result in soil degradation.

Soil degradation also can be the result of shortened fallow periods. Shortening of fallow periods can "short-circuit" the natural regenerative capacity of the ecosystem. Natural vegetation contributes organic matter to the ecosystem, and gradual accumulation of this organic matter allows the land to recuperate and become productive.

In Micronesia, degraded lands are characterized by depauperate vegetative cover consisting of savanna dominated by swordgrass *(Miscanthus)* or *Gleichenia* ferns and *Pandanus* trees. Frequent deliberate burning of vegetative cover make these lands increasingly unproductive (22,121).

Ways to prevent land degradation or to improve marginal and degraded lands include the following:

- lengthen fallowing periods,
- restrict and control burning,
- implement soil conservation measures,
- apply soil conserving cultural methods, and
- enhance reforestation programs.

Opportunity Lengthen Following Periods and Restrict Burning

It is well known that shortened fallow periods will degrade tropical soils because organic input into the soil from regenerated vegetation is curtailed (121). Furthermore, too frequent burning of old garden sites, shortened fallow periods, and open field row-cropping practices without sufficient addition of organic matter will rapidly deplete soil fertility (22). Severely depleted soils will support little vegetative growth. Soils with little vegetative cover are prone to erosion and leaching by heavy rainfall and strong wind.

Normal fallowing periods might be shortened by planting nitrogen-fixing legumes. Woody species might also provide useful products such as posts and fodder. However, care must be taken in choosing varieties; for example, giant Leucaena can be difficult to control and can grow tall quickly enough to shade out fruit trees (22).

Opportunity: Implement Soil Conservation Measures

Contour cultivation and terracing on sloping lands and covering freshly prepared soil with mulch may reduce soil erosion problems (143).

Terracing.—A classic example of soil conservation measures for cultivated lands is terracing of steep lands. One example of terrace farming is perennial herb cultivation on rock terraces in the USVI. Herbs and spices are grown essentially clean-tilled on narrow, irrigated rock terraces along with fruit trees that serve as windbreaks and also mark field boundaries (52).

Other terraces have been constructed on steep slopes using contour rows of closely spaced fast-growing trees. Trunks are allowed to stand, serving as retaining walls with the new growth regularly cut and piled horizontally above the trunks. At regular intervals soil is piled up on top of the organic debris for gradual formation of bench terraces. Hardy, tall grasses also have been used to form bench terraces. Both terracing and contours increase water infiltration and organic matter accumulation as well as control soil erosion (52).

Terraces are earth embankments, channels, or combinations of embankments and channels built across the slope of the land at suitable spacings and with acceptable grades (box 6-B and figure 6-3). They provide maximum retention of moisture for crop use and reduce soil erosion by removing surface runoff at a nonerosive velocity and/or reducing peak runoff rates (123). Terraces may also facilitate irrigation and drainage, as well as cultivation. Benches can improve drainage by concentrating runoff at the inside of the bench and then draining it along a controlled lateral gradient to a protected waterway. They are suited to annual, semipermanent and mixed crops and can be applied on slopes up to 300 (122). Through these mechanisms water quality in adjacent streams may be enhanced.

Terraces may trap up to 85 percent of the sediment eroded from the field, although they cannot stop erosion between terraces. Terrace construction may cause surface compaction and remove topsoil from large areas of the field. Uneven drying, pending, and severe erosion in different parts of the same terrace channel are also common, especially for the first 3 to 5 years after construction. In addition, misalignment of terraces may result in problems with maneuverability of machinery and maintenance of grass waterways.

The design and construction of a terrace system is labor-intensive and often expensive, and may require skilled professional assistance. Further costs include loss of land to terrace backslopes, loss of crops during construction year, higher labor and energy costs to work terraced fields, and costs of controlling insect pests that may be harbored in backslope grass strips. In addition, maintenance is mandatory to retain an adequate terrace cross section for proper functioning of the system (123).

The applicability of terracing in island areas may best be illustrated by example. During the Danish control of the USVI, the islands were nearly covered with stone terraces, allowing extensive cultivation of sugarcane on steep slopes. This method fostered a sugar economy that persisted for nearly 100 years. Similarly, early inhabitants of some of the Micronesia islands created terracing for agricultural purposes. Remnants of stone terracing still remain in Palau and the Marianas.

Box 6-B.--Terracing

Terraces not only control erosion but also can be used to facilitate irrigation and drainage, as well as cultivation. Reversed-slope benches, continuous or discontinuous, differ in width to suit different crops and slopes. Benches improve drainage by concentrating runoff at the inside of the bench and then drain it along a controlled lateral gradient to a protected waterway. Terraces are suited to annual, semipermanent, and mixed crops and some types can be applied on slopes of up to 300. Variations of conservation structures include:

- Bench terraces: A series of level strips running across the slope supported by steep risers. These can be used on slopes up to 25° and are mainly used for upland crops.
- Hillside ditches: A discontinuous type of narrow, reverse-slope bench built across the hill slope in order to break long slopes into many shorter ones. The width of the cultivable strips between two ditches is determined by the slope of the land. They are inexpensive, flexible, and can be built over a period of years. This treatment can be applied to slopes up to 25°.
- Individual basins: Small, round benches for planting individual plants. They are particularly useful for establishing semipermanent or permanent tree plots to control erosion. They should normally be supplemented by hillside ditching, orchard terracing, and crop covering.
- Orchard terraces: A discontinuous type of narrow terrace applicable on steep slopes up to 300, Spacing is determined by distance between trees. Spaces between terraces should be kept under permanent grass or legume cover.
- Intermittent terraces: Bench terraces built over a period of several years.
- Convertible terraces: Bench terraces with the spaces between planted with tree crops.
- Natural terraces: Constructed initially with contour embankments (bunds) 20 inches high on slopes not over 7° and on soils having high infiltration rates.
- Hexagons: Special arrangement of a farm road that surrounds or envelops a piece of sloping land treated with discontinuous terraces which are accessible to four-wheeled tractors. This treatment is primarily for mechanization of orchards on larger blocks of land and on slopes of up to 20°,

Contour Farming.—The practice of planting on a line perpendicular to the slope of the land is termed contour farming. This practice is relatively inexpensive, basically only requiring a reorientation of planting patterns. The effectiveness of contouring however, decreases as the inherent potential for erosion increases. Some climatic, soil, or topographic conditions may limit the application of contour farming,

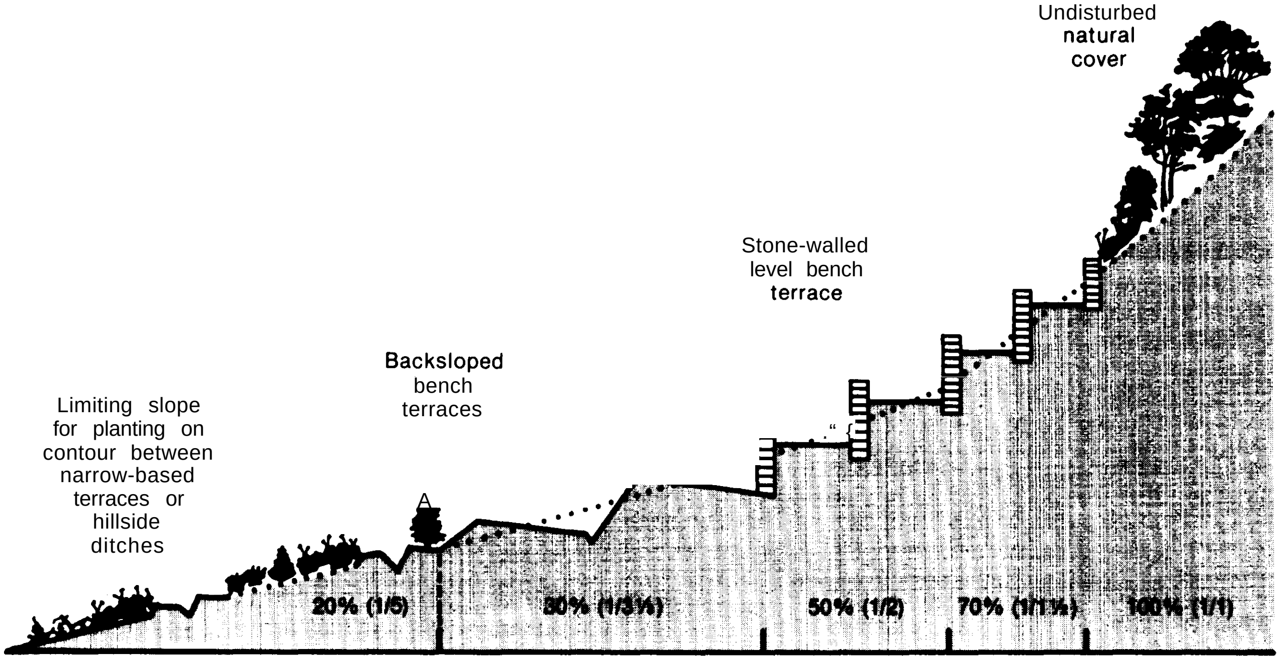
A variation of contour farming is contour stripping in which relatively narrow strips of crops are interplanted with close growing pasture grasses. The strips are oriented approximately on the contour and perpendicular to the slope. Similarly, strips of erosion-resistant crops can be alternated with strips of erosion susceptible crops, The actual width of the strips varies with the topographic features such as length, degree of slope, and exposure of the slope to winds, and with factors affecting field erodibility, e.g., soil texture, roughness, wind velocity, frequency, and direction (122).

Contour strip cropping may significantly reduce soil erosion beyond regular contour farming. The grass strips serve to slow the velocity of the runoff and further reduce soil loss, Contour strips are relatively inexpensive to install, however, some acreage is lost to the maintenance of the grass strips, headlands, and waterways, thus reducing productive acreage.

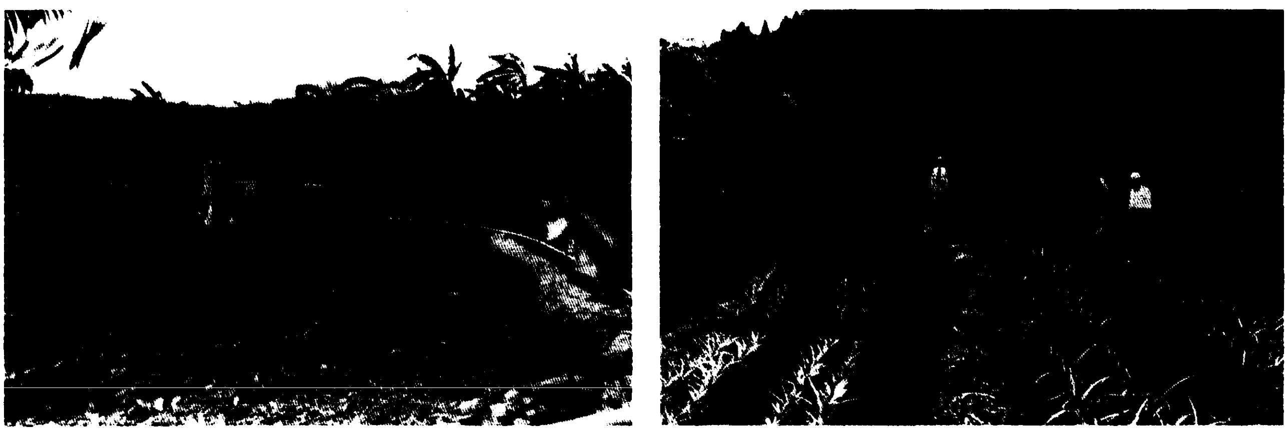
Many tropical areas suffer from severe soil erosion and implementation of some variation of these cropping schemes may serve to decrease soil loss. However, rainfall levels and soil depth may limit the effectiveness of these practices.

Mulching.—Mulches, nonvegetative, and processed covers can protect areas from severe soil erosion, and contribute to soil moisture reten-

Figure 6-3.—Slopes and Appropriate Conservation Measures



SOURCE: H.C. Pereira, "Soil and Water Management Technologies for Tropical Forests," OTA commissioned paper, 1982,



red W.

Terraces can be designed for varying farming scales and systems, and to fit differing availability of labor and capital, ranging from handmade stone terraces such as on this communal farm on St. Thomas (USVI) to large, grass-backed bench terraces developed at the Mayaguez Tropical Agriculture Station (Puerto Rico) in the 1930s.

tion. Mulches contribute to retention of soil moisture by reducing loss by evaporation as well as discouraging weed growth.

Organic (grass, leaves, etc.) and inorganic (plastic) materials may be used as mulch. Soil quality is enhanced by decomposing organic mulches. Further, organic mulches contribute to reducing soil temperature and thus keep root systems cool (102, 122). Plastic mulches, while more durable, may increase soil temperature.

Fertilizer application becomes more difficult in mulched fields; fungi growth may be encouraged in more moist areas and insect pests may become established in the mulch requir-

Photo credit: A. Vargo

Mulching is a common agricultural practice on the U. S.-affiliated islands to reduce weed infestations, help retain soil moisture, and provide soil cover. Organic mulches, which also provide nutrients as they decay, can be applied by simply cutting weeds on the site and planting through them after they have dried.

ing some pesticide application or biological control. However, appropriate mulching techniques, such as leaving space around the stem of the plants to reduce fungi and pest attack of the stem, can be employed to offset inherent problems with mulching.

Costs often prohibit widespread application of this method of erosion control. However, it may be appropriate for some open field crop lands, specialty crop lands, and "hot spot" erosion problems in large dryland agricultural areas (122) such as the south coast of Puerto Rico.

Land Leveling.—Land is often leveled or benched for purposes of water erosion control, irrigation, and moisture conservation. Land leveling may facilitate drainage and mechanization and reduce wind erosion by shortening field lengths and reducing slope (122).

However, land leveling is expensive and is profitable only for high-value crops. Puerto Rico employed precision land leveling to prepare approximately 5,000 acres for rice production in 1978. The effort was costly in both time and money. Currently, only 2,500 acres are producing (143).

Opportuntiy: Apply Soil-Conserving Cultural Practices

Careful selection of crops and cultural practices can minimize soil losses. Well-managed pastures and, to a lesser extent, certain cultivation methods of plantain, banana, coffee, and cocoa may offer varying degrees of protection against soil erosion on sloping lands. Conservation tillage (e. g., no-till farming) can reduce erosion. However, polyculture is the primary means to minimize the adverse environmental impacts of cropping on sloping lands. Interplanted shrubs or trees also can protect crops from wind damage and salt spray.

Soil-Conserving Crops and Intercrops.—Groundcover legumes such as Centrosema *pubescens, Desmodium trifolium,* and *Pueraria phaseoloides* can be grown to provide fast vegetative recovery on bare soil. These plants fix atmospheric nitrogen, add organic matter (green manure and forage), and shield the bare soil surface from erosion (74). In Papua New Guinea, winged bean traditionally is grown on stakes for pods and seeds or grown unstaked for tubers and as an effective ground cover. Every part of the plant is edible and contains high levels of protein (77).

Tree crops are the primary means for limiting soil erosion in tropical agriculture. These can be intercrops, or as boundary "hedgerows" on clean-tilled agriculture.

Conservation Tillage.—Conservation tillage involves allowing approximately one-third of the mulch from previous crop harvest to remain above the soil surface after planting (120). This cropping system is designed to reduce soil erosion and aid in soil moisture retention by absorbing the impact of rainfall and protecting the soil surface from wind abrasion. Further, the crop residue contributes to the decrease of soil temperature.

In addition to erosion control benefits, economic incentives for adoption of this technology exist. Reduced labor requirement—less time is required to till the fields; reduced preharvest fuel requirement—fewer passes across the field are required; lower machinery costs—

lighter, and thus less expensive, machinery can accomplish the tillage, and benefits of reduced soil erosion allow expansion of cropping onto sloping lands.

However, the crop residue which remains may also offer habitat for insect pests as well as plant diseases. While disease-resistant crop varieties may be available, increased pesticide applications may be required to control insect pests. In poorly drained soils conservation tillage may prove undesirable.

This tillage method also relies heavily on herbicides for weed control which may have far--reaching ecological impacts (120). Most herbicides do not attack the root systems of weeds, thus in tropical areas where the growing season is year long, frequent application of herbicides may be necessary.

Conservation tillage schemes have proven successful in reducing sedimentation from agricultural runoff. However, the increased chemical pollutants and nutrients may adversely affect water quality and aquatic life. Additions of nutrients accelerate plant growth in aquatic systems which in turn reduces oxygen concentrations. This accelerated eutrophication can significantly affect fish survival. Increased herbicide and pesticide applications may infiltrate groundwater supplies (120). Since the freshwater lens beneath islands is small, the contamination can be significant, affecting the entire island's freshwater supply. Contaminants contained in runoff and carried to streams and nearshore waters may damage associated aquatic life.

The net result of conservation tillage on nutrient pollution of surface water and groundwater will vary under different conditions. For example, losses for either system can be quite high if rainfall occurs shortly after fertilizers or pesticides are applied. Tropical regions generally receive abundant rainfall, thus increasing the chance for higher pollution rates, as well as necessitating increased fertilizer and pesticide applications since much would be lost in runoff.

Hedgerows and Shelterbelts.—Hedgerows (windbreaks) and shelterbelts which reduce field length and windspeed also help control soil erosion from wind and water (120,123). Further, they enhance water retention in the soil and improve associated stream water quality by capturing sediment from runoff. An early Danish conservation law (1840) in the USVI involved the maintenance of fruit tree stands as shelterbelts to enhance water retention. Applications such as this provide both ecological and economic benefits.

The effectiveness of any barrier depends on the wind velocity and direction and on the shape, width, height, and porosity of the barriers. Nearly any plant that reaches substantial height and retains its lower leaves can be used effectively as a barrier. Tree windbreaks have most application on sandy soils and in areas where there is substantial rainfall. Typically, on atoll islands where crops are extremely vulnerable to wind and saltspray damage, the beach strand vegetation is maintained on the seaward side of the island to function as a windbreak. Narrow rows of of tall-growing field crops, perennial grass barriers, solid wooden and rock walls also may serve as windbreaks (121). Windbreaks may interfere with large machinery, however, they should be applicable for small-scale agricultural operations.

Maintaining vegetated riparian zones along streams is important for maintenance of water quality and associated aquatic life. Streamside vegetation helps moderate water temperature fluctuations, filters sediments and nutrients harmful to aquatic life, and may provide habitat for fish spawning and breeding (120).

POTENTIAL STRATEGY: Enhance Revegetation Programs

A primary cause of land degradation is forest clearing, leaving the cleared land without

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6 Degradation of tropical land is a physical, chemical, and biological process set in motion by activities that reduce the land's inherent productivity, This process includes accelerated erosion and leaching, decreased soil fertility, diminished natural plant regeneration, disrupted hydrological cycle, and possible salinization, waterlogging, flooding, or increased drought risk, as well as the establishment of weedy plants that displace more desirable plant species. Evidence that the degradation process is advancing includes, for example, a reduction in the water-holding ability of the soil, a decrease in the amount of soil nutrients available to plants, a reduction of the soil's ability to hold nutrients, or soil compaction or surface hardening.

means to replenish soil nutrients. Because the major soil nutrient supply is in the vegetation, productivity of degraded lands could be improved, in part, by revegetation. Methods to enhance vegetative inputs to replenish soil nutrients include traditional and commercial agroforestry, short- or long-rotation forestry, or growing ground covers such as grasses or nitrogen-fixing legumes.

Choice of vegetation type for reestablishment depends on the objectives of revegetation. For exampIe, if lands are to be used for pasture, grasses and leguminous groundcovers maybe most appropriate. If direction of surface runoff into water catchments is a primary goal, grasses are probably preferable to trees, which transpire considerable amounts of water. However, if the watershed is steeply sloping, the greater erosion control afforded by brush and tree cover may be required to increase the longevity of the catchment. Further, on degraded lands where weeds easily can outcompete most smaller species, tree species that can shade them out may be necessary,

Selection of plant species is critical. Early succession species need to be highly competitive pioneers, able to outcompete weed species, and should have a dense and effective root system to minimize leaching and erosion (7). Many degraded soils commonly retain less moisture than protected soils (147), thus, early succession tree species may need to have tap roots—roots that rapidly grow deep into the soil that allow them greater access to soil moisture than shallow-rooted trees. In addition, tree species chosen to increase organic matter in degraded soils must be those that allow establishment of some undergrowth. Therefore, trees such as certain eucalypts probably should be avoided as allelopathic chemicals released by the trees into nearby soils preclude growth of understory plants.

Opportunity: Establish Forest Plantations

Rotation ages of tropical forest species vary and depend on the product to be harvested. Short-rotation species (first harvest in less than 6 years) like *Gliricidia, Leucaena,* and *Sesbania* can be harvested every few weeks for forage or green manure or every 6 months for forage and fuelwood. Harvest of poles from the Caribbean pine can take place several years after planting. Conventional long-rotation forestry of hardwood timber trees, such as teak or mahogany, can require 60 to 100 years before first harvest.

Nitrogen-fixing legumes possess favorable characteristics for both short-rotation forestry systems and for improving degraded land. Fast growing nitrogen-fixing shrubs such as *Sesbania* and *Crotalaria (27)* or nitrogen-fixing trees such as *Leucaena leucocephala, Casuarina* and *Acacia* are suitable for planting on degraded lands (70,71,75). For example, it is estimated that nitrogen-fixing *Leucaena* can supply 500 to 1,300 lbs of nitrogen per acre per year (75). Moreover, a variety of nitrogen-fixing trees can be used as fuelwood, fodder, nurse trees, timber/pulpwood, food, gum and medicines, or for shade trees. However, many of the fast-growing legumes can become pests in certain cases (e.g., Guam). This needs to be considered before species introduction is undertaken (7).

Reforestation of degraded lands provides benefits apart from products. Forests provide many environmental services such as reducing the force of wind, creating cool understory microclimates, protecting and, in some cases, improving the soil's productive potential. Foliage dropped by forest plants provide organic matter which, as it decays, improves soil fertility. Forests control soil erosion, regulate soil moisture, and mitigate flooding. Furthermore, forests may serve as sanctuaries of wild plants and animals and, therefore, increase and maintain greater species diversity.

Opportunity: Improve the Productivity of Degraded Grass and Fern Savanna Lands

Degraded lands have become quite extensive in the U.S.-affiliated islands, especially in southern Guam and the western Carolines. These lands commonly are no longer used for agriculture, although some may be used when more fertile areas are not available. The grass *(Miscanthus)* and fern *(Gleichenia)* species which predominate on degraded insular lands are aggressive species. Their dense networks of roots crowd out many other species and deprive them of moisture during dry seasons. Plowing and burning may allow temporary use of these lands for grazing, but commonly only encourage further grass and fern growth and expansion.

Grass and fern savanna lands could be afforested (or reforested) to increase wood, food, fodder, and fiber production. Trees protect soil from the effects of tropical heat, rain, and wind. Soil temperatures are lower under tree canopies, permitting reaccumulation of organic matter that restores soil structure and microbiota and enhances moisture- and nutrient-holding abilities. Bacteria on the roots of some tree roots can convert soil minerals to useful forms. In dry areas, trees can help to prevent the rise of saline groundwater. Where surface soils are dry or infertile, deep tree roots can tap underground reservoirs of nutrients and water and bring them to the surface. Tree species selected for reforestation of savanna lands should possess the following characteristics to counter those factors that allow grass and ferns to dominate:

- easy establishment,
- rapid early growth in poor soil conditions,
- deep rooting,
- dense crown to shade out grasses and ferns,
- nitrogen-fixing and soil-improving characteristics, and
- fire resistance (122).

Acacia, Calliandra, Gliricidea, and *Leucaena* species have been used successfully to reclaim such lands. Best tree growth occurs if the grass is cut and burned prior to planting, and if large seedlings are used to withstand competition with the grass (122).

Once an area of such species have been established and soil productivity regenerated, enrichment planting and other second-growth forest management techniques can gradually improve the economic value of the stand. Eventually, agroforestry and agriculture maybe introduced into the area.

Steps involved in reclamation might include:

1. inventory of degraded lands to classify them into subtypes;
2. protection of suitable areas of endemic communities;
3. development of fire prevention programs, including construction of firebreaks, public education programs, and improving the means to fight fires and enforcing fire laws; and
4. establishment of reforestation plantings on selected degraded lands using local species as well as selected exotics and development of plans for controlling aggressive exotic species and conversion of areas to more useful species (22).

POTENTIAL STRATEGY: Develop Local Soil Amendments

In traditional systems, nutrients cycle within the system and few nutrients are removed by harvest. In commercial technologies, especially monoculture, these natural cycles are broken and there is a larger resultant nutrient drain on the system. Introduction of additional nutrients is needed, either through manure, organic fertilizers (sea cucumbers, seaweed, dead grass and leaves, compost), or commercial fertilizer. Because most soils in the islands are relatively nutrient poor due to leaching, erosion, and other factors, the need to use soil amendments to obtain commercially acceptable yields is imperative (94).

Numerous fertilizer trials have been carried out in the U.S.-affiliated islands, and the use of commercial fertilizer is widespread. Most fertilizer technology has been adopted directly from the United States, despite evidence that tropical soils respond much differently to fertilizer than temperate soils. There also is growing concern about the potentially adverse impacts of fertilizer use on insular groundwater and marine ecosystems (94).

The U.S. Soil Conservation Service (SCS) has completed comprehensive soil surveys for all U.S. Caribbean islands; similar studies have been completed for all major U.S. Pacific islands. However, adequate soil testing to determine nutrient deficiencies is limited to Guam where a soils laboratory was set up by the University of Guam in 1975. Few other islands currently make use of this service. Implementation of this information may depend on further training of agriculture department personnel. Research also is needed on other methods of maintaining soil fertility such as green manuring, intercropping with legumes, fallow periods, and crop rotation (94).

Organic Matter.—Many organic materials contain components other than nitrogen, phosphorus, and potassium which can contribute significantly to increased crop yields, including secondary and micronutrients and, sometimes lime. The crop yield response to an organic amendment, however, follows the "law of diminishing returns"; the capacity of organic matter to elicit yield responses declines with succeeding crops **(83)**.

USDA has identified a number of ways that organic matter could be used more effectively as soil amendments:

1. improve methods of manure collection, storage, and processing (e.g., comporting) to minimize nitrogen losses that often occur in these operations;
2. apply wasted manures to lands;
3. apply wasted crop residues to lands;
4. increase use of sewage sludge on land; and
5. increase use of the organic/compostable fraction of municipal refuse **(83)**.

It is well established that microorganisms are beneficial to soil structure and that soil aggregation can be increased by the addition of crop residues presumably due to resultant soil microbial activity during the decomposition process (19). Burning crop residues in place instead of comporting destroys much of the nitrogen contained in the residue, Burning may result in soil erosion problems, destroy any soil-conditioning effects of the residues, and modify the ecological effects of the residue on the soil microflora. In some cases it causes the soil surface to become hydrophobic which can reduce infiltration and water storage (19).

It is unlikely that organic fertilizers will totally replace commercial fertilizers, nor should that be the goal. Evidence indicates that higher crop yields are possible when organic wastes are applied in combination with commercial fertilizers than when either one is supplied alone. Thus, organic amendments may increase the efficiency of commercial fertilizers *(83),*

Soil Microorganisms.—Soil particle aggregation and, therefore, erosion control can be effected by a range of polysaccharides and other gums that are produced by soil microorganisms (44). The size and composition of the microbial mass present determine the degree of the effect.

Mycorrhizae, a group of fungi associated with plant roots, often promote more efficient use of applied fertilizer *[62).* For example, in several experiments on tropical soils, legumes responded little to the addition of rock phosphate unless they were mycorrhizal. Uptake of minor elements with slow soil diffusion rates, like copper and zinc, also can be increased by mycorrhizal presence.

In naturally regenerating degraded tropical soils, the new vegetation will consist predominantly of nonmycorrhizal plants *(62).* Finally, it is well documented that plants with mycorrhizal associations transplant better than nonmycorrhizal.

Composts.—Composting is the biologic conversion of organic wastes to humus, a nutrient-conserving process carried out by a complex of aerobic organisms and microorganisms that occur naturally in soils. In simple systems, soil, manure, and plant residues, or a combination of animal, human and crop wastes, are layered in a pen or bin. The pile heats as the waste decays and is turned manually and rewetted as needed. The process commonly is complete in 4 to 12 weeks. More complex systems are more labor-, material-, and cost-intensive (73).

USDA recently developed a highly successful method for comporting sewage sludge, animal manures, municipal refuse, and pit latrine wastes called BARC (Beltsville Aerated Rapid Comporting). This method has been adopted widely in the United States and in some lesser developed countries. It is simple, effective, inexpensive, and allows considerable trade-off between labor and capital.

After compost is applied to fields, waste nutrients and nutrients from the organisms themselves are slowly released, allowing long-term uptake by plants. Compost also improves the physical structure of soil and its water-holding capacity.

Inorganic Soil Amendments.—One strategy with potentially significant applications to agriculture on U.S.-affiliated islands involves "turning rocks into fertilizers" using naturally and widely occurring inorganic materials as agricultural inputs.

The potential for agricultural uses of natural materials like zeolites and rock phosphates, and for increasing yields by mixing these inorganic materials with organic manures and composts containing soil microorganisms is thought to be considerable (65]. Geologists in Canada and the U.S. Geological Survey who have been studying some of the natural fertilization systems are enthusiastic about their potential uses in a number of countries where the economic and environmental costs of conventional fertilizers are prohibitive.

Zeolites are a family of common silicate minerals that often occur in or are associated with volcanic rock. Zeolite minerals participate in chemical exchange reactions that have been shown to increase crop yields in experimental systems and field trials. These minerals can take in nitrogen from manures and other sources and release it slowly in soils in a form plants can use (i.e., they have a high ion-exchange capacity). They can induce the breakdown of rock phosphate, making another important nutrient available to crops. Laboratory tests in Guelph, Ontario (Canada), have shown that zeolite treated rock phosphate releases its phosphate into soils up to 100 times faster than rock phosphate alone (112). Because of their high ion-exchange capacity and water retentivity, natural zeolites have been used extensively in Japan as amendments for sandy soils (65).

A variety of microorganisms are known to solubilize different insoluble inorganic phosphates, permitting their uptake by plants. Although the relation of these organisms to crop yield has been a subject of much controversy, recent research (58) demonstrated that yields of two study crops were higher after application of composts enriched with rock phosphate than after application of rock phosphate or of composts alone. Phosphate-enriched composts were associated with higher yields than even superphosphate, with its extremely high levels of water soluble phosphate. This may be because of the the slow release of phosphorus from enriched composts.

Opportuntiy: Introduce Salt-Tolerant Crops and Systems

Salt spray and saline soils are a significant production constraint on atolls and shorelines of larger islands. Research has been conducted on Tarawa, Kiribati, on the salt tolerance of crops and on technologies to minimize salt effects on crops. A variety of strategies, including raised beds, windbreaks, organic matter amendments, and drip irrigation have been suggested to minimize salt damage to crops. Table 6-8 lists the salt-tolerance of some common crops. Further, selecting or engineering strains of highly salt-tolerant crops could permit the expansion of agriculture onto currently unusable lands.

Photo credit: A. Vargo

Pandanus, or screw pine, is a common beach strand plant on Pacific islands due to its tolerance of salt spray and saline groundwater. Fiber for weaving is derived from the fronds, and the fruit is eaten on some islands.

Table 6-8.—Salt Tolerance of Certain Common Crops

Hi ah	Medium	Low
Arrowroot	Broccoli	Alocasia taro
Asparagus	Cabbage, head	Banana
Beet	Cantaloupe	Bean
Coconut	Carrot	Breadfruit
Kale	Cauliflower	Celery
Pandanus	Corn	Colocasia taro
Papaya	Cucumber	Radish
Spinach	Cyrtosperma taro	
	Lettuce	
	Onion	
	Pea	
	Sweet pepper	
	White potato	
	Squash	
	Tomato	

SOURCE E Soucie, *Atoll* Agriculture, Ponape Agriculture and Trade School, Pohnpei, Federated States of Micronesia 1983

Photo credit A Vargo

Depredation by the imported Giant African Snail hinders vegetable cultivation on several U.S.-affiliated Pacific islands. Research to develop an integrated pest management (1PM) strategy is being conducted at the American Samoa Community College.

POTENTIAL STRATEGY: Reduce Agricultural Crop Losses

Major crop and livestock losses in the tropics are due to diseases, pests, and weeds prior to and after harvesting. Accurate data for postharvest losses are not available for most U.S.-affiliated islands (99). However, crop losses probably are similar to estimates given for the tropics, which is around 30 to 40 percent (155, 156).

Application of appropriate pest, disease, and weed control may reduce losses, effectively increasing yields. Various control methods have been applied to combat agricultural pests, weeds, and diseases in U.S.-affiliated islands, including: use of pest-resistant crops; chemical, biological and cultural pest and disease control methods; and integrated pest management.

Opportunity: Use of Pest- and Disease-Resistant Crops and Livestock

Cultivation of pest-and disease-resistant varieties of crops and livestock is a common traditional method of protection from pests and disease (94,142). The use of pest-resistant crop varieties or plants serving as pest repellents make cultural control methods more effective in preventing pest and disease infestations.

As with cultivation methods, use of pest-resistant crops is effective in avoiding pest and disease infestations, is inexpensive, easily transferable to small-scale farmers, and has little adverse environmental impact. Although this strategy holds promise for widespread application on islands, it is constrained by high costs for research, field trials, and development, Furthermore, little scientific data is available on the performance of resistant crops and livestock on islands (142).

Opportunity: Cultural Control

Cultural control is the avoidance or reduction of pests and diseases through the use of certain cultivation or husbandry methods. Cultural control methods, such as the traditional cropping systems, provide the most common method of pest and weed control by subsistence farmers on the U.S.-affiliated Pacific islands (22,41,94,142). Cultural practices which serve to control pests and weeds include: polycropping, field and crop rotation, time of planting, and irrigation methods. Although cultural controls alone may not eradicate pests, they often can reduce pest populations and enhance other control methods (124).

In polyculture, some plants may serve as physical barriers partially concealing or protecting susceptible crops from pests. Other plants may emit or secrete repellents or provide favorable environments for predators or parasites of pest species (3). For example, in American Samoa, taro armyworm may be controlled by intercropping taro with *Coleus blumea* which serves as insect pest repellant (142). Further, low crop density inherent to polycropping may attenuate the spread of diseases.

It is well known that crop and field rotations may suppress pest and weed infestations. Irrigation and regular flooding in wetland taro cultivation (55) and drip irrigation system in semiarid row cropping (61) also reduce pest infestations.

Cultural control methods are effective (especially when combined with the use of resistant crops), inexpensive, easily transferable to small-scale farmers, and have little adverse environmental impact. However, development of new cultural control methods is constrained by high costs for research and development and by lack of documentation of local knowledge.

Opportunity: Chemical Control

This involves application of chemical agents to control pests, diseases, and weeds. Chemical biocides are easily applied and generally have an immediate effect. In the United States, pesticides play a major role in pest control, increase crop yields and give about a fourfold return on investment (85). However, the presence of disease, pests, or weeds does not indicate that chemical application of control is needed, because many potentially harmful insects can be controlled by parasites and natural predators. Unnecessary chemical application may destroy the natural balance and lead to further serious pest outbreaks.

Under certain circumstances, chemical control may be the only effective method of dealing with pest infestations, for example for crop pests and diseases in greenhouses (10) or cattle tick control (9). However, little is known on the proper chemical application or formulation for tropical crops and on the long-term effects of these chemicals on the environment (142). Further, on U.S.-affiliated islands, application of chemical pest control is expensive due to costly importation of agriculture chemicals (43,94).

Although chemical control has immediate results, its effectiveness is generally short-lived, and it is an inefficient way to control pests in the field. Often, only a small quantity (less than 0.1 percent) of pesticides applied to field crops reaches target pests and the rest of the pesticides remain in the environment to contaminate the land, water, and air (85). Pests may acquire resistance and some chemicals may adversely affect nontarget organisms (124). Resistant pests make subsequent application of the same chemical ineffective. Since extension workers on some islands are few or inadequately trained, pest resistance or upset of natural predator balance may not be noticed (99).

On U.S.-affiliated islands, the Environmental Pesticide Control Act of 1972 requires the registration of agriculture chemicals for sale and extends control to actual application by the user. Certain restricted chemicals may only be applied by certified personnel, and penalties may be levied against those who misuse chemicals. Most pesticides, however, are not registered for use on tropical crops. Therefore, under U.S. regulations, special registration is required. This is done by field trials and monitoring of biocide residues in compliance with EPA regulations. These procedures require funds and skilled staff, and thus are beyond the capacity of most existing island institutions (99).

Since most U.S.-affiliated island are small, inappropriate application of chemical control may have very serious adverse environmental impacts.[7] Contamination of water lenses by the use of agriculture chemicals on small islands is of major concern (66); limiting or improving agriculture chemical applications may reduce contamination of the environment.

Opportunity: Locally Produced Pesticides

Certain local products may be able to take the place of some imported agrichemicals. For example, soap sprays were principal insecticides during the early 20th century in the

[7] A pesticide spill on Truk resulted in a fish kill estimated at 20 tons and another on Ulithi (Yap) may have contaminated the water supply; however, no tests have been run (24).

United States (17). Soap sprays are biodegradable, may kill enough pests to prevent serious damage to plants yet leave sufficient numbers to provide food and, thus, build beneficial populations of natural predators. Coconut oil soaps may be an effective pesticide against some insects and are readily available on most U. S.-affiliated islands. However, little research has been done on formulations, effectiveness, or tolerance by various tropical plants.

Pesticides also can be derived from certain plants that can be locally grown. Crude extracts from plants have been used as pesticides for thousands of years, and a recent compilation of plants used for pest control listed 700 species (l). Twenty-five species possess characteristics making them particularly suitable for propagation and use by resource-poor farmers (e.g., perennial species requiring little space, labor, water, or fertilizer with an easily processed product and possessing complementary uses).

The neem tree *(Azadirachta indica)* seems particularly promising for pesticide production on the U.S.-affiliated islands. The neem is native to the Indo-Pakistan region but has spread throughout the tropical world, including the Pacific and Caribbean islands. A group of biologically active constituents found in neem leaf, fruit, bark, and seed reportedly provide antifeedant, growth regulatory, repellant, hormonal, or pesticidal control in more than 100 pest species (l).

Neem leaves, neem seed oil, and the "cake" resulting from oil extraction can all be used for pesticide. The cake can be worked directly into the soil and neem oil can be spread through a simple sprayer. A number of other products, such as livestock feed, soap, and cosmetic oils can also be produced from the neem. The neem is salt-tolerant, can be grown on relatively infertile soils, and has been demonstrated effective at improving such soils. Research on neem tree cultivation and uses is being conducted by USDA, including the Tropical Agricultural Research Station at Mayaguez, Puerto Rico.

Opportunity: Biological Control

Biological control is a method whereby a predator, parasite, or disease agent is used to combat undesirable pests, diseases, or weeds. Identification of biological agents involves intimate knowledge of both pest and control agent, requiring considerable research, experimentation, and field trials (66).

Although biological control of pests and weeds may hold promise, development is costly and time-consuming. It requires funds, special facilities, and skilled staff; and thus it is beyond the capacity of existing island institutions (99,142).

Biological control works best on long-term crops, such as trees, which allow the control agent ample opportunity to become established. Biological control has been implemented in the U.S.-affiliated Pacific islands with varying success for eradication of fruitfly (66), the giant African snail (18), and rhinoceros beetle (79,99, 142).

In 1963, USDA succeeded in eradicating both the oriental fruitfly *(Dacus dorsalis)* and the melon fruitfly *(Dacus cucurbitae)* from Rota island (CNMI) by a method of "male annihilization" (killing male flies with a toxic attractant) and the sterile male technique (flooding the area with large number of sterile males). However, in recent years, the melon fruitfly has reappeared on Rota (66) possibly due to an ineffective quarantine program. Recently, introduction of an insect *(Pareuchaetes pseudoinsulata)* has proved effective in controlling a notorious weed *(Chromolaena odorata)* on Guam (66).

Generally, biological control is simple to implement once precise control procedures and control agents have been identified. Sometimes introduction of biological agents may have reverberating adverse effects after the target pest has been controlled. For example, the marine toad *Bufo marinus* was introduced both intentionally and accidentally through much of the Pacific islands during the last 50 years. The toad was thought to be a good biological control agent due to its large size and wide adaptability. It was introduced to Guam from Puerto Rico through Hawaii originally for insect and garden slug control and rapidly spread over the island. Later it was introduced throughout the remainder of Micronesia and American Samoa. While the toad did reduce slug and other pest populations, it also reduced populations of beneficial insects; contaminated drinking water; killed freshwater fishes, pets and, reportedly, some humans (18).

Opportunity: Integrated Post Management-

Integrated pest management (1PM) refers to the management of pest, diseases, and weeds using a combination of control methods. It relies on a balance of biological and chemical controls, and cultural practices, such as polyculture or timing of irrigation. Its goal is to coordinate multiple pest management technologies to assure stable crop production and maintain pest damage below the economic injury level while minimizing hazards to humans, animals, plants, and the environment (124). 1PM is considered the best long-term control strategy, both economically and environmentally. Under 1PM, chemical controls are used only when a predetermined economic level of damage has been reached.

Effective pest and disease control programs may increase productivity, quality, and thereby marketability of crops and livestock. High-quality products can be exported to metropolitan markets with little difficulty. For example, the occurrence of melonfly on Rota (CNMI) and Guam prevent fruit export from these islands to Japan as well as to other islands (66). For subsistence farmers, where the major bulk of the crop is consumed locally and little enters the market sector, reduction of crop losses results in greater security against lean years.

On U.S.-affiliated islands, the major stumbling block for the implementation of pest management is neither lack of technologies nor lack of funding, but lack of highly skilled and motivated agricultural staff and good agriculture extension services. Although some pest control methods, such as cultural control and 1PM, hold great promise for effective pest control on islands, government subsidies that lower the costs of agrichemicals may undermine other pest control methods which have less detrimental effects. Furthermore, islands lack aggressive quarantine programs to prevent reinfestation and reintroduction of pests. Strong policy commitments of local administrators to implement an effective pest control together with an effective quarantine program are also absent (66,142).

Pest control methods will have little effect on islands without concurrent efforts to prevent reintroduction of pests and diseases from other areas via incoming cargo such food imports from high risk areas. The USDA Animal and Plant Health Inspection Program (APHIS) operates on most U.S.-affiliated islands (43,142) and is administered by local Departments of Agriculture. However, the current program lacks an integrated preventive program (68), which might include:

- public education on the importance of plant and animal quarantine;
- rigorous inspection of incoming cargo, both by ship and air;
- inspection of planes and ships for insects and other pests;
- definitions of which countries are high risks for new pests;
- a list of crops to be protected and from what organisms; and
- continuous education programs to increase skills of inspectors.

APHIS, the University of Guam, and the United Nations' Food and Agriculture Organization (FAO) have developed training programs in plant protection and quarantine, and the FAO project on Strengthening Plant Protection and Root Crops Development in the South Pacific has recently reviewed plant quarantine programs in the FSM, Marshall Islands, CNMI, and Palau (39).

Quarantine regulations made along political rather than geographical boundaries also may unnecessarily restrict export of some agricultural products. For example, a quarantine on export of all citrus products was imposed on the FSM while its cause—the citrus moth—is reported to be found only in the western Caroline Islands. Thus, although unaffected, exports also were prohibited from the eastern Caroline Islands (39). USDA entomologists and plant pathologists could conduct surveys of pests of economic importance in the U.S.-affiliated islands, review quarantine and fumigation regulations, facilities and procedures for each major exporting island. Such surveys should result in better information for use by both USDA and island governments in their agricultural inspection and quarantine activities. This also may open U.S. and other markets to previously restricted agricultural commodities from the islands (39).

SUMMARY

A variety of agricultural methods are practiced in U.S. insular areas. However, significant constraints hinder application of certain agricultural technologies and agricultural development in many U.S.-affiliated islands. Factors that support and hinder application and implementation of sustainable agricultural technologies for U.S.-affiliated islands are many and vary between regions, islands, and polities,

Small land areas and population, fragmented land masses, great distances between islands, and isolation from major markets are not conducive to modern commercial development. Land tenure systems characterized by small parcels also make some forms of commercial development unlikely. Small farm size, however, does not constrain subsistence agriculture development and some forms of smallholder commercial agriculture.

Additional major constraints for modern agriculture development in the U.S. Pacific islands are limited arable land areas and low soil fertility. Limited fresh water on low islands and on semiarid regions of islands is constraining to conventional cropping methods. Environmental factors such as droughts and typhoons, and constant threat of pest and disease outbreaks are serious problems for agriculture. Furthermore, costly and irregular transportation services, poor storage facilities, and small markets on U.S.-affiliated islands compound the problems.

Universally high energy costs and expensive imported goods and supplies make application of energy-intensive commercial agricultural technologies uneconomical for most small tropical islands. This is especially true for adoption of typical U.S. mainland field cropping technologies which is based on a temperate climate, scarce and expensive labor, large-scale and highly mechanized operations, and abundant land.

Availability of high-paying government jobs and generous U.S. social support programs, make it difficult to find skilled farm workers at reasonable wages. For some islands, strong traditional social support and extended family welfare systems tend to hinder motivation toward working in low-paying "unprestigious" agriculture jobs or entering into risky commercial agricultural enterprises. Low labor productivity together with application of inefficient agricultural technologies make commercial farming uneconomical.

In U.S. Pacific islands, modern commercial agriculture development is further complicated by the heavy influence of traditional customs. Many islanders are caught between their own aspirations for higher levels of material living, which they hope to attain through commercial development, and the demand for observing customary kinship and family practices. Commercial agriculture often requires regular and long periods of work, prescribed schedules, and also accurate accounting of expenditures and income, Yet, demands to meet customary obligations to share with relatives are difficult to ignore, especially when farmers are dependent on regular reciprocal assistance. Under this system commercial enterprises are likely to operate under suboptimal conditions.

Opportunities

Despite these constraints, most islands have conditions that are conducive to development of certain types of crops, livestock, or "agricultural packages" (a combination of resources and methods that is productive and can be applied profitably at an acceptably low economic risk) for development.

Sustainable agriculture technologies maximize the use of abundant (inexpensive) or renewable resources and minimize the use of scarce (expensive) or nonrenewable resources. For the technologies to be readily adopted, they should maximize output per unit input of the scarcest resource. For example, if labor is expensive or scarce, labor productivity should be increased (e.g., by use of labor-saving equipment); if land is the most limiting factor, land yields should be increased through the use of intensive practices. Similarly, if water is scarce, water use efficiency should be increased through water management practices such as drip irrigation systems or hydroponics.

Technology packages should also be tailored to the local ecological, climatic, and sociocultural conditions. Characteristics of crops that generally are appropriate to U.S. island conditions include crops that: 1) are resistant to pests, diseases, and weeds; 2) thrive in poor soils; 3) require little or no irrigation; 4) require relatively little nonrenewable agricultural inputs; 5) require relatively little labor; and 6) produce high yields (48]. Crops should recover rapidly or suffer minimal damage from occasional adverse weather conditions such as cyclonic storms and droughts. For export, crops should be high quality, high value, low weight and bulk, or have a long shelf life. Characteristics of livestock appropriate to tropical islands include those that are resistant to diseases, pests, and parasites; that thrive on poor feed and forage; require little care; and that can adapt to variable weather conditions.

Few or no crops or livestock are so ideal as to fulfill each of these requirements. However, these desired characteristics can serve as objectives in crop, cultivar, and livestock choices. Because conditions vary among and within islands, ranking of objectives must be made on a case-by-case basis.

Some intensive, high-yielding farming systems are suitable for the larger islands. However, for the most part, agriculture systems on smaller and more remote U.S.-affiliated islands systems should be simple and nearly self-sustaining, including:

- systems that use minimal mechanization, thus avoiding expensive repairs, spare parts, and fossil fuel imports. Where mechanization is required, use of small-scale or simple equipment should be developed;
- systems which require little skilled labor, but which generate employment;
- systems that maximixe use of local renewable resources and minimize use of nonrenewable resources; and
- systems which maintain the productivity of local and "downstream" environments.

Agricultural Development

Great diversity in agriculture systems is likely to persist on U.S.-affiliated islands. While opportunities for large-scale farming may be exploited by outside investors willing to bear the high risks for the potentially high returns associated with a successful export commodity, development of smallholder agriculture provides a greater likelihood of success and breadth of benefit distribution. Compared with large-scale farming, the benefits associated with smallholder agricultural development include:

- less risk of adverse impacts on traditional social systems (especially for U.S. Pacific islands);
- less dependence on foreign capital;
- larger employment-generating effects;
- broader distribution of increased farm income;
- greater compatibility with island ecological conditions;
- less dependence on imported production inputs;

- more widespread nutritional benefits; and
- potentially greater agricultural stability resulting from greater agricultural diversification (43).

Common characteristics of smallholder farming systems include the relatively modest acreage requirements per operation, heavy reliance on family rather than hired labor, and significantly lower capital requirements per operation compared with large-scale agriculture. Also, a strategy which is likely to emphasize import substitution (at least in the early stages of development) probably is more likely to succeed and be less costly than attempting to promote large-scale export-oriented farming (43).

POTENTIAL STRATEGY: Improve Research and Extension Services

In order to accelerate agriculture development, research programs need to be directed to specific goals clearly relevant to island development. Although the need for research is widely recognized, the capacity of most U.S. Pacific island institutions is limited. Furthermore, effective research is hampered by inadequate or unavailable baseline data and skilled research staff. Levels of research needed for agriculture development include (48):

- *operational research* at the farm level to increase productivity and profitability of farm operations through monitoring and experimentation in farms;
- field *trials* at field experimental stations for testing new varieties, fertilizers, pest management, and new technologies;
- *strategic research* on broad agricultural development issues affecting many areas, including social and economic issues; and
- *basic research* on agriculture problems with no predetermined practical application in mind.

The on-farm operational research and field trials are best done onsite at each island institution. However, since the capacity of small island institutions to support complex research is limited, basic and strategic research maybe more effectively conducted at large institutions (48) such as the University of Hawaii or the University of Puerto Rico. Although agriculture research has been conducted in the U.S. Pacific islands, many research activities are not designed to apply directly to the development needs of the islands. Further, research results are commonly not presented in a format usable for development planners or decisionmakers.

Although island governments should focus on research that is critical to their special local needs, this should be supplemented by taking advantage of research done at similar institutions at neighboring islands. Research performed by the South Pacific Commission, Caribbean Agriculture Research and Development Institute, and other regional research institutions may provide useful information (48, 87). It would be to the advantage of small island governments to establish cooperative relationships with international research institutions or major universities who can help broad strategic and basic research (48). Integrated development planning of island renewable resources cannot be effectively achieved because research and planning of renewable resources are not well coordinated in island polities (87),

After appropriate technology and strategy have been formulated for implementation, extension agents communicate this information to the farmers. Ideally, extension agents should be supported by an extension station with skilled professional staff in various fields. Although this condition may exist on large, well-developed islands, provision of agriculture extension services to the widely scattered farmers on U.S. Pacific islands is extremely difficult (48]. Lack of trained and motivated extension staff or the wrong kinds of extension agents may hinder effective communication with farmers. In some areas (e.g., Yap and Palau) where subsistence farmers are women, male extension agents are ineffective because it is considered inappropriate for men to teach women. In such situations, female extension agents would be more effective and appropriate *to* convey information to farmers (48).

Although extension services in Puerto Rico and the USVI are relatively well developed, transfer of modern technologies to Puerto Rico's farmers remains slow. This may be due to the relatively small size of the agriculture sector and scattered geographical location of farmers, and also because extension workers rarely have appropriate prior experience with modern technologies to guide farmers (61).

Research knowledge in certain areas (e.g., semiarid agriculture in Puerto Rico) lags significantly behind commercial practice. Generally, the agriculture experiment stations have made little or no effort to incorporate the results of commercial experience in their technology packages. Furthermore, existing links between research and extension, and the present level of funding are inadequate to address the magnitude of the problems which exist in the U.S. Caribbean islands (61). If research is to be effective, the gap of knowledge between researchers and commercial farmers must also be closed.

One of the ways of overcoming this problem is to conduct on-farm agronomic research trials. On-farm research provides documentary evidence of the nature and magnitude of biological, technical, economic, and social constraints. Moreover, on-farm research can provide baseline data for extrapolation to other farms where conditions are similar. Finally, on-farm trials make the process of research and development more understandable and accessible to other farmers, decisionmakers, and service organizations.

POTENTIAL STRATEGY: Improve Education in Agriculture

Apart from agriculture extension services, a need also exists for education and training programs for future farmers on most islands. On U.S. Pacific islands, agricultural education is inadequate. Two schools in Pohnpei offer agricultural education, three island institutions offer programs at the junior college level (Palau, CNMI, and American Samoa), and the University of Guam offers college-level courses. In the U.S. Caribbean islands, agricultural education programs and facilities are adequate. However, strong negative attitudes toward agricultural trade hampers participation of people in agriculture development, especially among the youth. Students also commonly lack hands-on experience with farming.

Although agricultural education programs exist, improvement is needed to enhance their effectiveness, particularly for the less-developed islands. In general, constraints to agricultural education in the U.S.-affiliated islands stem from lack of funding, qualified teachers, and of interest on the part of students due, in part, to the status attached to high-paying jobs with the government (app. F). Agricultural education effectiveness could be achieved through improving education in general, providing training for farmers, and providing public education programs.

Opportuntiy: Improve Education in General

All island areas have public education systems which can accommodate nearly all school age children through the secondary level. However, the educational programs generally do not prepare the students to fill employment needs for island development such as agriculture. Generally, emphasis has been on academic pursuits or preparation for white-collar employment. This has led to outmigration of high-school graduates and persistent shortages of manpower in agriculture trades and other such occupations. Interest in agricultural occupations might be enhanced if ecology and agriculture courses or on-farm training were offered at all educational levels.

Opportunity: Provide Training for Farmers

Low educational levels of most farmers may pose a problem. In this case, education and training can be presented through nonwritten communication methods with audio-visual aids. Effective education and training may be accomplished by using local examples and by showing rather than telling. Workshops and on-the-job practical training for farmers may also bean effective way to convey information. Involvement of farm organizations in agricultural development programs may enhance farmers' awareness of new agricultural programs and activities (48).

Opportunity: Provide Public Education Programs

Public awareness campaigns through the media or agricultural fairs may also be an effective way to convey the importance of the agriculture sector to the general public, and to counter the general negative attitude young people have toward farming as a trade. Agricultural fairs also can serve to introduce new crops or new products to the public and a means of testing public acceptance. The U.S. Virgin Islands holds an annual agriculture and food fair on the two larger islands, St. Croix and St. Thomas (153).

Photo credit: USFS-ITF

Youth conservation worker programs can introduce local people to basic principles of ecology and help strengthen environmental understanding while providing needed labor for such programs as reforestation and protected area management. Here, Young American Conservation Crops enrollees plant mahogany in a Puerto Rican public forest.

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Chapter 7
Management of Aquatic Resources: Nearshore Fisheries and Aquaculture

CONTENTS

Box

Chapter 7

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.

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.

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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-

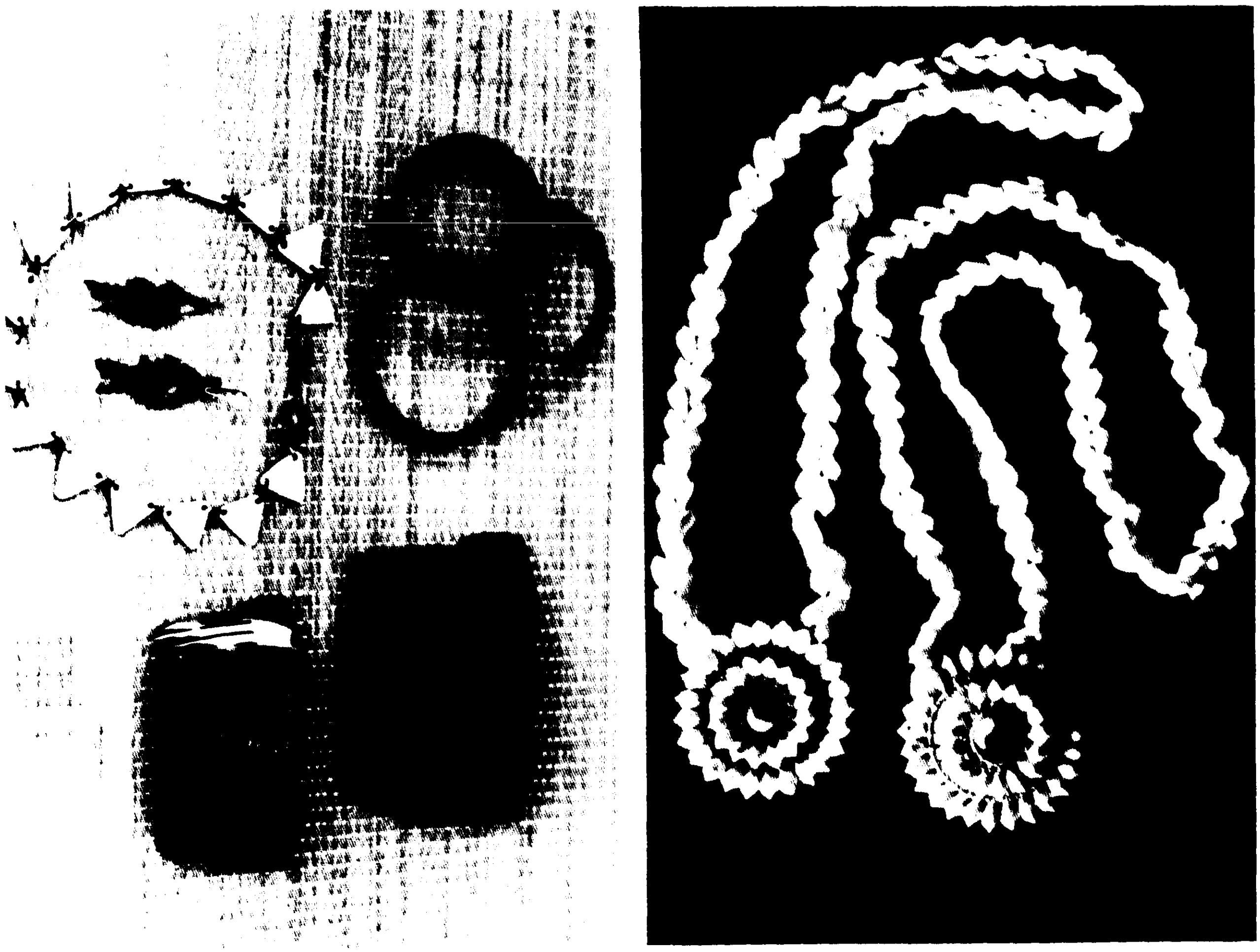

Photo credit: M Vitarelli

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).

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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 longliners 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.

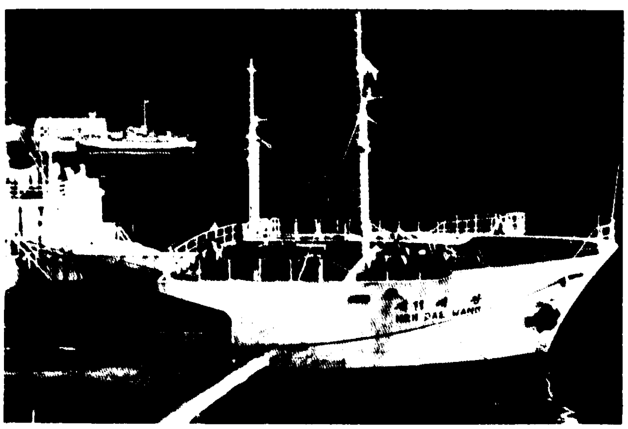

Photo credit: A. Vargo

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 alade 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. Researchcinethat these are the fastest-growing bivalve mollusks; they provide large quantities of with 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 in 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-

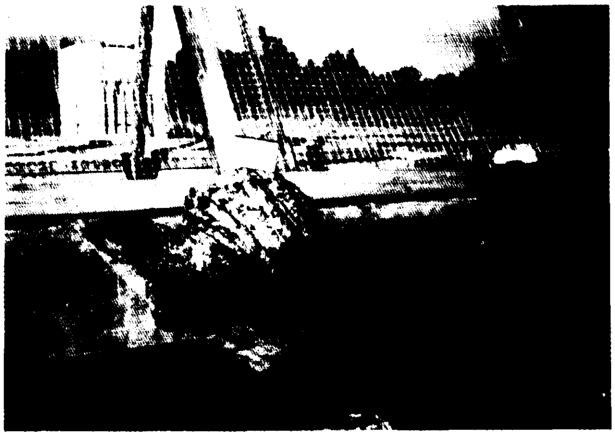

Photo credit: Office of Technology Assessment

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).

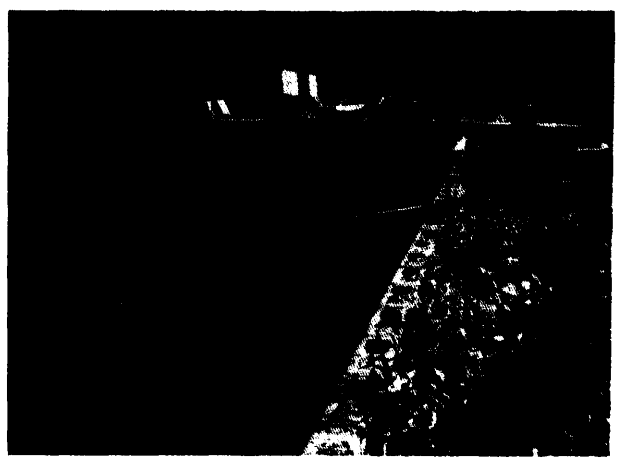

Photo credit: Office of Technology Assessment

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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Chapter 8

Technologies Supporting Agricultural, Aquacultural, and Fisheries Development

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Chapter 8

Technologies Supporting Agricultural, Aquacultural, and Fisheries Development

INTRODUCTION

Consideration of the ecological integration of island resource systems is integral to island renewable resource management and development and to optimum use of human and natural resources. Two other kinds of integration are important as well: 1) integration in the development of the various components of food and kindred products industries, and 2) integration of resource development with other forms of economic development.

Little is gained from increasing agriculture or fisheries production if what is grown or caught is not purchased, if a substantial part of it is lost to pests or deterioration before it can be purchased, or if no means exist to get it from the producer to the consumer. Thus, integrated development of food and kindred products industries requires that attention be given not only to the modes of production, but to preservation or enhancement of product quality and value (preservation and processing), fulfillment of product specifications determined by consumer demand (marketing), and product storage and transportation.

Conversely, integration of the provision of basic human services (e.g., water, energy, and waste treatment) with resource management and development is not a required component of resource development and is not commonly practiced on continents. However, such integration can provide "double-duty" from government infrastructure investments on small islands. Airstrips and even roads can be used as passive water catchments on water-poor islands. Residential wastes can be a source of nutrients for farms or forests. Aquiculture of certain plants can even aid water purification allowing reuse by humans. Development of tourist attractions could include efforts to preserve endangered species or habitats of critical importance to fisheries in multiple-use protected areas, and development of the handicrafts industry associated with tourism can provide a means for rural people to earn income and to maintain traditional skills.

Agriculture, aquiculture, and fisheries production systems also can be integrated with energy production technologies. For example, intensive mariculture farms need large quantities of seawater to supply oxygen to and flush wastes from ponds, and pumping is an energy-expensive operation. Such farms could be built around powerplants which pump large quantities of cooling water daily from the sea. In the future it may also be possible to integrate aquiculture with ocean thermal energy conversion (OTEC) systems, passive seawater energy systems, biomass conversion systems, and solar pond systems. On-farm production of energy from animal and/or crop wastes, using digesters, can reduce energy costs to farmers. Such systems may help islands reduce their reliance on imported oil.

Both of these forms of integrated development commonly involve comprehensive planning and broad government involvement, For example, development of the various components of food industries may require government incentives to entrepreneurs to enter lagging sectors so that their services can be provided to growing ones. Similarly, determining the potential for investments in large public infrastructure to provide secondary benefits probably will require considerable detail in project planning, specification of engineering design, facility siting, etc. Analysis of such factors must occur on an island-by-island basis.

INTEGRATED DEVELOPMENT OF A FOOD AND KINDRED PRODUCTS INDUSTRY

A commercial food and kindred products industry includes not only food and fiber production activities (see chs. 6 and 7), but also processing (the biological, chemical, or mechanical transformations of products subsequent to harvest), distribution, and marketing (figure 8-l). In the United States, before agricultural commodities reach consumers, they must be assembled, processed, packaged, warehoused, stored, transported, and distributed through the institutional food trade wholesale and retail outlets (93).

In a well-developed food and fiber industry, each of these components commonly is undertaken by different private individuals, businesses, or cooperative organizations. With each successive step, value is added to the product through transformation or distribution. Prices are raised, but revenues also are captured within the local economy. (For example, the nonfarm activities provide as much as 85 percent of the value added to the U.S. food and fiber system's output (93)).

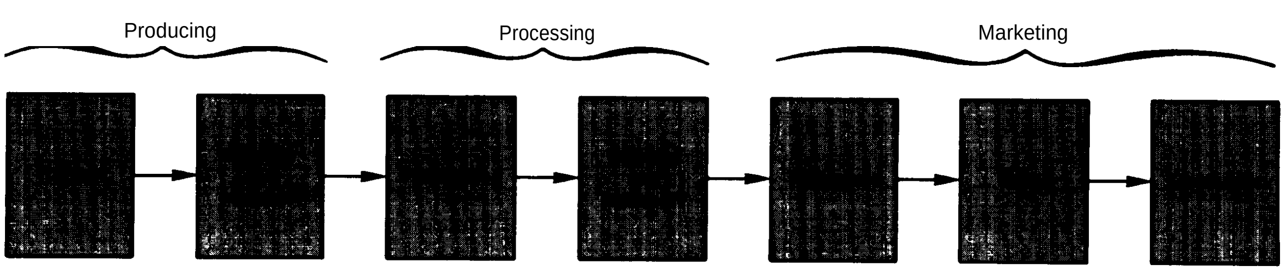
Food and feed processing technologies essentially transform raw materials into higher valued products with uniform marketing characteristics and longer shelf lives than the source materials. Such technologies tend to augment interdependence, encourage specialization, and are subject to economies of scale (82). They also promote the transformation from a barter economy to a cash economy. Finally, because convenience foods are preferred on many islands, increased local processing of foods has substantial potential to replace products currently imported.

On most U.S.-affiliated islands, fresh food is marketed directly by the producer (farmer or fisherman) to the public through roadside or harborside stands and open air markets. Thus, the producer is responsible for transporting, marketing, and maintaining the quality of the product. Some food may be sold to government food distribution centers, a small amount is sold to small retail stores, and still less is distributed to supermarkets or off-island (figure 8-2).

Only Puerto Rico's food industry approximates that of the United States or other developed countries. In the absence of complementary private sector development of the components of food industries, the processing, marketing, and distribution components can be centralized–through government-supported cooperatives or organizations—until private sector entrepreneurs take over (figure 8-3).

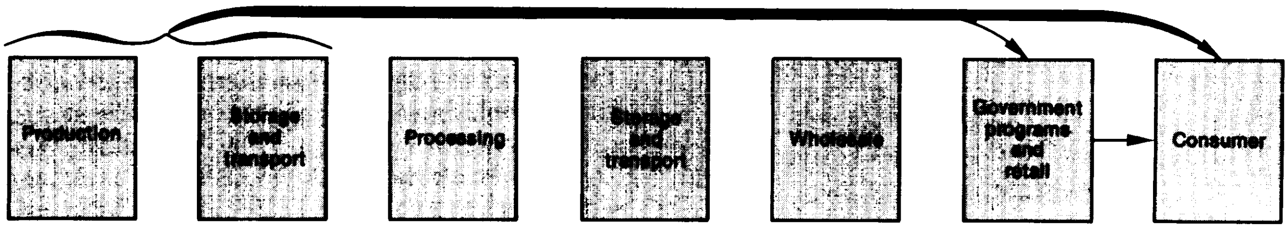
Besides raw materials, resources critical to processing include skilled people, information, and supporting infrastructure such as energy, water, and transportation facilities. Marketing, in particular, depends on reliable transportation systems.

Figure 8-1 .—Modern Food Industry Components



In a well-developed food industry different private sector individuals, businesses, or cooperative organizations commonly are responsible for each segment of activity.
SOURCE: Office of Technology Assessment, 1986,

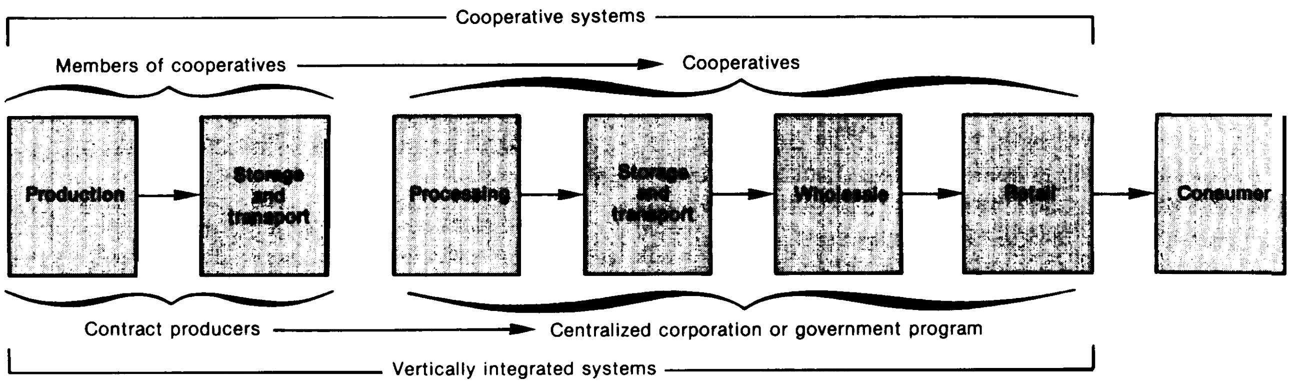
Figure 8-2.—Common Island Food Industry Systems



On most U.S.-affiliated islands, fresh food is marketed directly by the producer (farmer or fisherman) to the public through roadside stands or open air markets. A small amount is sold to stores for retailing. Little food is processed or exported (requiring wholesaling).

SOURCE: Office of Technology Assessment, 1986.

Figure 8-3.—Organizations Supporting Food Industry Development



In the absence of private sector development of the roles of food industries, processing and marketing components can be centralized, via cooperatives or centralized organizations, to provide these services until private sector enterprises can take over.

SOURCE: Office of Technology Assessment, 1986.

Food Preservation and Processing

Several methods of preserving and processing traditional foods for subsistence use exist in the U.S. Pacific islands. These include drying or smoking of fish, coconut meat, *Pandanus* fruit; fermenting coconut sap for coconut wine; and, in some areas, preserving breadfruit by storing it in the soil (2). The primary objective of traditional food preservation/processing was to ensure continuous food supplies during warfare, natural disasters, and off-seasons.

Today, the major goals of preservation/processing are to increase product storage life and quality, to minimize crop wastage and spoilage during peak production seasons, and to ease shipping and marketing (82). Food processing also may increase market demand (e.g., by increasing ease of food preparation). Furthermore, local processing of food may provide substitutes for products currently imported.

Primary and secondary processing and preservation methods range from simple and small-scale to complex, large-scale operations. Primary processing involves the preservation of crops and other products, whereas secondary processing deals with more complex processes such as extraction of plant oils, fermentation, or manufacturing of food products.

Food and feed processing methods throughout the U.S. Pacific territories are generally undeveloped. In Puerto Rico, the food processing industry is a strong manufacturing sector, primarily processing raw material imported from the United States and foreign countries (77). The strength of this sector may be due, in part, to the existence of a Food Technology Laboratory established at the University of Puerto Rico Agricultural Experiment Station.

Primary Food Processing Methods

Primary processing and preservation methods include refrigeration and freezing; dehydration (sun-drying, smoking, hot-air drying, and freeze drying); retort processing; irradiation; and hot-water bath treatments. Several of these processes can be combined or conducted sequentially.

Refrigerated Storage.—Proper storage facilities are needed to reduce postharvest losses from spoilage, insects, rats, or other pests. On most U.S. Pacific islands, storage facilities are inadequate because it is costly to provide modern storage facilities for the many small islands that are scattered throughout vast expanse of ocean. Low-temperature storage can provide protection from pests and spoilage and extend the shelf-life of perishable fresh products such as fruits, vegetables, and fish. However, low-temperature storage generally is not economical for most island crops because of the high energy cost. Furthermore, for most Pacific islands the use of cold storage is constrained by lack of or irregular power supply,

Refrigeration of foods for short-term storage (freezing for long-term storage) is nonetheless desirable, as it is safe, maintains flavor, and is suitable for many foods. Controlled atmosphere refrigeration (using carbon dioxide gas) can preserve certain fruits and vegetables for up to 21 days (82). Easy processing and packaging and acceptance of products worldwide make the potential for frozen tropical food excellent (cf: Bacardi frozen concentrate tropical fruit mixers).

While refrigeration is common in the U. S.-affiliated Caribbean, refrigeration and food freezing facilities other than household refrigerators largely are limited to larger hotels and restaurants throughout the U.S. Pacific. An American Samoa tuna cannery has a large, commercial refrigeration and freezing facility.

Icemaking and refrigeration are essential if fish are to be sold at other than dockside locations. High temperature is the single most significant factor leading to loss of quality. Fish that can be stored for 2 weeks frozen may last only a day or two at 500 F. It is generally recognized that a large part of the growing demand for marine products must be met through improvements in fish utilization, not just expanded catches (54).

Losses of fish may be heavy even on board, and in the period after docking and before marketing. Keeping fish alive in “wells” until landing, shaded, or covered with wet seaweed or other such materials may also enhance preservation. Losses could be reduced from the beginning by keeping vessel surfaces clean and cooled with seawater, and by careful handling (48).

If transport to markets is required the catch is further reduced from exposure as well as insect infestation. For many fisheries use of ice during transport is not possible; icing can, however, be delayed up to about 6 hours if the fish is consumed soon thereafter. Rapid chilling can be efficiently achieved by layering ice (prefer-

Photo credit: Office of Technology Assessment

Packing fishery products in ice remains a primary preservation technique on many Pacific islands despite irregular ice availability. Shown here, fish are being removed from ice packing and displayed for sale in a local market.

ably in flakes or small pieces) and fish in a covered box or hold area. Only sanitary water should be used to make the ice, and ice should not be reused once fish have been stored in it.

Ice machines that do not require gasoline, diesel oil, or electricity are being developed in some areas. A low maintenance biomass-fueled icemaker has, for example, been developed at the Asian Institute of Technology in Thailand. Ice forms as heat is extracted from water in a closed container during the conversion of liquid ammonia to gaseous ammonia. A compact solar refrigeration system uses the same technology but the ammonia-water solution is heated in the pipes of a solar collector (48). Solar-powered zeolite refrigeration systems are now being developed and may have particular relevance for use in small remote island areas (86).

Dehydration.— Food dehydration is a common, relatively simple, and inexpensive primary processing technology. Depending on the product, sun-dried items can be placed on racks or on iron roofs. Sometimes wire netting is placed over drying racks or platforms to reduce dirt and insect contamination (82). Although sun-drying is simple, cheap, and easily transferable, it is limited by the availability of sunny days. In some areas, in fact, peak crop harvest coincides with the rainy season. Sun-drying alone, moreover, frequently will not reduce the moisture content of products to a level low enough to prevent fungal or bacterial growth (82). Thus, while sun-drying is suitable for home use, for initial preservation, or for nonfood items, handling and sanitation problems render it less suitable for most volume processing for sale (65).

Fish commonly are preserved in rural areas of the tropics by sun-drying, but significant losses result from spoilage, contamination, and insects. Drying on raised structures could reduce some of these losses. Solar fish dryers can be made simply and inexpensively with wood (to form a frame) and plastic or glass (to provide cover), A wide variety of solar dryers have been designed with these and other inexpen-

Box 8-A.—Zeolite Refrigeration Systems

Maintenance of food product quality and reduction of product loss might do as much for tropical island economies as expansion of agriculture and fisheries and puts no added pressure on scarce resources. Refrigeration would solve many problems of food preservation and storage on the U.S.-affiliated tropical islands, but the energy requirements of conventional absorption refrigeration systems pose a constraint to the application and use of this technology.

Solar coolers, using natural zeolite minerals as the adsorbant, are now being developed (86) that show promise for use on small tropical islands to extend the life and therefore the potential markets for perishable food products. Because of several unique, properties of zeolites, they can be used to provide efficient refrigeration with low-grade energy such as solar heat. Once fully developed and available for purchase, zeolite-based solar coolers have the potential to provide food refrigeration or freezing; refrigerated transport; and space conditioning (heating and cooling, depending on seasonal need) for livestock and for commercial and tourist facilities.

The solar refrigerator and walk-in cooler are the technologies of most immediate application and widest possible use. Coolers can be used onsite or installed on flat bed trucks or on boats for field use. One technology being developed uses waste heat from internal combustion engines, significantly reducing the weight of the system as compared to solar based~systems.

Zeolite solar technology is initially highly capital-intensive, thus those people who most need it probably cannot afford it without government or private subsidy. However, where such technology is used to market more produce than could otherwise be saved and sold, increased income can be expected to result, and low-interestt might be repaid in a reasonable time. Nonsolar zeolite systems have low initial costs and can be used without subsidies wherever waste heat is available.

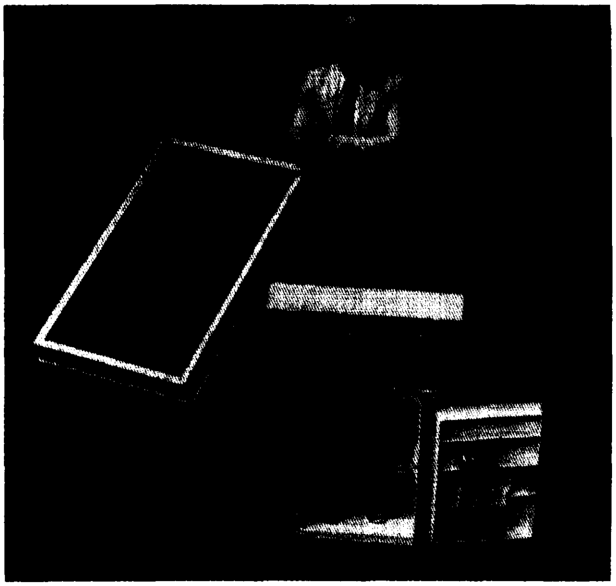


Photo credit: D. Tchernev

This small-scale solar-powered zeolite refigeration system may be particularly appropriate for remote areas or roadside markets where energy availability prevents the use of conventional refrigeration systems.

sive and readily available materials (including old oil drums, thin metal sheeting, and even sun-dried mud). Fish exposed to the flow of heated air in such structures dry very rapidly, and high temperatures reduce spoilage by mold and bacteria. Low-cost agrowaste-fueled fish dryers and combined agrowaste/solar dryers have also been designed and constructed in the Philippines (48).

Hot-air drying and smoking are accomplished by placing the product on drying shelves or racks in ovens using natural-draft smoke or forced hot air. Hot-air dryer designs vary depending on the crops, on the types of dried products desired, and on the type of available fuel (82). Hot-air drying and smoking may be limited by fuel availability and cost. Dryers can be made from simple wooden or bamboo racks, steel racks, or durable steel drums. Forced hot-air dryers have been used effectively for drying various island products such as copra, black pepper, chili peppers, and herbs.

Smoking is a traditional method of preserving fish products. Smoking dries the product, and certain substances in smoke kill bacteria, particularly in the presence of salt. Simple smokers consist of trays hung in the column of smoky air above a fire. A variety of ovens and kilns have been developed in Africa and the Philippines (48).

Smoking, hot-air drying, and sun-drying may be used in combination for drying products. Dehydration also is frequently combined with other processes such as salting (used for thousands of years to preserve fish) and sugar curing. Spices, seasoning, tropical fruit flavors, and other specialty products seem to offer primary areas for expansion of dehydrated products. In addition, byproducts and waste products of dried foods can be added to animal feed formulations (82).

Dehydration also may be accomplished by freezing and drying at the same time. Freeze-drying technology may be applied to selected, high-valued products, provided reliable electric power is available (82). Freeze-drying maintains the flavor and helps protect the cellular integrity of the food. However, this technology requires high amounts of energy and skilled labor, and therefore cannot be applied economically on many islands.

Retort Processing.—Retort canning or pressure cooking is a common method of preserving fruits and vegetables, and can be used on some fish and meats. The goal of such thermoprocessing is to heat the product to microbe-killing temperatures of around 100° F. Traditional canning equipment is readily available and systems have been developed for lesser developed areas of the world (82). Acid fruit products are easily canned without substantial health hazards as the acid level prevents spoilage by most toxic organisms. Retort canning of nonacid foods such as vegetables and meats, however, can be a health hazard if quality-control procedures are not followed.

The retortable pouch–a multilayer adhesively bonded package that will withstand thermoprocessing temperatures—may maintain higher quality foods than those retorted in conventional cans and may require less energy due to shorter cooking times at lower temperatures (97). Further, retort pouches have an improved product-to-package weight ratio compared to cans, providing savings in transportation. This saving may be reduced by secondary packaging used to increase product durability in transport.

Irradiation.— Irradiation for preserving food and crops has been used both experimentally and commercially in many countries (69). Irradiation is considered an alternative to chemical preservation of foods and crops, or where refrigeration and retort processing are not feasible (table 8-l). Low doses of radiation prevent sprouting of tubers, destroy insects, and inhibit mold on fruits and vegetables. Medium to high doses of radiation can preserve foods for long periods of time (69,70). Low doses of radiation for spices, hog carcasses, and some fruits and vegetables have been approved by the U.S. Food and Drug Administration (83). Use of high doses of radiation for control of insect pests on produce, and for preserving fruit and vegetables recently has been approved. Irradiated mangoes have been exported from Puerto Rico to the U.S. market (60).

Irradiation could reduce the use of pesticides and inhibit maturation and spoilage of crops, thus extending shelf life and possibly making some foods more available or less expensive. Application of irradiation technology, however, requires the availability of electric power, skilled personnel, and a high initial capital cost making it an unlikely prospect for use on most islands.

Table 8-1 .—Effects of Food Irradiation

Dose	Rads	Purposes
Low-dose	1-1oo kilorads	Control insects in grains and flour Inhibit sprouting in potatoes Sterilize trichina worms in fresh pork Inhibit decay, control insects in fresh fruits and vegetables
Medium-dose. . .	100-1,000 kilorads	Destroy Salmonella and other bacteria in meat and poultry
High-dose	1,000-3,000 kilorads	Control insects, micro-organisms in dried spices and enzymes used in food processing; destroy botulism spore

Dose: Dose is calculated by knowing the energy given off by the radiation source, the distance between the energy source and the target material (food and its packaging) and the duration of treatment. "Rad" stands for "radiation absorbed dose." 1 kilorad = 1,000 rads.

SOURCE: S, Sachs, "Q & A Irradiated Food at the Supermarket, " *USDA Food News for Consumers 3(1): 14-15, 1986.*

Hot-Water Bath Treatments.—Hot-water bath treatments are an alternative to fumigation or irradiation to eliminate pests, especially fruit flies, in fruits. It has been used as an alternative to fumigation with ethylene dibromide, which recently was banned from use on all fruit and vegetables for trade in the United States. Fruit, such as papaya, are immersed in water for 40 minutes at 108° F followed by a 20-minute immersion in water at 120° F. This treatment killed all eggs and 99 percent of insect larvae in commercial-sized lots of papaya in Hawaii. In general, hot-water bath-treated papaya maintains its quality, including the flavor, texture, absence of blemishes, and absence of hard spots on fruits (98). This method holds promise for wide application on islands because it is simple, inexpensive, and does not depend on expensive imported materials.

Secondary food Processing Methods

Secondary food processing systems, in general, involve more complex techniques, higher capital investments, and more energy-intensive technologies than primary processing. On U. S.-affiliated islands, secondary food processing systems include fermentation, oil extraction, and starchy crop processing.

Except for coconut oil extraction, commercial secondary food processing methods are undeveloped in U.S. Pacific islands. However, in Micronesia a traditional coconut wine (toddy) is made by cutting the stalk of a coconut flower and allowing the sap to drip into a container to ferment naturally. Secondary processing is common in Puerto Rico; for example, brine-fermented citron is one of the oldest fruit processing operations on the island (77).

Fermentation.—Fermentation of fruits is a common method of preservation and flavor-enhancement, and is used in many cultures to derive alcoholic beverages. Fermentation of fish and shrimp was originally developed in Southeast Asia as a means of flavor enhancement. Since this generally involves hydrolysis in the presence of high salt concentrations, products (generally a liquid or paste) have good keeping qualities. Nutritive quality is maintained, and the process is simple (48).

Plant Oil Extraction Methods.—Chemical and physical extraction methods are available for extraction of oils from plants. Depending on the products, oil extraction ranges from simple, inexpensive, small-scale techniques to complex, capital-intensive extraction methods. Basically oil extraction involves drying the product, chopping it into small pieces for pressing and/or chemical extraction and fractionation to obtain the desired oil (82). Coconut oil can easily be extracted from dried coconut meat (copra), by pressing or boiling. This can be accomplished using common kitchen implements or in a factory setting with proper quality control and precise extraction procedures (67,82). Oil from the ylang-ylang *(Cananga odorata)* flower is extracted through similar procedures.

Starch-Crop Processing Methods.—A number of relatively simple processing technologies for making flour, chips, and pellets from common starchy island crops such as rootcrops, coconuts, breadfruit, plantain, and banana are available. These are relatively simple technologies which basically involve chopping and/or shredding the crop into small pieces and drying it or grinding it into flour. Flour may be processed into pellets and packaged in various ways *(21,77).*

A simple cottage-scale flour-grinding operation has been in operation for several years at Macheweichun Xavier Society in Truk. It involves the use of wood-fired dryers, a flour grinder, a drum shredder, and miscellaneous hoppers, trays, and containers (21).

Summary

Although U.S.-affiliated islands offer opportunities for food processing development, the pacific islands in particular are constrained by high energy costs, small markets, and relatively small and unreliable domestic production of raw materials. The energy requirements for certain processing technologies, such as freeze-drying, refrigeration or freezing, irradiation, and retort processing, can be substantial. This may seriously handicap application on U. S.-affiliated islands where energy is costly and irregularly available. Availability of fresh water may also be a constraint for resource poor islands such as atolls.

Although Puerto Rico has the capability for processing most food products, it is constrained by the limited quantities and the high prices of raw materials produced locally. Hence, food processing industries are forced to import raw materials from neighboring islands or from the mainland United States (77).

Establishment of regional or local cooperative food processing centers may overcome the constraints provided by the small size and fragmentation of islands of the U.S. Pacific territories. A processing center could provide a strong link between processing and production, and may provide technological support to producers and marketers thus facilitating commercialization of local products (82).

Cooperative processing and preservation centers could absorb crop surplus not taken by the fresh produce market, preventing waste and providing intermediate products for further food and feed formulations. Local producers might be encouraged to expand crop production if processing facilities guaranteed a market for excess products: sustained levels of production above local subsistence needs can take place when a stable cash market exists to absorb the surplus (70). It is estimated that between 30 to 50 percent of fruits and vegetables produced in the Commonwealth of the Northern Mariana Islands (CNMI) have been discarded because they have no market outlets (87).

Development of cooperative food processing facilities will require coordinated development of marketing services, island infrastructure, agriculture production, and managerial skills. Government cooperation and support probably is necessary.

Opportunity: Expand Research in Postharvest Technologies for Island Products

Postharvest technology research commonly is biologically or physically oriented, thus complementing production research. Some postharvest technology research focuses on the biological or chemical properties (e. g., composition, quality, safety, nutritional value) of products that affect the handling, storage, transportation, preservation, and effective use of such products. Other postharvest technology research focuses on the mechanical technologies used to assemble, process, package, warehouse, store, transport, and distribute products.

A 1983 OTA assessment concluded that public sector research in postharvest technology and economics can be justified because:

1. benefits are distributed beyond those who bear the costs, and substantial social advantages are derived from both public and private research;
2. in the absence of public sector support and guidance, postharvest research might be biased strongly toward mechanical and chemical technologies, since economic returns can be extracted in the short run; and
3. for those situations where private research might be detrimental to industry competitiveness, a mix of public and private research may best preserve competition or reduce market power.

Some areas of research, such as:

1. new food sources and their development,
2. naturally occurring food contaminants, and
3. yields in relation to productivity versus nutritional components, might best be undertaken by joint public sector/private sector organizations.

Three research agencies in the U.S. Department of Agriculture (USDA] conduct and fund postharvest research: the Agricultural Research Service (ARS), Economic Research Service (ERS), and Agricultural Marketing Service (AMS). Although ARS conducts some postharvest research, including some in Puerto Rico and the U.S. Virgin Islands (USVI), it is not organized to manage, conduct, or be responsive to regional research needs (93). ERS has International Economics Divisions which identify trends in food demand in foreign countries (on a regional basis) and draw implications for export markets in those countries. Its National Economics Division primarily assesses the organizations and performance of the major U.S. commodity subsectors (animal products; crops; and fruits, vegetables, and sweeteners).

AMS is an action agency primarily devoted to distribution of market news to the agricultural community, inspection and grading of food products, and other regulatory activities and some research. AMS has responsibility for the conduct of studies of the facilities and methods used in the physical distribution of food and other farm products; for research designed to improve the handling of all agricultural products as they move from farm to consumers; and for increasing marketing efficiency by developing improved operating methods and facilities (93).

The Agricultural Experiment Station of the University of Puerto Rico has developed a Food Technology Laboratory devoted to fostering the development of processing industries. An associate degree in Food Technology is offered at the University's Utuado Regional College. Product research since its inception in the late 1940s has included: canned sweet potatoes, canned fruit nectars, frozen fruit concentrate, canned soups, frozen root crops, jams, jellies, and marmalades. Although many of these efforts failed to reach commercialization, and others failed to survive (primarily due to economic reasons), the food processing industry showed rapid growth between 1960 and 1970 in diversification and sales volume (77). However, because quantities of acceptable quality fruits and vegetables were not reliably available from local producers, the Puerto Rican food processing industry shifted to the processing of imported raw materials.

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Opportunity: Develop New Products From Extant Crops and Catch

Local processing of crops can provide higher returns to growers than exporting raw materials, and can provide import substitution opportunities. Major opportunities for development of new products from locally available crops are coconut oil products; fruit juices, jams, jellies, and marmalades; and animal feeds.

Coconut Products.—The major commercial crop in the U.S. Pacific is coconut, from which copra is made. Copra oil processing plants exist on Majuro, Moen (Truk), and Pohnpei. Yap is in the process of building a plant. The Pohnpei Coconuts Products plant has developed a line of products—laundry and bath soap, dish soap, cooking oil, body oils, and shampoo—for the local and tourist markets. Plants on Truk and Yap will offer similar products, mainly for import substitution. Copra oil also is a potential substitute for diesel oil, but its cost ($4.00/ gallon) compared to imported diesel oil ($1.50/ gallon) is prohibitive at present (73).

Fruit Products. —Surplus fruit crops can be made into jams and jellies, juiced and bottled, or used in production of fruit ices, currently popular in areas having refrigeration. Small-scale juicing machinery, suitable for small quantities, are available and are employed on some Pacific islands. Through a successful Yap government-sponsored radio campaign, coconut milk has replaced large amounts of imported canned beverages; similar campaigns could promote locally produced juices (73).

Animal Feed.—Another major avenue for substitution of imports with locally produced and processed products is animal feeds. Feeds for livestock come from a variety of sources depending on the kinds of livestock raised and the husbandry methods. Livestock feeds include green forage, pasture grasses, hay, silage, feed concentrates and, for some livestock such as pigs and chicken, left-over food or crop wastes, In Puerto Rico and the USVI, most cattle are raised on improved or unimproved pastures. Dairy cattle are supplemented with feed concentrates (5), and silage and green forage such as *Leucaena leucocephala* are used occasionally to supplement cattle feed. In Puerto Rico, hay is fed to horses and calves during the dry season. About 10,000 tons of hay are produced yearly on about 2,000 acres and another 4,000 tons are imported (101).

Although the demand for animal feed is high, practically all feed concentrates are imported to U.S.-affiliated islands. Pohnpei imports about 400 tons of pig feed concentrates annually (85) and Puerto Rico imports about 500,000 tons of raw materials for livestock feed concentrates annually. None of the latter incorporate ingredients that can be produced locally (5).

High costs of imported feed concentrates constrain development of livestock industries on most islands. Imported feed concentrates are expensive and may represent one-half to two-thirds of the total cost of producing meat and dairy products in the U.S. Pacific territories (38). Furthermore, unreliable shipping has caused shortages of feed forcing farmers on small islands to ration and substitute feed. Rationing and substituting local materials for feed have resulted in decreased livestock production and reduced feed conversion efficiency. Shortages may also cause a “feed shortage mentality” on the part of unsophisticated farmers resulting in rationing of feed even when an adequate supply of concentrates is available on islands (5).

Establishment of plants that process local raw materials for feed may minimize crop waste, provide a market for crop surpluses during peak production seasons, and make use of currently underutilized resources. Such plants could also provide substantial benefits to farmers by increasing market demand and absorbing supply not taken by the fresh produce market (38). Development of alternative markets can moderate supply fluctuations and contribute to increased market efficiency.

Many attempts have been made to produce feed concentrate from local raw materials. For example, a feed processing plant on Palau, using copra meal, fish parts, and imported rice hulls, grain, and vitamins, was established in 1976. However, the plant was forced to close when the copra oil mill closed down (45). In general, ingredients such as fish meal, vitamins, and mineral supplements still must be imported (5,85). An animal feed processing plant currently is operated on Guam, but low-quality feed hinders its ability to compete with imported products (65).

On U.S. Pacific islands, a variety of local raw materials offer potential as feed components, such as copra meal, breadfruit, banana, root-crops, and various agriculture wastes. *Leucaena* leaves, which contain up to 30 percent protein (49), can be dried and used as an ingredient of feed concentrate. Excessive feeding of *Leucaena* to nonruminant animals can cause hair loss and ill health and poor feathering in poultry, because it contains a harmful chemical called "mimosine" (49). However, the toxic effects of mimosine are reversible and can be neutralized when certain micro-organisms are inoculated into cattle feed (79). Mimosine content in *Leucaena* leaf meal also can be reduced by adding ferrous sulfate to rations, soaking it in water overnight, or boiling it for a few minutes.

In Puerto Rico, byproducts from local pharmaceutical companies, tuna or pineapple canning plants, rum breweries, and sugarcane refineries can be used as ingredients for animal feed concentrates (72). Quantities of these byproducts, however, are limited and only seasonally available. These products could substitute for only about 10 percent of currently imported feed concentrates (5) and are not sufficient alone to support a feed processing facility.

Although the use of local produce for ingredients in animal feed is technically feasible, it is seriously constrained by the high production costs for small-scale operations and by the unreliable and seasonal availability of local raw materials (5,67,82,85). Because of these constraints, local raw materials generally can only be used as an extender for imported animal feeds (67). However, in most cases it is cheaper to import finished feed from large foreign operators than to blend imported and domestic raw materials (5,67,85). High fuel costs, costly maintenance of equipment, and difficulty in getting spare parts are also major hindrances to operation of local processing plants in most U. S.-affiliated Pacific islands.

Marketing Development

Opportunities for market development exist despite small local markets and highly competitive export markets. In addition to the small size of local markets, marketing on U.S.-affiliated islands is constrained by low levels of production, lack of marketing skills, and for small producers primarily on U.S. Pacific islands, by the inability to meet marketing demands (e.g., consistency in quality, quantity, and pricing). Under certain circumstances, however, cooperatives may overcome these constraints (102). Another way to facilitate marketing, is linking small-scale "satellite" farmers and fishermen to large-scale, well-established, producers. This system has been effectively instituted for ornamental plant producers in Puerto Rico (6). Although increased penetration of export markets is possible, it is considerably more difficult than developing local markets. In either case, government intervention may be needed.

Development of Local Markets

Farmers and fishermen use a variety of marketing methods to sell their product. In general, local markets are small relative to agriculture production potential. The absence of alternative market outlets, such as export markets and food processing plants, and inefficient distribution and marketing of fresh produce, lead to unstable prices, unnecessary product losses and spoilage, and inability to meet the demands of institutional buyers.

The local market in Puerto Rico, although relatively small for most commodities, is stable. Although local marketing methods in Puerto Rico are not as advanced as in the mainland United States, they appear adequate. Local produce such as plantains, bananas, pineapples, and others are sensitive to market fluctuations; even small surpluses can depress prices, since surplus crops cannot be readily exported off-island. Thus, some crops, such as coffee, are protected against competing imports by local

Photo credit: Office of Technology Assessment

Large open-air markets, where the majority of locally produced agriculture and fishery products are sold directly from the producer to the consumer, are typical of many island areas.

regulations (47). On the other hand, the local market for some crops is, in a sense, "protected" by relatively high transportation costs of imports from the mainland United States (about 2.5 cents/lb for grain and 6 to 7 cents/lb for refrigerated products) (101).

About half of the food tonnage consumed in Puerto Rico is produced locally (100). The percentage of the local food market that can be captured by Puerto Rican food producers is limited by local production potential and by consumer preference for supermarket convenience food produced mainly by mainland U.S. food processing corporations (40).

In the U.S. Pacific islands, food imports are substantial. However, imported commodities are mainly sold in the major urban centers (38). Only a small fraction of the urban populations consume imported fresh food. Therefore, only a small amount of imports can be substituted by locally produced fresh food. Opportunities to develop the local markets on U.S.-affiliated islands and reduce imports are based on the potential for supplying various sectors of the local markets such as government-sponsored programs (e.g., school lunch, food stamp, and old age programs), tourist, and military markets.

Currently, most food products for the military and tourist markets in the Pacific are imported from suppliers outside Micronesia, thus, the potential for import substitution is great, However, hotels and military facilities require regular supplies of high-quality produce currently unavailable on the islands. Even if only part of the fresh produce requirements can be supplied locally, it could make a significant difference to local economies.

Opportunity: Substitute Locally Produced Food for Imports in Federally Funded Food Assistance Programs

In American Samoa, Guam, and the CNMI, opportunities exist to increase gradually the use of locally produced commodities in federally funded food assistance programs. Part of block grant funds (e.g., for school lunch or old age programs), could be used to purchase locally produced commodities, including processed items, instead of imports. The CNMI Food Stamp program requires that 25 percent of food stamp expenditures go to the purchase of locally produced commodities. These requirements increase the use of local products and benefit local producers (38), Gradual increases in the required percentage could result in additional benefits to producers and consumers.

Opportunity: Develop the Tourist Market

Tourism represents potential demand for agriculture and fisheries products where significant tourist industries have developed, such as in Guam, Palau, the CNMI, Puerto Rico, and the USVI. For Puerto Rico, the impact of tourism on agriculture development is not known. In the USVI, however, certain small-scale agriculture ventures are directly dependent on the tourist industry (13). Tourism in the Freely Associated States (FAS) and American Samoa is hindered currently by weak airline linkages with major Asian/Pacific markets and relatively expensive fares (38), but has the potential to become a significant market as it develops. In Guam and the CNMI, tourism provides the major private sector income generating activity; about 450,000 tourists visit Guam and Saipan annually (38) and prospects for continued growth in visitors is high (3).

Although large numbers of tourists visit the CNMI and Guam, local producers can take little advantage of this market because of the monopolistic practices of tourist facility (e. g., hotel) operators. Japanese interests control most of the tourist industry and have set up a number of barriers for local suppliers to access this market. Only small amounts of commodities such as food and locally made handicrafts enter into the tourist market (102).

Opportunity: Supply Military Markets

The military presence on Guam and Kwajalein represents potential demands for local agriculture and fishery products. Military personnel and dependents in Guam make up roughly 20 percent of the resident population. In the Marshall Islands, the Kwajalein Missile Base has a population of about 7,500, most of whom are Marshallese employees and dependents living on nearby Ebeye Island (35]. Although these populations represent potential markets for fresh produce, most food is currently imported from suppliers outside Micronesia.

While local farmers could supply at least part of the fresh produce requirements, irregular and limited supplies of local produce make it impractical for satisfying the military markets (see app. c). In addition, accounting advantages accrue through military dependence on centralized supply of warranted products. Only if the centers do not carry a particular commodity, or fail to meet minimum quality standards, are local commanders encouraged to procure locally. A Department of Defense team recently was sent to Guam to evaluate prospects for greater reliance on local markets, particularly of fresh foods. However, only small amounts of local products are likely to be bought by military employees, dependents, and civilian employees in the near future (35).

Opportunity: Develop Interisland Markets

Trade in selected agricultural commodities within Micronesia also is possible. The potential for intraregional trade depends both on coordinated development planning and strengthening surface and air transportation services among the islands (38), The most direct step to developing markets for Micronesia crops would be to conduct a pest and disease survey of Micronesia to provide a basis for U.S. Federal quarantine regulations affecting Guam and other potential markets. If quarantine regulations were revised, some traditional crops could be exported to Guam and other areas where demand for traditional foods is unfulfilled (15).

Development of Export Markets

Export potentials for the U.S. Pacific differ from that of the U.S. Caribbean islands, due to differences in geography, and the socioeconomic conditions. Puerto Rico and the USVI have ample opportunity to export fresh produce due to the cheap and frequent ocean transport to major east coast markets (60).

Currently Guam and CNMI have the best prospects for agriculture exports outside of Micronesia. Guam and Saipan islands have good air transportation links to Japan, a potential overseas market. Wide-body passenger aircraft serving Micronesia have the capacity to ship air freight containers. Japan seems to be the most promising export market, because of its high per capita income and already large volume of imported fresh produce. A recent study concluded that avocados and papayas had the best export potential in the Japanese markets, with other possible exports being tomatoes, sweet corn, bell pepper, melons, and ornamental plants (12). However, Japan's strict quarantine regulations preclude most fresh produce exports from Micronesia. Until the fruit fly is eradicated on Guam and the CNMI and effective methods for treating fresh produce are found, Japanese markets will remain closed to Micronesia exports. At present, only copra and green bananas can be freely exported into Japan (app. F, 65).

Removal of U.S. import tariffs on produce from Caribbean Basin countries as a result of the Caribbean Basin Initiative, has not seriously affected the local market for Puerto Rican products. However, import tariff reductions seriously hurt the potential for export of fresh produce from Puerto Rico (101). Exporting Caribbean countries have a competitive advantage in lower wage structures ($2 to $4 daily as compared to $16 to $26 in Puerto Rico), which results in lower product prices even after addition of transportation costs. To increase food exports, Puerto Rican producers must both reduce production costs and improve the quality of their produce, thus reducing competition between Puerto Rican products and foreign substitutes.

Integrated Production, Processing, and Marketing

Neither production nor marketing can be developed in isolation and one cannot be successfully developed without attention to the other. Without viable markets, production will stagnate or decline. Without regular and reliable sources of product, market development and expansion cannot occur. Many opportunities exist for integrating production and marketing to make these activities more efficient and mutually supportive. Such integration can remove certain constraints that affect each sector in isolation. For example, commercial small-scale operations may be handicapped by small and unstable markets or inadequate transportation services; small producers commonly are not able to produce uniform quality products, do not have access to adequate capital and, generally, lack marketing skills. Cooperatives and/or vertical integration of agricultural systems (linking smallholder farmers with large producers or processors) may help mitigate such constraints and provide enterprises capable of capturing economies of scale.

Cooperatives[1]

Cooperatives are known to be a useful way of organizing and mobilizing capital and people in developing communities. Cooperatives offer an alternative when conventional corporations are unable or unwilling to enter markets because of inadequate return, high risk, or lack of capital. A producer cooperative provides some economic benefit to individuals as they earn a livelihood. A consumer cooperative—in essence, a buying club—helps individ-

[1]This section is summarized from N. Nathanson, "The Suitability of Cooperative Enterprises for the Production of Food on the Territorial Islands of the United States, " OTA commissioned paper, 1986.

uals pool their resources to obtain products not otherwise available on acceptable terms. The return on the member's investment is almost always of secondary importance; the desire for a particular type or quality of product is paramount,

While small farmers face real difficulties purchasing small quantities of supplies competitively, and can ill-afford expensive equipment, farmer co-ops can competitively purchase supplies, services, and equipment and market produce for the benefit of the entire group. Groups of farmers may even purchase a sizable tract of land and work it together, either by subdividing the land or sharing in the production of the entire tract. The more highly organized food producer cooperatives provide fully integrated programs for their members. These may arrange bulk purchases of supplies, lease planting and harvesting equipment to individual members, process and market the finished product, provide financing for members, and even conduct research and development in new crops or techniques. Other co-ops are more limited in purpose.

Advantages and disadvantages to co-ops exist relative to capital enterprises. One major advantage is the built-in incentive for members to use services offered, increasing the cooperative's revenues, However, members generally lack incentive to purchase more than one share; this limits cooperative capital and can ultimately necessitate debt financing. There also is a danger of short-sighted decisions by members with diverse interests or limited knowledge of market economies. Some argue that not enough profit motivation exists in a cooperative organization to assure sufficient earnings for future growth. Nonetheless, the cooperative structure seems, in some cases, to be encouraging increased agricultural production on the islands.

In Puerto Rico and the USVI, some tradition of market-oriented agriculture exists, but there is little modern, competitive agriculture in the Pacific under the control of indigenous populations. Exceptions occur with the help of cooperative enterprises, whose member-investors have a direct need for the produce or service supplied.

A Successful Small-Scale Cooperative: SFCA.—Only about 5 percent of the land in the Northern Marianas is suitable for agriculture, and much of that requires irrigation. Public resources and private capital directed at the preparation of farmland have been very limited. Nevertheless, the Saipan Farmers' Cooperative Association (SFCA) is demonstrating that, with competent management, and a modest amount of public and private capital, small-scale agricultural co-ops can have a measurable impact on food supply. With nurturing, SFCA could become a model for agricultural development in other Pacific islands.

SFCA has 85 producing farmers as members. Its principal activity is the retail sale of member produce; a secondary activity is the procurement of supplies and animal feed for sale to members. Chartered in 1972, SFCA was nearly bankrupt by 1980, but since new management took over in 1982, it has been far more successful. Sales have increased from $133,000 in 1982 to $575,000 in 1984. The co-op has little capital but a $10,000 line of credit allows it to pay members cash for products.

SFCA does not guarantee members a fixed price, or purchase products that are below a market standard, but it has been able to purchase most of what its members produce, Most products sold are fresh fruits and vegetables along with some locally processed and baked goods, eggs, and honey. No meats or fish are sold. A major problem in earlier years was spoilage, but with more attentive management and a higher sales volume, this has been greatly reduced.

SFCA sales, while growing, still represent only a small fraction of the market potential. To serve more of Saipan's dispersed population, SFCA will need more retail outlets.

A Struggling Multiservice Cooperative: FEDA. —The Federation Para El Desarrollo Agricola de Puerto Rico (FEDA) is a complex federation of some 20 producer associations in Puerto Rico. It operates a tropical fruit juice processing and marketing plant and provides financial and technical assistance to 600 regularly participating and 600 intermittently participating member-farmers who supply the fruit. FEDA has developed all the elements of a fully integrated agribusiness program, including a modern processing plant, new techniques to raise productivity, a revolving loan fund to finance plantings, and a functional organizational and management structure. The average member earns about $4,000 per year farming, and through FEDA can increase the farm's income by at least 50 percent.

The primary product of the federation plant is passionfruit juice, but seven fruits are processed. FEDA also raises rabbits and pigs for sale as food, using the waste from the juice plant for animal feed. FEDA also has spawned a nonprofit institute which conducts botanic research to improve productivity and trains farmers to grow tropical fruits.

FEDA enjoyed considerable success in its early development years, but with an enormous debt load and high overhead costs, it is not yet financially self-sustaining. FEDA's obligation to purchase the product of participating farmers places a tremendous demand on its financial resources. Member farmers who set policy through their elected directors tend to set the price they receive above market price, further taxing FEDA's resources.

To assure financial success and to use the plant fully, new off-island markets for fruit juice must be developed. Major U.S. distributors require enormous quantities of product, more than FEDA can now provide. Ultimate success will depend on the ability to market an estimated 10 million pounds of fruit annually. FEDA is attempting to market to local distributors in South Florida and New York where large Caribbean populations live. It may be, however, that greater returns to the farmers could have been realized by concentrating on locally used foods rather than specialty export products.

Cooperatives That Failed: USVI Fishery Cooperatives. —The Farmer Cooperative Service of USDA, between 1975 and 1978, partially financed fishery cooperatives in St. Thomas (with 44 fishermen) and St. Croix (with 51 fishermen). The cooperatives were formed to provide a more organized and sanitary method of selling catch and to help members purchase supplies such as fuel and ice. Most members were part-time fishermen who had been selling their catch on street corners. Spoilage and fish poisoning were common.

Each proposed cooperative called for the eventual construction of a waterfront supply and receiving facility with a cooler, freezer, fuel pumps, cleaning area, and retail sales area. The co-ops would also sell fish to hotels and restaurants. Both co-ops appear to have been well-planned technically, but both failed. Several factors contributed:

- members were required to sell their catch to the cooperative at a price well below street market price, and the volume available for sale was consistently below projection due to overfishing, theft, and damage to the fishermen's traps;
- both operations were substantially in debt as a result of their financing structures, expensive overheads, soaring fuel prices, and inflation; and
- the fishermen's association never became a strong, cohesive organization and had difficulty setting operating policy, maintaining market discipline, and selecting competent management.

A Potential Cooperative in Koror, Palau.—At least one-half of Palau's population lives in the capital city of Koror, where traditional foods largely have been replaced by canned imports. Although consumers seem to prefer fresh local produce, interest in farming has declined.

Residents of some outlying communities recognize the market potential of island crops, and have steadily increased production of fruits and vegetables since 1977. Primary factors limiting further growth in local food production appears to be related to distribution problems: bad roads, lack of refrigeration during shipment, rats, and handling all take their toll.

All farming is done on individual plots, but some rudimentary cooperative associations have formed. One group of Melekeok farmers shares the cost of shipping produce from their island to Koror. Two small retail outlets have developed to market the produce of certain suppliers on an informal cooperative basis. With some assistance, these associations could develop a formal cooperative similar to the Saipan Farmers' Cooperative Association.

Opportunity: Support Cooperative Organizations.—Few local government agencies or private organizations on the islands actively encourage the development of agriculture or fisheries cooperatives. Although the Government of Puerto Rico has established financing and technical assistance programs to encourage the development of cooperatives, the emphasis has been in housing development and retailing. Despite attempts for at least 3 years, FEDA was unable to obtain local financing, although it secured almost $3 million off island. Only after FEDA obtained considerable mainland attention was it able to obtain local support.

Local governments can encourage development of cooperatives by investing in infrastructure (e.g., roads) and providing tax benefits and technical assistance. Production and marketing specialists may be particularly needed. Guaranteed contracts for the purchase of locally produced items by schools, welfare and social service programs, or tourist facilities could provide market stability. The CNMI government's preparation of a 56-acre plot of land for lease to local farmers has contributed to the success of SFCA; continuation and expansion of such actions could bring the local economy sizable benefits.

A number of mainland-based organizations could become involved in development of cooperatives on U.S.-affiliated islands. The National Cooperative Bank chartered by Congress in 1978 provides financing and development assistance for cooperative business and housing. A nonprofit subsidiary, the Consumer Cooperative Development Corporation (CCDC) has the specific mission of assisting low-income development cooperatives. CCDC will provide "advances" to promising organizations to develop business plans or marketing programs, and could provide term financing for projects like SFCA or FEDA, but probably should not be considered a primary source of startup or development capital. The National Cooperative Business Association provides education and information-sharing services to cooperative businesses through publications, conferences, seminars, and direct technical assistance.

The Agricultural Cooperative Service (USDA) helps farmers maintain successful cooperatives by performing studies on the production, marketing, financial, organizational, legal, social, and economic aspects of cooperative activity. The service also provides technical assistance (based on applied research findings) in running cooperatives, organizing new cooperatives, cooperative merging, and in developing strategies for growth. The service collects and publishes statistics on cooperative activity in U.S. agriculture, and its monthly "Farmer Cooperatives" magazine reports on developments in the field of cooperative development and management.

Verticality Integrated "Contract" Systems

The formation of integrated food production/processing/marketing systems is likely to be a successful method of increasing food production on U.S.-affiliated islands. Contract farming is one method of vertical integration which extends benefits to small farmers as well as to large producers.

Under this system, businesses contract with small farms to raise a specified amount of raw materials at a guaranteed price (and may produce materials themselves]. To coordinate this system, the company determines product quantities required to fulfill identified consumer demands and maintain desired market prices, Commonly, the company provides farming inputs (e.g., fertilizer), some production assistance (technical and financial), and central processing facilities and marketing services. Thus, the farmers own and operate their farms, the central operation unit buys, processes, and sells the product, resulting in an integrated enterprise capable of capturing economies of scale (6).

Integrated contract farming provides significant benefits to both producers and consumers:

- small farmers can capture the benefits of economies of scale in processing and marketing and so obtain greater returns than as independent producers;
- because pricing decisions are made prior to delivery of the product to market, price uncertainties are shifted from farmers to consumers;
- farmers receive greater access to markets, which may be expanded through advertising and promotion underwritten by the central company;
- consumers are assured of more standardized product quality and, perhaps, access to a range of product quality at varying prices; and
- consumers receive relatively stable product availability and price (71).

Numerous examples of successful vertical integration of agricultural enterprises exist in Puerto Rico (71). For example, the Puerto Rico Department of Agriculture provides financial assistance to both the processing and distribution facilities and to "satellite farmers" supplying the broiler and ornamental plant industries (6).

Black pepper production on Pohnpei initially was similarly integrated, although farmers were not under contract and the central processing and marketing unit was a government-run agriculture station. Since high quality is essential to market Ponape pepper successfully, the state government subsidized quality control by supplying staff and processing equipment to the Agriculture Station. Farmers brought mature pepper to the station for weighing and processing by agriculture division staff. The close control of the drying process and prompt packaging by agriculture division staff helped to ensure a uniform, high-quality product (19). After sale of the processing equipment to a nongovernmental organization, pepper quality and exports have declined. The Pohnpei State government plans to repossess the processing equipment (73) and, presumably, return to the integrated production/processing/marketing system originally established.

Transportation

Good transportation services are essential for marketing produce as well as for agricultural and aquacultural development. In the Pacific islands, sea transportation services are inadequate to provide farmers with access to markets within Micronesia or to Hawaiian or Asian export markets (38). Inter-island transportation problems most often exist in the frequency and expense of transportation services, as well as the absence of any scheduled transportation service to some outlying islands. Intra-island shipping services are few and roads connecting outlying areas to urban centers commonly are unpaved and irregularly maintained. Scattered location of islands, great distances between producers and markets, and small volume of product constrain increased transportation services. Because of inadequate road systems, farmers from remote villages are unable to bring their products to markets in the urban centers (19,38).

The U.S.-affiliated Caribbean islands generally have adequate and regularly scheduled, reliable transportation services. Puerto Rico and the USVI have close contacts with the U.S. mainland and many island residents frequently travel there (101). The Caribbean islands have long been a tourist haven and thus airline and cruise ship transportation is readily available. Additionally they lie within major shipping routes and historically have been transshipment points between South and Central America to Europe. Transportation related difficulties in these islands are more often related to expense rather than availability.

Even where sea transportation services are adequate, e.g., between the U.S. mainland and the U.S. Caribbean islands, the costs are high. This is partially due to U.S. Federal regulations requiring the use of U.S. carriers for interstate commerce and Federal Government negotiation of air routes between the United States (ineluding U.S.-affiliated islands) and foreign countries.

The availability or frequency, quality, and cost of transportation in island economies is generally dictated by: distance and geography, market size or demand, and technology. In the Pacific, the general pattern is one of substantial distance, small markets, and technologies that make transportation an expensive service (25).

Technological advances have increased the transportation options available; however, costs and investments required to use these technological opportunities also have risen substantially. For example, with increases in aircraft size and carrying capacity providing greater passenger/cargo and distance capabilities, operating costs have risen and larger airport facilities are required. Newer aircraft are cheaper to operate than older designs when fully loaded, but can be significantly more expensive if not full. If cargo carrying capacity is to be increased, vessel/aircraft size and/or trip frequency must generally move upward. with this increase, freight costs and attendant business risk would likely also be higher (25).

Economic risks for transportation businesses are compounded in small markets where the potential for local fluctuations are greater. Maintenance and enhancement of international transportation infrastructure is a particularly difficult economic development task. The major capital assets of transportation providers, ships and aircraft, are unlike other corporate capital assets: airplanes and vessels can be rapidly relocated to other markets. Even when a transportation company is financially solvent or is making a modest profit, the level of business success is often measured against standards other than local or corporate gains. Profitability and business risk are measured not only within the local economy, but also are compared with other markets (25).

Many producers will assume transportation costs in order to become or remain competitive in a market: this is frequently the case for outlying producers. It should be noted that these outlying producers begin with a cost disadvantage, attributable partially to transit expenses for inputs. where production cost, including transportation, is a key determinant in the success of a producer, the transport equation is a major factor in economic development. The value of the products needing transportation, and their perishability or sensitivity to transport risks must be carefully assessed prior to investment. In a large transportation market, a canceled flight may mean a delay of several hours, while it could well mean a several day delay or total loss of goods in a small market.

Intra-island and Inter-island Transportation

In many Pacific islands, inter-island and intra-island surface transportation typically is inadequate to provide producers with reliable market access and inputs, such as animal feed and fertilizers, are difficult to obtain. Inter-island shipping services and associated harbor docking/storage facilities need to be upgraded to enable an expansion of renewable resource-based enterprises. For example, the general logistical problems of supplying feed, equipment, and supplies and transporting the products to markets, as well as expense imposed by current transportation systems, hinder aquiculture development (20) and often preclude significant commercial livestock production (38) in many of the U.S.-affiliated islands.

Intra-island Transportation. -Lack of farm and other secondary roads on many Pacific high volcanic islands inhibit accessibility to currently unused agricultural land and hinder market access from existing farms. Fostering of agricultural and aquatic enterprise development will necessitate construction of secondary roads where this deficiency represents a significant constraint, such as in the Federated States of Micronesia (FSM) and Palau (38) and the south side of Pohnpei (19). Although infrastructure development generally is given high priority in development plans, the amounts allocated to road construction may not be adequate to address farm needs.

The dirt and coral roads of Micronesia are notoriously poor and heavy rains result in impassable mud, ruts, potholes, and sometimes washouts. In addition, poor roads result in high vehicle repair costs and can reduce the productive lifetime of vehicles already shortened due to salt-air corrosion. The expense and expertise required to maintain roads in good condition may be beyond some local government capabilities (19). In addition, while roads bring access to markets, they also expose formerly traditional communities to outside influences and accelerate the departure from the traditional lifestyles to which some people prefer to adhere (27).

In some cases alternative transportation might be considered. For example, for several years, a locally built shallow-draft barge has transported lumber successfully from Pohnpei's southern mangrove forests into Kolonia. while the use of draft animals for transportation is not a viable alternative for most islanders, the practice exists in some rural areas. Carabao (a Southeast Asian water buffalo) are used by some rural families for transport of such items as building materials. The number of carabao—130 in the FSM islands in 1983, and 16 on Palau in 1982—is so small that use trends cannot be determined (85).

Inter-island Transportation: Remote Islands to Population Centers.—The remote or small coral islands and atolls provide a special set of management problems. The infrequency and often unpredictable transportation service sometimes result in occasional food and supply shortages in the outer Marshall Islands (67). Many outer islands, and particularly atolls, lack basic infrastructure and transportation facilities necessary to future economic development activity such as medium-draft docks or harbors for export and import trade, to support fishing fleets, or airstrips to facilitate emergency evacuation in case of storms, injuries, or epidemics. A dilemma in interisland transportation is the cargo capacity limitation imposed by airstrip size. The length of most outer island runways precludes economically efficient cargo airplanes; conversely, the short-takeoff and landing (STOL) craft used have minimal cargo capacity and, thus, the cargo space tends to be relatively costly (25).

Many development activities on outlying islands currently are determined by the availability and frequency of sea-going transportation services. On many small atolls and remote islands, boat visits are infrequent and often unpredictable. Part of the frequency problems are attributable to the lack of appropriate ocean infrastructure compounded by the natural roughness of the Pacific Ocean's high seas. Relatively loose scheduling of calls is commonly required because narrow, dangerous channel passage or anchorage/cargo handling often is achievable only at certain tides (25).

Some islands within this category rely on copra production, which requires little support infrastructure. Copra transportation within the Marshall Islands is well organized, though logistically it is not a simple task. Sailing canoes or small boats (20 to 30 feet) with small outboard motors or inboard diesel engines transport the copra to a common collection point within each atoll (67).

Copra from the outer islands is transported to Majuro for processing by small transport vessels which carry trade goods, cargo, and passengers throughout the Marshalls. Four "field trip ships" currently are operated by the Republic of the Marshall Islands Government and privately owned ships have occasionally provided similar services in recent years. A typical round-trip voyage from Majuro lasts 2 to 3 weeks and includes stops at four to six atolls. The length of each stop and duration of the entire trip is unpredictable because departure and arrival times and transit of reef passes must be adjusted daily to tides and weather conditions. This unpredictability can compromise the quality of the copra, since it deteriorates if it is stored too long, and may prevent the product from reaching buyers in a timely manner (67).

Opportunity: Upgrade inter-island Air Links

Each of the FAS governments has devoted considerable efforts to upgrading inter-island air links. For example, 19 runways have been constructed on the outer Marshall Islands since 1980. These can accommodate small 14- to 16-

Photo credit: Office of Technology Assessment

This Airline of the Marshall Islands (AMI) aircraft and airfield on Ailinglaplap (Marshall Islands) are typical for those remote atolls having airfield facilities.

passenger planes operated by the Airline of the Marshall Islands (67). Recently, a missionary organization, Pacific Missionary Aviation, organized villagers in the outer atolls of the FSM to construct short airfields for emergency air evacuation, improved communication, and mail service. Today, airfields have been completed on Pingelap and are being constructed on Mokil and Ngatik in Pohnpei (39). The construction of small airstrips on other outer islands (that can afford the loss of productive copra land) could help to stimulate economic activity, tourism, and communication, and facilitate government administration (39).

Intraregional and International Transportation

potential for intraregional and international commodity exports in the Pacific islands are hindered by inadequate transportation services, particularly in the FAS and American Samoa. Little or no regularly scheduled surface shipping exists between the FAS or American Samoa and Asian-Pacific markets (38). Even where transportation services are available, the expense often hinders tourism and export potential of certain commodities. Rates for air cargo from U.S.-affiliated islands are based on international schedules rather than domestic rates, making shipping expenses extremely high (80).

An additional factor is the nature of most Pacific markets. Generally, the markets are import-heavy, with very limited out-bound cargo. The one-way traffic is a contributing factor to high cargo carrying costs; in Pacific markets, these rates must amortize the costs of virtually empty cargo holds on the out-bound voyage (25).

Opportunity: Coordinated Regional Transportation Development

Strategies to increase resource industry development would necessarily involve developing adequate land and water transportation and, in some instances, air shipment (30). The potential for intraregional trade depends on strengthening surface and air transportation services among the territories and on coordinated development planning (38). Quarantine and inspection services must be upgraded concurrently with transportation to reduce the risks of accidental introduction of harmful pests into the islands (88).

Coordinated regional development of the transport network is one means to address the problem of virtually empty back-haul. Experience in the deregulated air industry has shown that focus of commercial carriers on the more lucrative parts of the Pacific regional market has generally left the smaller Pacific points with reduced service (25).

Another strategy for increasing cargo capacity and reducing freight costs is a passenger/freight mixed load approach. Dedicated air cargo services have had little success in the pacific due to the economic context. The mixed use approach probably would increase revenue/load potential while reducing business risk. This strategy, however, does not overcome the problems of converging seasonal peaks of passengers and cargo.

Opportunity: Subsidization of Air Transport

General transportation problems in the Pacific islands may restrain development of certain enterprises which require imported inputs or export capacity. For example, the high costs of air freight within the region, together with the general lack of airline services, make it difficult to obtain needed equipment and supplies. The high cost of transportation also reduces or eliminates the profit margin on products destined for export. Some form of government subsidy for the shipment of supplies and products (56), or government-sponsored identification and/or research into more cost-effective forms of transportation for the U.S.-affiliated islands, could be considered to help remedy this situation.

Another approach would be to amend the Essential Air Services program, which guarantees a minimum level of service to small communities, to include cargo movement needs in the service level determination process. Although this would increase Federal liabilities by raising minimum guarantees, carriers may fulfill minimum requirements without subsidy as island economies develop.

INTERSECTORAL INTEGRATION

Some basic human services required by island people as by those elsewhere are clean water, energy, and safe disposal of wastes. In addition, development trends of U.S.-affiliated islands require that the services required by tourists and increasingly urban populations be provided. These services commonly require large government investments in infrastructure and dedication of land and other resources to their operation. However, these forms of economic development are not necessarily competing with resource management and development. In many cases, they can be designed and developed to provide long-term secondary benefits to agriculture, aquiculture and fisheries. For example, the airstrip on Majuro (RMI) also serves as a passive water catchment, collecting the rainwater that falls on the cement surface and directing it into a holding pond that can be tapped for use. Roads can be similarly designed.

Although analyses of the potentials for combining such developments with renewable resource development must be performed on an island-by-island, and probably case-by-case basis, which is beyond the scope of this report, a number of means to derive benefits for resource development from infrastructure development can be suggested, including:

- integrating agriculture and aquiculture with energy development,
- integrating tourism and resource development, and
- integrating urban development with resource management.

Integrating Agriculture and Aquaculture With Energy Development

Energy is a major limiting factor to economic development, particularly in the U.S.-affiliated Pacific islands. Fossil fuels must be imported and the operating and maintenance costs for oil and gas energy production systems are high. Thus technologies conserving imported fossil fuels or using renewable energy sources are preferred.

The energy demands in Micronesia are small but increasing; in aggregate 5.8 million barrels of petroleum fuels (excluding jet fuel) are imported annually. The cost to local governments is high. Metered rates, where they exist, usually have little correlation to the cost of production. Local governments often subsidize use by at least 50 percent (91). Given policies of not actively collecting bills, this can rise to 100 percent (24).

Puerto Rico and the USVI have well-developed networks for electricity production and distribution. It is unlikely that development of renewable resources (e.g., for processing plants) may be hindered by the lack of electricity. The cost of electric power, however, is high (77). In the past, the rural poor in Puerto Rico depended on cheap, accessible wood for cooking, but today that demand has diminished considerably and firewood is only used occasionally (68). However, charcoal commonly is used for backyard barbecues and roadside food stands,

Energy availability and cost will continue to be a major economic development problem in the Caribbean and the Pacific. In the short run, energy conservative activities and technologies not dependent on expensive fuels are needed. In the long run, renewable sources of energy, based primarily on the sun and the oceans, must be developed. Although this energy has been considered "free," establishment and maintenance of the infrastructure required to tap it are costly and can require long payback periods. Alternative energy sources are being explored in all of the island areas. These sources include energy from biological processes, thermochemical processes, ocean-related energy generation, and hydropower.[2] Each of these can be developed to include components mutually beneficial to agriculture, aquiculture, and energy.

Agriculture and Energy Development

Agriculture can be integrated with several other technologies to conserve and recycle resources and energy, increase production efficiency, and improve island environments. Opportunities exist for generation and use of biomass for energy generation and biogas energy from animal and crop waste and residue.

Energy from the conversion of wood and other plant matter represents an important, potentially underexploited resource for the islands. As renewable domestic energy resources, these can help the islands reduce their dependence on imported oil. Energy could be derived from numerous types of biomass, including wood, grass and legume herbage, crop residues, animal manure, food-processing wastes, oil-bearing plants, seaweed, and many other materials (50,95).

Wood Fuels.—Fuelwood, including coconut husks and shells, is the most plentiful and least expensive source of energy in Micronesia, and on most atolls the only source. Most of this fuel is used for cooking and sometimes for creating smoke to repel insects from homes and gardens. Fuels used in cooking largely are byproducts of the food production system: dried husks of mature coconuts, husks of *Inocarpus* nuts, and wood from secondary vegetation generally from fallowing garden sites (15). Charcoal is not widely used, though species that make high-quality charcoal (*Leucaena* spp., *casuarina,* and mangroves) occur commonly on the high islands (24).

Conversion to wood-fired electric plants in Micronesia is not foreseeable in the near future. Labor and capital investments are generally higher for fuelwood plantations than for conventional stands due to higher stocking densities (often 20 to 40 times as high) which in turn affect the cost of seedling production. More mechanized harvesting and processing methods are also required. Converting electric plant facilities and adjusting existing grid sizes also would be costly.

Coconut-Derived **Energy Products.—A** number of coconut palm products traditionally have served as primary fuel sources in the U.S.-affiliated Pacific islands. Coconut husks and shells have been the major Marshallese cooking fuel for centuries. Husks and shells also fuel copra dryers; distillation of salt from seawater; melting of lead for fishing weights; and bleaching of the *Pandanus* leaves used in woven sleeping mats and fine handicraft items (67).

Coconut shell charcoal has been considered as a possible byproduct of copra making in the Marshall Islands. High shipping costs, relatively high labor costs, and small potential output would make centralized processing prohibitively expensive, although decentralized processing on the outer islands (where there is excess labor) might be possible (67).

The use of coconut palm biomass to fuel larger scale activities such as steam generation

[2] A complete analysis of these technologies is beyond the scope of this assessment. For further information see (50,51,52,53, 55,94,96).

is technically possible (16). Difficulties lie in in collecting, storing, and handling the quantities needed for such uses. In the Marshall Islands, husks could be gathered in large quantities on Majuro Atoll. However, husk shipments to Majuro from the outer islands are not possible given current shipping capacity; the sheer volume of whole nuts or husks would be 10 times greater than the volume of copra from an equivalent number of nuts. The costs of expanding service and of acquiring new ships probably would be prohibitive. If husks were gathered in large quantities for fuel, moreover, they would not be available for decay and return to the soil. Atoll soils are very sandy and organically poor, and loss of this nutrient input overall could have a negative impact (67).

The use of coconut oil as a substitute for diesel fuel is being examined in a number of countries. Tests conducted in Western Samoa have shown that coconut oil can be used alone or in a blend with diesel fuel without affecting engine power. Particulate matter in the coconut oil, however, clogged fuel filters after a few hours of operation. Injector coking and residue accumulation on other internal parts were expected to be serious problems (63). Further research may reveal a way of avoiding these by pretreatment of the coconut oil, modification of engine design, fuel blending with petroleum products or ethanol, or a combination of approaches (67).

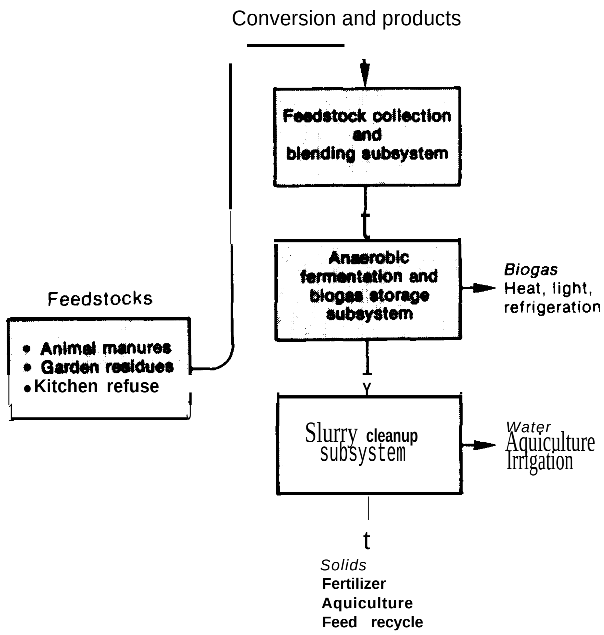
Successful coconut oil-fueled engines also could be used for power generation, thus eliminating the supply problems inherent in basing petroleum-fueled generating systems on remote islands. A 1983 cost comparison in the Marshall Islands showed that a 10-kW coconut oil-fueled, generator-expeller combination would be cheaper than a photovoltaic system of the same size (28). Neither system, however, is affordable by outer island standards, and they were not compared to standard diesel-powered systems. Moreover, the comparison did not account for fluctuations of coconut oil prices or declining costs for photovoltaic systems as the efficiency of that technology improves. These factors could drastically affect the comparison (67).

Biogas.—Considerable interest exists in enhancing agriculture production through new and sometimes innovative integration of diverse technologies into one production system. These include waste recycling by anaerobic digestion to derive energy and nutrients—energy-integrated farming. By adding simple components, this system also can be integrated with aquiculture or residential waste disposal. This innovative system has not been used widely for commercial application, perhaps due to lack of support by local practitioners, continuity in technical assistance, or social or economic analysis.

The major objective of energy-integrated farming systems is to transform animal or crop wastes cheaply into useful products and, thus, effectively recycle a wasted resource. The core of the system is a digester: an oxygen-free container in which organic matter is fermented by micro-organisms producing "biogas" and a thick slurry (l). Biogas is comprised of about 60 percent methane and 40 percent other gases principally carbon dioxide. The same fermentation process occurs in nature whenever organic matters decompose in the absence of oxygen, e.g., in animal digestive tracts or in swamp muds. The organic matter for recycling need not be animal wastes. Crop residues, leaves, grasses, straw—virtually any organic material suitably prepared—can be used independently or in conjunction with manures to produce biogas. Induced fermentation processes in digesters can be made more efficient by controlling the variables such as quantity and quality of organic materials and temperature (l). The quantity of biogas and residue produced in the digester depends on the amount and types of organic matter, the capacity of digester, and ambient temperature.

Completely fermented slurry has reduced harmful organisms, is virtually odorless, and retains the fertilizer value of the original material. Solids can be manually or mechanically separated from the liquid. The resulting sludge can be processed and used for various purposes, such as potting soil or as an animal feed additive (1,11). Slurry and sludge also can be used for fertilizing agricultural lands or to fertilize

Figure 8-4.—Components of On-Farm Biogas Systems



SOURCE A.G. Alexander, "Assessment of Energy-Related Farming Technologies for U S Insular Areas," OTA commissioned paper, 1986

aquiculture ponds. Biogas can be used to fuel a variety of gas burning appliances such as lights, stoves, refrigerators, or even to run modified gas-fueled engines (1,32).

Although each system is different, the basic components of an energy-integrated farming system are the same, with three basic units (figure 8-4) (l): 1) a collection and blending system in which organic matter (manure and wastes) is collected and mixed with water before fermentation, 2) a biogas digester wherein anaerobic fermentation of organic matter takes place and biogas is produced and stored, and 3) slurry and wastewater storage or separation. Effluent can be used directly or the solids can be separated from the liquid and used separately.

Social, economic, and environmental benefits derived from the digester system include:

- reduced fuel, fertilizer, and/or animal feed use;
- avoided costs of waste disposal to achieve compliance with Environmental Protection Agency regulations;
- sales of farm products which are otherwise wasted;
- increased yield and quality of traditional farm commodities;
- reduced production costs;
- decreased purchased fuel or fuelwood use through substitution of biogas; and
- reduced health hazard and environmental pollution caused by improper treatment of wastes (l).

In addition, water is needed to wash wastes into the system on a daily basis. Thus, a program to build biogas systems could result in improved water systems for families as well as improved sewer systems which could help alleviate health problems (15).

Biogas production lends itself to a broad scope of applications ranging from single-household, manually operated digesters with little need for high efficiency, to huge, costly, corporation-sustaining complexes totally reliant on high technology and having closely calculated "payback" scenarios that dictate their ultimate success or failure (1). Currently, a viable biogas plant requires a minimum of four to five confined pigs or cattle (53). Development of energy-integrated farm technologies in the near term (6 to 7 years), probably will affect comparatively few farmers having existing large manure supplies and pressing need for its disposal. In the longer term (8 to 20 years), small-farm and household-level biogas units could be implemented that could contribute to the general welfare of insular communities.

Small-Scale Operation. —In small farm operations or rural family farming, biogas can be used for lighting or cooking. The solids can be separated from the residual liquids by coarse sieving or merely by gravity separation in a small settling pond designed for periodic draining and cleaning (l). Wastewater can be used for garden irrigation, or can be cleaned by an inexpensive aquiculture of organisms such as tilapia and water hyacinths that thrive on the rich suspended organic matter still contained in the digester effluent. The major constraint for increased application of small-scale operations is the strong cultural resistance of many

This plastic lined settling pond is part of the small-scale biogas system in the Northern Mariana Islands. The effluent from the pond is discharged through an irrigation system.

islanders to handling animal wastes. Furthermore, the initial capital cost is outside the capacity of most small farmers.

Large-Scale Operation.—Although opportunities for large-scale integrated farming systems exist, implementation and widespread application are seriously constrained by: 1) lack of large livestock operations that can produce enough recoverable wastes, 2) lack of expertise in design, installation, and operation, and 3) lack of capital support *(1)*. The largest commercial application of energy recovery of wastes using fermentation principles was recently installed by the Bacardi Corp. in Puerto Rico (84). Benefits derived from large-scale operation include potential direct substitution of purchased utility power and periodic sales of excess power to local utilities. Indirect substitutions include the recycled mineral nutrients contained in the digester solids and wastewater, in protein recycled to farm animal feed, in imported dry-feeds and feed concentrates substitution with greenfeed, and on-farm production of plants and aquatic organisms produced in the aquiculture subsystems (l).

Aquaculture and Energy Development

Aquiculture can be integrated with irrigation and other agricultural support systems, as well as with wastewater treatment and energy development, to the mutual benefit of each development component. Because power is a basic commodity in developed and developing economies, and most power-producing plants are constructed in coastal zones, powerplants

Photo credit: Office of Technology Assessment

Slurry derived from this large-scale biogas system is directed through aquiculture tanks containing tilapia and water hyacinth before being discharged through an irrigation system, thus, providing several benefits in addition to energy generation.

and mariculture systems could be designed to be mutually beneficial.

The oceans of the world, and the Pacific in particular, are a reservoir of potential energy. There currently is no available low cost and simple means of exploiting this potential in substantial quantity. Numerous technologies being researched may one day change this situation although, with the exception of wind-powered shipping, this does not seem likely to occur for several decades. Major ocean energy systems potentially suitable for the tropics are ocean thermal energy conversion (OTEC), passive seawave energy systems, and biomass and solar pond systems. Integration of aquiculture with these technologies may improve their economic feasibility and make productive use of ocean energy "wastes."

OTEC systems use large quantities of cold water pumped from deep ocean areas to the surface, similar to natural upwellings of cold waters along some continental coasts (94,96). OTEC uses the surface water as a heat source and the cold deep water as a heat absorber. The "fuel" is free, but low efficiency means that very large volumes of warm and cold water must be circulated through the system. The energy and material cost of pumping large volumes of cold water from considerable depths effectively precludes the development of small-scale OTEC systems.

A byproduct of OTEC schemes is artificial upwelling of deep, cold waters. Tropical surface waters are nutrient poor, but the deep water is nutrient-rich. Such water, after its temperature change has been used to generate energy, can be used for mariculture. The culture systems use the upwelled, nutrient-rich water and abundant sunlight for primary productivity (mainly phytoplankton) on which other organisms are cultured in sequence. Such technology may be applied wherever the land borders deep seas (e.g., atolls and volcanic islands) primarily along the equatorial belt, where solar radiation is plentiful.

Artificial upwelling mariculture systems have been demonstrated on St. Croix and in Hawaii. The USVI project has since closed and is considered a failure due to a need to supplement upwelled water with additional nutrients and rapid spread of infections and disease within the monoculture organisms (59).

Since 1981, a number of mariculture experiments have been conducted at the Natural Energy Laboratory of Hawaii (NELH), an alternate energy research, development, and demonstration center. Some species demonstrated higher growth rates in comparison to natural rates or those in other aquiculture systems. Currently kelp and abalone are being commercially cultured using NELH's "artificial upwelling," and plans are underway to grow algaes to produce a nutritional additive, pharmaceutical-grade biochemical, pigments, vitamins, and fertilizers. Indications are that development of artificial upwellings do not need to be involved in power generation to be financially attractive (9).

Wave energy systems are a more steady and predictable energy source than the winds from which they draw their energy, yet variations in wave size and energy are substantial. Wave energy is concentrated at the sea surface, consequently a wave energy collection device needs to be of substantial extent, hindering its applicability to small islands (14). However, sedentary species can be cultured in much of the area otherwise reserved for energy generation.

Biomass energy generation systems have primarily focused on using kelp, a large, coldwater seaweed. Submerged reef areas and lagoons are probably available near the U.S.-affiliated islands where other macroalgae could be grown, but the nutrient-rich water required is largely lacking in tropical areas.

In several places in the Caribbean, including St. Croix, pilot programs have studied the feasibility of converting raw algal biomass into methane gas and other sources of cheap, nonpolluting energy (17). Algae are grown on enclosed (often floating) artificial substrates, harvested periodically, and converted chemically to gas. Two major problems influence the success of this process: 1) the relative scarcity of large, fleshy algae in island waters, particularly in light of intense fish grazing; and 2) the cost of nutrients and processing chemicals (103). This technology probably is more suitable for open ocean culture rather than nearshore systems (14).

Solar ponds use a strong salinity gradient to suppress convective mixing of a body of water heated by the sun (55). A substantial supply of salt is needed to maintain the required highly saline bottom layer. Hypersaline ponds in Puerto Rico and the USVI and Pacific atoll lagoons may lend themselves to solar pond energy generation. The cleanliness of the air on small islands and the clarity of the sea water would greatly reduce one of the problems with land-based ponds: heat-absorbing leaves, dirt, etc., accumulate in the surface layer reducing the heat collected by the highly saline lower layers. Certain salt-tolerant species, such as brine shrimp (used in livestock and fish feeds) probably can be cultured in these ponds with little detriment to energy generation.

Integrating Tourism and Resource Development

Tropical island environments not only encompass a variety of economically important renewable resource systems, they also attract tourists. The integrated development of renewable resource uses and of tourism will require careful planning, but is preferable to isolated and possibly conflicting approaches to these two opportunities for economic development on the islands.

Economic benefits and negative environmental and social impacts as well have been attributed to tourism in developing countries (33). Whether the former outweigh the latter has been a matter of some debate among economists and social scientists. While small tropical islands may be particularly vulnerable to tourism’s negative impacts, with proper planning and management, tourism development may be paced and integrated with resource management in ways that maximize the economic and environmental benefits of a tourist industry and mitigate its adverse impacts (3). For example, tourism can provide both the need and the capital means (as well as one rationale) for protecting natural areas, as well as the impetus for repairing environmentally degraded areas. Tourists represent potential consumers of island products, and their presence creates jobs in a variety of production and service sectors.

Local governments can set objectives for integrating tourism into island economies and decide what environmental and social changes can be tolerated and what resources can be committed. If the scale of development exceeds the limits of change acceptable to the environment or community, a tourist destination could quickly “peak out” and stagnate or decline in popularity.

Impacts of Tourism

Tourism research to date has primarily focused on economic and social impacts (3). The potential benefits of a tourist industry include increased job opportunities, improvements in infrastructural services, and increased tax revenues and foreign exchange earnings. Income from tourism can help offset deficits created by imports of raw materials and manufactured goods.

The quality of the environment, which is what attracts tourists to the islands, however, can be compromised by tourists themselves. Demands for land, water, and waste disposal generated by tourism may stress the limited resource base of small islands. Waste disposal, especially from large development, can be a particular problem if effluents are discharged into lagoons or other nearshore areas with limited circulation. Other potential contributors to environmental stress are construction and recreational activities (66). Tourists may disturb wildlife, trample coral, and collect live shells and corals. It has been estimated that 1 live coral head was collected for each 230 visitors to Hawaii—equivalent to about 19,000 to 24,000 specimens in 1 year (3). All of these environmental impacts will vary with the character and intensity of tourist site-use and development, and resiliency of the ecosystem (7).

Some of Caribbean tourism's most visible impacts are on the environment. In the space of one generation, natural coastal and beach areas have been displaced by hotel and marina expansion. Mountain faces and pristine landscapes have been etched with condominiums and roads. Large developments have alienated vast land areas from traditional uses and even modified climatic features (41). Sensitive ecosystems like swamps and mangroves have been irreversibly disturbed and lobster and fish beds have deteriorated (43).

Tourism may also have negative socio-cultural impacts, including changes in demography, lifestyles, consumption patterns, work and leisure habits, and loss of traditional values and customs, These effects vary with the numbers of tourists (relative to native population), and with the extent of the cultural and sociological differences between the tourist and indigenous populations (89), Their impact can be large on island territories with small populations.

Finally, some of the positive economic benefits of tourism may have been overstated. Tourism can function as a seed industry if profits are reinvested in other sectors of the economy. This does not happen as often as expected; much of the income from tourism goes off island to purchase imports, many for the tourist industry (3).

The failure of tourism to benefit the local economy on a greater scale, and the imposition of burdens on the local population to the benefit of the industry (e.g., loss of public beaches to resorts) has, in some cases, contributed to a sense of resentment by the resident population. Tax incentives encouraging to tourism development means loss of revenue for local governments. Local people become frustrated because, while they are employed in a range of jobs from low service positions to middle management, top managers and owners are usually foreign (10). It has been argued that potentially negative impacts of tourism on a host country are primarily a concern and responsibility of government (26), since private sector involvement is likely restricted to financial and economic considerations.

Pacific Tourism.—Tourism has developed only on certain Pacific islands; vast stretches of ocean separate destinations. Statistics on tourism in the Pacific are scattered among myriad sources and are not presented in a consistent or standardized format. The Pacific Area Travel Association annually compiles one of the more complete and detailed compendiums of statistical information on tourism, but does not cover Palau or the Marshalls.

Tourism development is a stated goal of each of the U.S.-affiliated island governments. Guam

Photo credit: Office of Technology Assessment

The natural beauty, unique cultural settings, and historic sites of the U.S.-Affiliated tropical islands attract growing numbers of tourists.

and Saipan have reached the intermediate stages of the tourist development model proposed by Butler (4), as defined by: 1) increasing external influence on tourist infrastructure, 2) large numbers of tourists who use the services of travel agents and other organized infrastructure, 3) declining rates of increase in tourist numbers, 4) heavy advertising and marketing to attract visitors and extend the tourist season, 5) the presence of major franchises and chains, and 6) some local opposition to tourism. The more remote islands of Micronesia attract considerably fewer visitors than do those of the Marianas chain. In 1981, only 20,981 visitors were recorded for Palau and the FSM combined, most from the United States (44,61,62). American Samoa also receives few tourists.

Many of the same factors that constrain renewable resource development also constrain the development of the tourist industry in the Pacific region. These include lack of reliable, inexpensive, frequent air service; lack of developable land for transportation and facilities; insufficient infrastructure; a reliance on imported foods, materials, and energy; and lack of trained personnel. Availability of transportation is often cited as the primary limiting factor in the development of an island's tourist industry (64). The distance between service points necessitates large aircraft, but lack of market populations prohibits reasonable operating cost structure (62). Carriers, routes, and timetables change frequently. Water supplies critical to tourism also are small on many islands. Depending on the nature of development, potable water requirements could vary from 100 to 500 gallons per person per day (22,99).

Finally, in some areas, cultural traditions inhibit acceptance of tourism as a viable option for earning a living (29,31,90). Even where tourism employment is acceptable, avoidance of hostility among local people is linked to the provision of good jobs, not menial employment only, and to local ownership (66). Management jobs, however, are primarily filled by expatriate personnel rather than local people, possibly leading to frustration.

Caribbean Tourism.—Many attractive beaches, an ideal climate, and proximity to major markets have given the Caribbean an advantage in competing for international tourists. However, only with the advent of mass tourism of the 1950s and early 1960s did tourism become a major economic activity in the region (81). The Caribbean region captures almost 3 percent of world tourism. As a result, the importance of tourism has become pervasive, and it has become the leading sector for the majority of Caribbean microstates (42).

Puerto Rico and the USVI depend largely on visitors from the urban populations of the United States and Europe. In the USVI, tourism is the base of the private economy and the major economic activity contributing to the gross domestic product (GDP) and employment generation (43). Tourism is economically, socially, and physically pervasive. The territory has received over a million tourists annually since 1972 and, in 1979, total visitors outnumbered local residents by a factor of 13. Their gross expenditures were double the entire operating budget of the Virgin Islands local government. Because it is so labor-intensive, the tourist industry has a considerable impact on employment, generating nearly one-third of all island jobs. Tourist infrastructure dominates the insular landscape. The islands' tourist economy makes the territory a major growth center within the eastern Caribbean; however there is no consistent, reliable, quantitative base from which to assess the economic contributions and performance of the tourism industry (81).

In Puerto Rico, which is economically more diversified, tourism accounts for a smaller portion of the GDP and total employment (81). Although tourism accounts for only about 5 percent of GDP, it creates linkages throughout the economy which result in increased total output by nearly all other economic sectors. Thus, for every tourist dollar spent between 1970 and 1980, GDP increased by an estimated average of $1.25 and total gross output by an average of $2.08. In all, 142 jobs were created in Puerto Rico in fiscal year 1980 for every $1.0 million spent by tourists, including an estimated total of 1,442 jobs in agriculture (75).

Caribbean tourism appears to face a challenging period ahead. A new recognition exists within Caribbean governments of the costs and benefits of tourism, and of the need for long-term planning with accurate market information (81). Long-term tourism viability will probably require a more focused marketing strategy, and it may depend on the industry's linkage potential with domestic sectors, such as agriculture and fisheries (43).

Local governments may need to insist on substantial local shareholding and participation in tourism-related companies. Residents could be trained as tour leaders in a program similar to the intensive summer training at the University of Hawaii School of Travel Industry Management.

Opportunity: Create Linkages Between Tourism and Island Producers

Systematic management to promote increased use of local agricultural produce in hotels and restaurants could help encourage regularity of supply and quality (18). Similarly, increased use of island handicrafts for decor in tourist facilities, and sales of handicrafts to tourists can foster this resource-based productive sector.

Whereas large, "industrial tourism, " characterized by hotels and infrastructure meeting international standards, require substantial investments in support facilities, and largely depend on imported foods, smaller scale, economy-class tourism, and "craft tourism" with "homestays" can make more use of island products. The islands could strive to attract more tourists of the second type, including "explorers" and "adventurers" (3). Educational tourism also is becoming popular as upscale travelers seek opportunities to learn about the culture and environment of remote areas. Promotion could be approached from the islander's perspective. What is special and important to the person who lives there? What would they like the tourist to see to get a true sense of the place?

Handicrafts Industry Development[3]

Island peoples have traditionally used fibers, shells, wood, and other local materials to make a wide variety of implements and decorative objects (table 8-2). Although some loss of skills has become evident on some islands in recent years, considerable interest in and demand for island handicrafts exists, mainly on the part of expatriate and tourist populations. Handicraft industries, if developed with attention to efficient production, marketing and quality control, could contribute significantly to island economies; attract more tourists; foster preservation of traditional art forms and pride in indigenous skills; and make productive use of some natural resources that might otherwise be left unused.

Many contemporary handicrafts in the islands are derivatives of traditional forms, in some cases miniaturized and standardized for sale to tourists. Other are innovations, fashioned with newly imported tools and materials, and geared to the tastes of tourists and other nonnative buyers, Few handicrafts today are integral to life and culture on the islands.

Pacific.—The rich variety of traditional handicrafts in Micronesia reflects the cultural diversity of the islands. Basketry and handweaving of natural fibers was the most widely spread skill, developed to a fine art in eastern Micronesia where wood was scarce. Containers with elaborate shell inlays were characteristic of Palau, and pottery was made where clay was available in Palau, Yap, and Saipan. Loom weaving was practiced in the central Carolines and tapa cloth (made from tree bark) was made in Samoa. The Trukese were skilled in both woodwork and fiber arts.

[3]This section is summarized from M. Vitarelli, "Handicrafts Industry Development and Renewable Resource Management for U.S.-Affiliated Pacific Islands, " OTA commissioned paper, 1986; and from D. Sheehy, "Traditional Crafts in the U.S.-Affiliated Caribbean Islands: An Addendum to Handicrafts Industry Development and Renewable Resource Management for U. S.-Affiliated Pacific Islands," OTA commissioned paper, 1986.

Table 8-2.-Primary Resources Used in Craft Production in U.S.-Affiliated Pacific Islands

Name of raw material	Where used	Type of material (and part used)	Crafts made from materials
Coconut (tree)	all islands	fiber (leaves) wood (trunk) husk, shell of nut	baskets, purses, mats spears, bowls twine, ladles, jewelry, belts
Pandanus (tree)	all islands	fiber (leaves) wood	mats, fans, purses, baskets, pillows, hats, wall decorations, cigarette cases, woven sails for model canoes, etc.
Banana (tree)	most islands	fiber (leaf sheaths)	lava-lava skirts, cordage, wrapping used in other crafts
Mangrove (tree)	high islands	wood	wood carvings, statues
Breadfruit (tree)	low islands	wood	carvings, model canoes
Ivory nut palm (tree)	Pohnpei	nut	carvings, jewelry
Mahogany (tree)	high islands	wood	carvings
Ironwood (tree)	most high islands some low islands	wood	carvings
Dort (tree)	Palau	wood	carvings
Ifil (tree)	many islands	wood	carvings
Paper mulberry (tree)	American Samoa	fiber (inner bark)	tapa cloth
Hibiscus (bush)	all islands	fiber (inner bark) wood	fiber leis, mwarmwar, ropes, nets, “grass” skirts, carvings
Bo-jo-bo (vine)	Saipan	nut	bo-jo-bo dolls
Tumeric (herb)	most islands	root	yellow dye for fibers
Bamboo	high islands	woody fiber	fish traps, hair combs, navigation charts
Trochus Shell	most islands	shell	jewelry (exported for use as buttons)
Pearl oyster	most islands	nacreous shell	jewelry, inlay for wooden bowls, carvings
Turtle shell	most islands	tortoise shell	jewelry, combs, women’s “money plates”
Cowrie & other shells	most islands	entire shell	jewelry, purses, ornaments, parts of decorative wall hangings
Coral (red & black)	W. Carolines	coral	jewelry

SOURCE: M. Vitarelli, “Handicrafts Industry Development and Renewable Resource Management for U.S.-Affiliated Pacific Islands,” OTA commissioned paper, 1986

While the range, diversity, and variety of form; quantity; and quality of handicrafts have all decreased, only certain traditional skills have disappeared. Many interesting new forms of handicrafts have emerged in part because tourists, foreign museums, and shops all express an interest in purchasing island crafts. Market surveys have shown that Pacific island handicraft products are readily salable within and outside the territory, for example, to major outlets in Hawaii, the U.S. mainland, and Canada (78). However, production at reasonable prices must be stimulated and the success of the industry currently depends on tourism, not export.

Development of handicrafts as a small industry has not yet occurred within the Pacific islands for a number of reasons. Local products often lose out in competition with cheaper imports. In some areas, tourist demand for handicrafts outstrips local supplies of quality products offered at consistent prices. Guam, for example, attracts many tourists and has numerous outlets for sale of handicrafts, yet few are locally produced. The lure of a steady income through government employment may be largely to blame. Handicrafts are normally home-produced and marketed on an individual basis, and in one’s spare time. Production is rarely an organized group effort, although exceptions occur (e.g., museum-employed draftspersons on American Samoa; a National Endowment for the Arts project on Palau; the Small Industries Workshop on Truk; Ponape Coconut Products packaging; crafts groups at Kolonia, Pohnpei; and a few government-sponsored projects).

Few producers have marketing skills and no cooperatives or intermediary marketing agencies exist to supply these and help assure regular quality production. Also lacking are mechanisms for the preservation and transfer of handicraft skills; a guaranteed market in some areas; and an assured, constant supply of raw materials, some of which must be prepared for

Photo credit" M. Vitarelli

Traditional crafts, although gaining importance as commercial items, retain their practical application in everyday island life. Shown here, coconut leaves are being woven into a utility basket by an island draftsperson.

use. Even today, periodic depletion of resources, and delays in getting materials to draftspersons sometimes hampers production.

Caribbean.— As in the Pacific, traditional crafts until recent decades played a vital role in the daily lives of most Puerto Ricans and Virgin Islanders. Historically, most were dependent on traditional craft skills for many of their everyday necessities.

The traditional handicrafts currently found in Puerto Rico clearly reflect three major strains in the island's cultural history. Woven hemp hammocks were common to the local Arawak Indians and are still fabricated locally. The bomba drums and painted coconut husk masks and *maracas* are clearly of African derivation. Certain musical instruments, carved wooden animals, and *santos* (religious icons) are uniquely Puerto Rican but draw from Spanish prototypes. Other prominent Puerto Rican craft forms are pacemaking; jewelry made from local seeds, shells, and coconut shell; basketry; machetes; wooden furniture and caning; tinwork; and pottery and papier mache masks.

As the modern technology and factory-made goods of the United States were increasingly imported by the islands from the 1920s to the present, three general trends of change were observable. First, many handicraft skills were eclipsed or were forgotten through disuse, as foreign-made or factory-made items were imported. Skills at roof thatching, for example, were all but lost as corrugated tin and other ready-made materials were used to cover people's homes; brooms, vine baskets, palm hats, hand-hewn wood furniture, fish traps, and other common necessities were increasingly of foreign origin.

Second, as society became more commodity-oriented and the dictates of the marketplace played an ever-increasing role in the production of handicrafts, crafts that were not competitive as commodities fell into desuetude. As the set of esthetic criteria that determined quality shifted from those of the local, primarily rural and agricultural community members to those of the city-dwelling consumers of urban San Juan and foreign lands, traditional crafts that could find a niche in the marketplace commonly suffered an esthetic disjuncture. In some cases, the change in the process of crafts production from the craftsman devoting great attention to each individual piece to the craftsman having to maximize the number of pieces produced in order to meet the demand resulted in greater standardization, reduced artistic diversity, and miniaturization.

Finally, the burgeoning tourist industry, hand-in-hand with underemployment, created an economically appealing situation for those interested in producing and selling handicrafts for foreign tourists. Many (if not most) of these craft items were made and marketed as souvenirs or "hand-made" crafts and did not draw on local traditional craft skills or esthetic ideals.

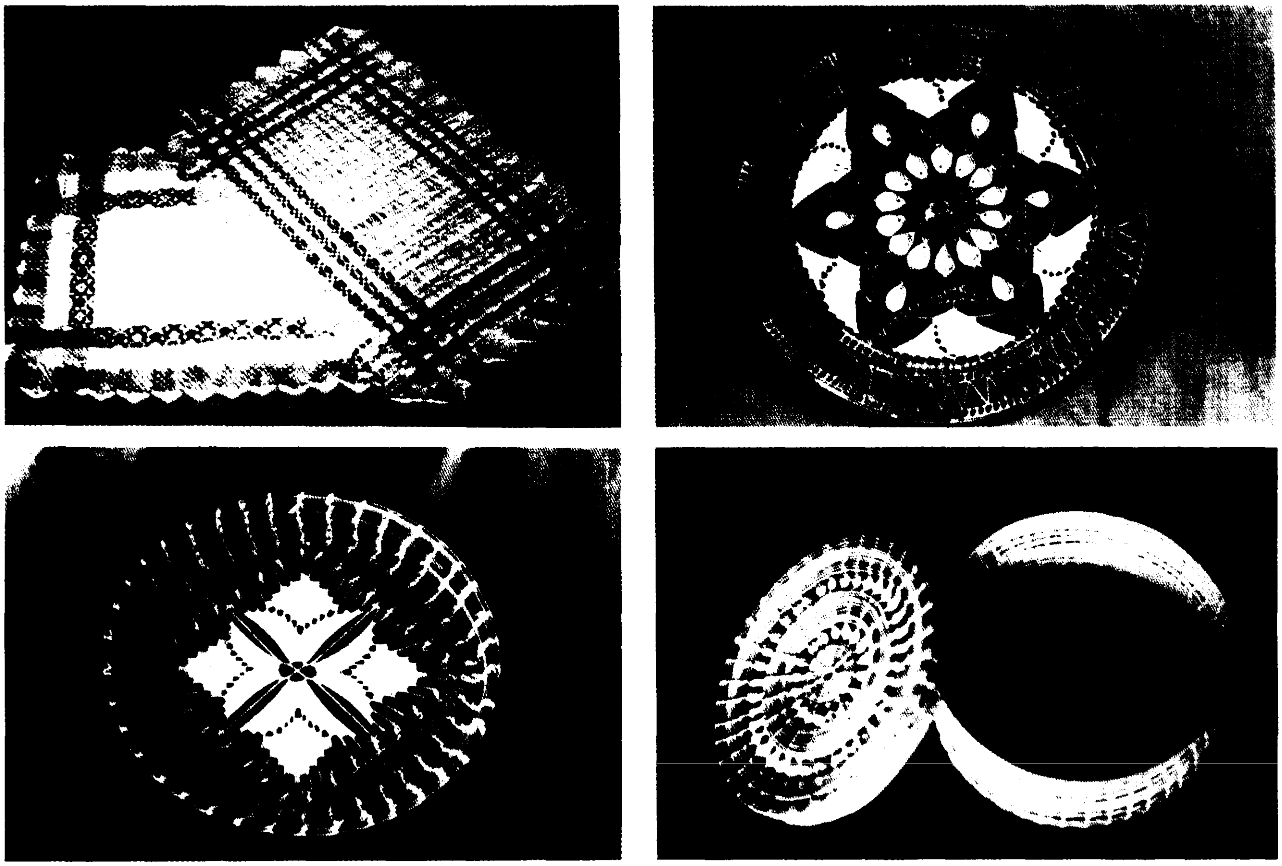


Photo cradit: M. Vitarelli

Traditionally used raw materials such as pandanus and coconut leaf fibers and shells still are used today in many fine island handicrafts. Clockwise from top left 1) Marshall Islands' place mats, 2) Trukese wall decoration with cowrie shell accents, 3) Marshall Islands' sewing basket with cowrie shell accents, and 4) Trukese decorative tray.

Although Puerto Rico's crafts have clearly suffered a decline in this century, in many cases there has been a renewed vitality since the 1950s. The Institute of Puerto Rican Culture, created in the 1950s, began a policy of stimulating the practice of indigenous traditional arts through contest, local and islandwide crafts fairs, exhibits, and education programs. More recently, the Office of Crafts Development of the Administration de Fomento Economico provides technical assistance and some tools to traditional craftsmen. It also has instituted an annual recognition program of Master Craftsman of the Year and Young Craftsman of the Year, bringing prestige, recognition, and greater visibility to Puerto Rico's craftsmen. In addition, several crafts items have been consciously promoted as symbols of insular identity, such as the omnipresent carved wooden coqui (a small frog).

Traditional crafts of the U.S. Virgin Islands suffered a similar decline as did the crafts of Puerto Rico, but have not enjoyed a similar renewal of vitality. Few traditional craft items have been converted successfully to commodities for the tourist or local market. Some crafts traditions continue, such as fishnets, fish traps, and the woven grass hats of Frenchtown, but they are to be found at the margins of daily life.

Traditional crafts have not received the governmental recognition and support in the USVI as they have in Puerto Rico. The Virgin Islands Council on the Arts and the multicultural education divisions of the local public schools have given some attention to local traditional culture, but to date there has been no comprehensive survey to inventory local crafts and assess the needs of local traditional craftsworkers, nor has there been any focused government effort at conserving local handicrafts.

Opportunities to Encourage Handicraft Industry Development.–Several measures can be taken to mitigate these constraints and to encourage the growth of a handicrafts industry in the U.S.-affiliated islands. Producers, for example, can cooperate for specific purposes (advertising, participation in fairs) and standardize prices for handicrafts. Island hotels, restaurants, and offices can make more use of handcrafted items in place of imported glass and plastic decorative items. Perhaps with Federal Government support, island governments could:

- aid in the provision of tools, materials, and workplaces;
- help establish vocational training in schools and master-apprentice programs for transfer of skills from elders;
- provide publicity, sales promotion, and sales agents;
- establish museums and cultural centers (with handicraft sales shops) on major islands;
- provide funding for filming or other documentation of crafts being made to aid skill transfer and educate visitors;
- where export is feasible, compile a trade index or list of overseas products, producers, and retailers for distribution overseas;
- create tax incentives for organizations and businesses who support local handicrafts, or culture and the arts; and
- prepare handicraft development plans.

In the latter, planners must choose between emphasis on limited production or mass-production; indigenous handicrafts or innovative derived forms; local consumption or export. Except in unusual cases, in the near-term handicrafts are likely to remain a source of supplemental income to small-scale artisans, thus programs to increase the earnings potential of handicrafts must be long-term (56). A wise approach to development might be cautious step-by-step expansion, building on existing skills and focusing on quality and organization before mass-production is attempted.

If a systematic effort is made to improve and expand the handicraft industry, methods of conserving and/or replenishing supplies of raw materials must be researched and implemented to avoid depletion. As limited rural lands continue to be developed in the U.S. Caribbean, and as certain crafts grow in popularity, resource depletion may hinder development of some crafts. Reforestation programs could be initiated to ensure a continuous supply of wood, laws enacted and enforced regulating the collecting of shells and coral, and neutral lands set aside for cultivation of fibers (40).

Integrating Urban Development With Resource Management

Renewable resource management can be integrated into urban development in a number of ways, including: wastewater treatment and reuse to protect nearshore ecosystems and for land fertilization, and development of urban forestry to provide noise reduction and other environmental services and a source of high-value wood for small-scale artisans.

Wastewater Treatment and Reuse

Providing safe drinking water and protection of groundwater supplies are important goals in the U.S.-affiliated islands. Solid waste management, including controls over littering and centralized refuge collection and disposal, is also needed. Sewerage linkups to appropriately designed treatment plants and outfalls are needed by many urban subdistricts and villages (39).

Most U.S.-affiliated islands are facing problems in ensuring safe water supplies and adequate sewage disposal. For example, reports from diving groups suggest that Truk lagoon is becoming so polluted that, unless waste disposal in the lagoon is minimized, divers may venture elsewhere in the future, reducing tourist income (39). In July 1982, sewage pollution in Truk lagoon activated a cholera outbreak leading to loss of life (8).

Although EPA is constructing outfalls and treatment facilities for domestic sewage on the islands, funds are inadequate for hookups to individual houses and businesses. Thus, sewage pollution remains a serious problem. Construction of sewage outfalls and treatment plants has been accomplished or is planned for Pohnpei, Kosrae, Yap island, and Falalop on Ulithi (Yap). Solid waste disposal and landfill management continue to be challenges (39). The need to manage wastewater discharges and solid waste disposal will continue to grow with the populations unless remedial actions and novel approaches which reduce construction and maintenance costs are identified and initiated.

Integrated Aquiculture/Wastewater Treatment Systems.—Seaweed or aquatic plant cultivation might also be used for water treatment (57,58). Aquatic plants effectively strip much of the nutrients from wastewater, thereby reducing eutrophication effects in the receiving water body (46). The use of aquatic plants for wastewater treatment has considerable potential for use in the tropics because of the stable environmental temperatures. Aquaculture systems for water treatment have been instituted in several areas of the continental United States (23,76) and this concept deserves more attention for application on the islands (56).

Land-Application of Sewage Sludge and Wastewater.—Treated wastewater is not now used for irrigation on the U.S.-affiliated islands. On St. Croix, use of a saltwater flush system in some areas makes wastewater too saline (47). However, wastewater blended with impounded runoff can be used for irrigation.

Some wastewater facilities plans in Puerto Rico call for the land disposal of some effluents via irrigation (34). However, there is declining interest in this since irrigation demand has diminished (47).

Adequately digested and disinfected sewage sludge could be valuable as a soil conditioner and fertilizer in many areas. On Guam, treated sludge is used to a very limited extent by local farmers. In other areas, cultural beliefs would have to be overcome and facilities constructed to yield safely treated sludge. An increasing concern is the extent to which heavy metals and toxic substances enter sewer systems and concentrate in sewage sludge (37). Only the Umatic/Merizo waste treatment facility on Guam employs land treatment on a relatively large-scale, but the success of this operation has been hampered by operating and maintenance difficulties. These, plus land availability and public acceptance constraints are major obstacles to land treatment of wastes.

Urban Forestry

Urban forests have a number of influences on the quality of the residential and urban environment in addition to contributing to an esthetically pleasing environment. Although little information exists on the effects of open-grown trees and 30 to 50 percent tree canopy cover applicable to urban forest situations (74), urban trees can reduce the kinetic energy of raindrops thus protecting parks, lawns, and unpaved roads and may help regulate water runoff. Trees shade buildings, thus reducing ambient air temperatures and, perhaps, reducing energy consumption by air-conditioners. On the other hand, trees can restrict air flow around buildings and reduce the cooling effect of wind on the buildings. Urban noise can be ameliorated by woody vegetation, which serves as a barrier to sound waves, and dense litter layers, which absorb sound (74).

Forests and forest soils in and around urban areas can serve as “sinks” for air pollutants such as carbon monoxide although, of course, they also can be a source of allergens. Urban forests also commonly are inhabited by birds, some of which are insectivorous and reduce insect populations perhaps reducing the need for pesticides. Finally, urban forests can serve

as a source of valuable woods. Urban and roadside trees that must be removed for other reasons supply much of the raw material for a small wood crafts and specialty furniture industry on St. Croix (USVI). This use of available wood could be a model for economic use of wood where large-scale commercial forestry is not feasible (92).

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Chapter 9

Resource Development Planning for U.S.-Affiliated Islands

INTRODUCTION

The small size of islands, and consequent scarcity of land and resources makes it undesirable and probably infeasible to concentrate human populations and activities on ever smaller areas of land, Similarly, although some resource recovery efforts are needed, small populations and economies disallow expense of large amounts of scarce capital and labor on artificial provision of environmental services or continuous reclamation of degraded areas. Clearly, the preferred alternative is to prevent degradation of the island ecosystem, Through application of rational management activities, ecosystem benefits may be sustained over the long term.

Resource management refers to decisions of policy or practices regarding how resources are allocated and under what conditions (or arrangements) resources may be developed (30). Resource management includes both **planning** activities in which resource management objectives and techniques for achieving those objectives are systematically identified and **implementation** activities in which specific management techniques are used to allocate resources among uses (and users) (25)

Planning processes typically involve several steps:

1. identification of some goal to be achieved (or problem to be mitigated),
2. identification of alternative ways in which the goal can be achieved,
3. evaluation of these alternatives,
4. choice of a strategy, and
5. specification of how that strategy is to be implemented (25).

In the development of resource management programs, there are three levels of planning: policy, program, and project. **Policy** planning refers to the broad choices that must be made among multiple and frequently competing resource management objectives. At this level the questions to be answered are explicitly value choices. In practice, such policy choices commonly are expressed in terms of 5-year development plans, State policy plans, or similar documents. Such policy statements provide some indication of a general awareness of resource management problems as well as the emphasis that such problems should receive. There are, however, no guarantees that resource management problems will receive systematic management attention (25)

Program planning refers to the identification and evaluation of alternative ways to achieve some resource management objective. A partial list of such techniques includes zoning, tax incentives, or direct subsidies to resource owners to maintain certain resource uses (e. g., agriculture, protected habitat), outright purchase of development rights to lands, and performance standards for certain uses. All of these management techniques have been or are currently being employed in a number of U.S. continental States (25).

Project planning is sometimes used to describe the detailed administrative guidelines and procedures for implementing a particular management strategy, or the detailed specification of a particular resource use consistent with resource management program objectives (25).

Policy, program, and project planning require different kinds of information and analysis. Policy planning must address a mix of value and empirical questions. As planning becomes more specific there are fewer explicitly value issues and more empirical questions (25).

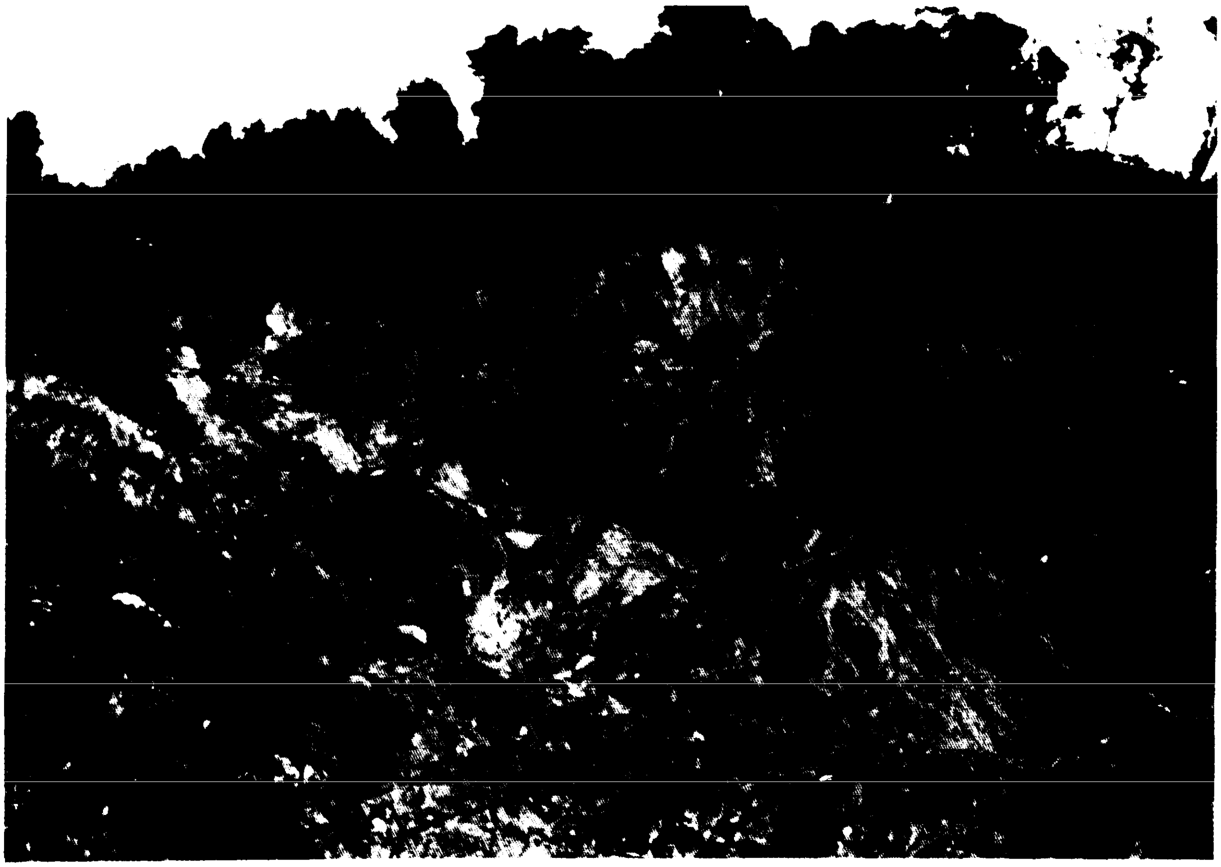


Photo credit: J. Bauer

Landslides, a common hazard on tropical high islands, may be promoted by inappropriate land use such as hillside construction or agricultural cultivation in erosion-prone areas.

Basic information and the appropriate technologies for analyzing that information are widely agreed to be a fundamental requirement for successful resource management (3). However, the types of information collected and stored, the types of analysis performed and how these activities should be integrated into resource management programs depend on the nature of the resource management problems confronted by an island, the degree of geographic specificity in planning and management efforts to deal with these issues, and the particular management techniques that are being employed for problem mitigation.

Resource Planning Goals for U.S.-Affiliated Islands

Island resource systems exist in close proximity and are strongly interrelated. Decisions that affect one resource are likely to affect other "downstream" resources. For example, conversion of island forests to agriculture, or removal of mangrove habitat for the purposes of coastal development can lead to degradation of reef areas through increased siltation. Conversely, mining of reefs, which act as natural wave energy and storm surge buffers, may lead to increased erosion or other damage to coastal areas, Integrated management of natural systems requires thorough knowledge of the interrelationships between resource systems. These interrelationships are often critical to the functioning of the whole island system (11).

Natural systems management problems are usually perceived in two ways: 1) as the **consequences** of particular resource uses, or 2) as **conflicts** over alternative resource uses. Accordingly, two general approaches exist to resource planning:

1. A use in mind; where to do it or put it?
2. A particular resource or an area of land; what to do with it?

The first approach is a frequently used, single-purpose planning methodology, After having established need and other socioeconomic considerations, the process involves translating use requirements into biological and physical (biophysical) site-selection criteria. As perceived resource values change, this has increasingly become a question of "where not to put it?" Overlay maps showing areas of high economic, social, or cultural value plus physical impediments commonly are used in a technique advocated by McHarg (29) to show where development would adversely affect the least number of community-determined values (18).

The second approach is relevant where a landowner, administrator, or manager wants to assess the resources under his jurisdiction and determine if an area is allocated to the most productive sustainable uses. To a limited extent, this planning approach may be taken by a private landowner who has flexibility in his operation, surplus resources, and usually substantial areas of land. It is not characteristic of tradition-bound agriculturists or pastoralists living at or near subsistence levels, nor of corporate landowners with a narrow mandate and large plant investment to protect through using products from the land (e.g., pulp and paper company). It does, however, often characterize the planning and management of public lands (excluding military lands or nature reserves). Countries undergoing rapid increases in population are adopting the approach of looking at the limited land estate and asking what to do with it to promote national economic and human well-being (18).

Both approaches are predicated on concerns about the long-term ability of the resources to provide goods and services **efficiently** and **safely. Efficient** resource uses are keyed to the natural constraints of a site. Such uses generally are efficient in maintaining a flow of goods (e.g., crops) and services (e.g., watershed protection), although there are exceptions where a higher flow may be provided efficiently by overcoming minor physical limitations (e.g., by improving drainage in soils). **Safe** uses build in an avoidance of ecological backlash (e.g., avoid unstable slopes, flood-prone areas—unless one wants to take a risk or alter the site by making corrective investments) (18).

Planning Needs and Constraints[1]

Each U.S.-affiliated island government has designated a planning office. In general, these offices are responsible for compiling information on factors affecting the economic development of these islands, presenting a framework for decisionmaking by island leaders, planners, and the public and advising their governments on rational development planning.

Some of these planning offices also are responsible for maintaining libraries and bibliographies of information for use by government personnel and the public. For example, the Guam Bureau of Planning has established a cataloged Planning Library to assist people conducting research on Guam. A Coastal Planning Bibliography was produced in 1978 in association with the development of the Guam Coastal Zone Management Plan, and a "Guam Inventory of Planning Information" was prepared in 1976 and updated in 1981 (17).

[1]The Office of Technology Assessment conducted a survey of resource development planning and management offices in U. S.-affiliated islands in April 1986. Respondents were asked to comment on how important they perceive the planning constraints identified by Lowry (25), whether their office uses any of the analytic techniques described, and the actions they think would do the most to improve resource development planning on their island. Of the 80 surveys sent out, only 8 were returned.

A number of plans analyzing resource management and impacts of development activities have been prepared in each island area either by internal planning offices, in cooperation with the Department of Commerce through development of Coastal Zone Management plans, or by the United Nations. Unfortunately, different plans are rarely centralized or aggregated. The Freely Associated States (FAS) were required to prepare 5-year comprehensive development plans under the terms of the Compact of Free Association. These plans commonly describe goals and problems, but tend to remain so general that they provide little guidance for island decisionmakers to evaluate potential projects.

Although ample evidence exists that improved resource management is unlikely in the absence of planning, it cannot ensure sustainable resource management. Planning processes may go awry for a number of reasons, including:

- lack of resources for planning,
- inadequate planning expertise "in-house" and heavy demand on existing island planners,
- lack of data for planning,
- lack of understanding of natural processes,
- lack of understanding of the social and political contexts in which plans are to be implemented.
- inadequate problem specification,
- inadequate specification of management alternatives, and
- use of planning as a substitute for management.

Lack of Resources for Planning

Lack of resources for planning is a common constraint on U.S.-affiliated islands. Planning requires a substantial amount of skilled personnel, information, and time. Those resources frequently are not available for resource system planning or, when they are available, they may be diverted to other planning enterprises that show more promise of immediate payoffs.

Inadequate Planning Expertise

The number of people involved in planning on the islands and their total years of experience are limited. Resource planning and management offices in the FAS, for example, are understaffed; they lack resource data and exercise little regulatory authority (app. F). Environmental protection boards in the FAS have not effectively compelled developers to evaluate alternate sites and procedures. Outside expertise is needed, at least initially, to help train planners and to plan and evaluate specific development proposals.

Lack of Data for Planning

A further constraint is posed by the lack of reliable data on almost all aspects of the economic and population structures of the islands. Census data commonly are suspect and many other data have not been collected. The unavailability of such data presents considerable problems for development planning (8).

While some insular polities have gathered extensive data and developed data management systems, others are still in need of basic information. Regardless of the island's level of data management development, an overall need still exists for further information gathering and research on basic biological systems, as well as improved data management and communication systems (app. F).

Detailed economic development planning, including identification of manpower and manpower training needs, is required to instigate any significant movement towards self-reliance (8). However, collection and analysis of many data are largely beyond the current capabilities of many insular government planning offices, especially since each government agency commonly collects information specific to its own functions. These data may not be collected for each island or island region within a territory, may not be standardized to allow aggregation, and may not be integrated into one system (5,6, 7,8,9,10).

Lack of Understanding of Natural Processes

Designing a resource management program requires a basic understanding of cause and effect relationships of biological and physical processes. Ignorance of such relationships can give rise to unexpected and sometimes severe unintended impacts. In addition to inadequate baseline biological data for organisms or resources to be managed, this appears to be an important constraint confronting island planners and resource managers.

Lack of Understanding of the Social and Political Contexts in Which Plans Are To Be Impemented

A central problem in the evaluation of management alternatives is the question of which values (or whose values) will be used to assess the worth of proposed management strategies. If the management alternatives do not reflect the values of those who are most affected by the plan, the effectiveness of management efforts are likely to be undermined. The evaluation of alternatives is particularly critical in island environments in which the values of the planners may be different from those of would-be "clients."

One way of ensuring that the choice of management strategies reflects the values of clientele is to involve them more intimately in planning processes. However, such involvement need not take the form of public hearings at which clientele may respond to a completed plan—a conventional strategy of "citizen participation" used in U.S. community planning processes of the 1960s and 1970s. To the extent that resource management programs do not reflect island values regarding man/environment relationships or cannot, through a process of community education, be shown to be consistent with those values, they are not likely to be successful (25).

Inadequate Problem Specification

In developing a resource systems management program, the possibility of inadequate problem specification always exists—of focusing on the wrong problem. For example, rather than identifying a problem as its underlying cause (e.g., overpopulation), it maybe more useful to define the problem by its adverse effects related to the underlying cause (e. g., resource overexploitation). In specifying resource management issues to be addressed, the central question should be: what adverse conditions need to be avoided or reversed?

inadequate Specification of Management Alternatives

Many contemporary resource management programs are "technique-driven" rather than "issue-driven." Often some particular management technique is touted as the management technique to be employed with particular resource management problems. Too little attention is paid to other alternatives or to the particular political and social context within which a resource management technique will be employed.

Use of Planning as a Substitute for Management

Planning sometimes becomes a substitute for management because it was hoped that the activity would be a catalyst for generating public support for resource management activities that would be socially or politically divisive. When that support fails to materialize, the "plans" are left unimplemented. Planning activities also may be encouraged as symbolic activities to reassure people that "something is being done" about some problem or condition,

RESOURCE DATA COLLECTION AND INFORMATION MANAGEMENT

Most resource planning techniques require a number of "sub-assessments" each requiring different types of information necessary to the formation of effective management plans, including:

1. *Biophysical* assessment—requiring information on factors affecting the physical and biological suitability of a site for various uses, including climate, geomorphology and geology, soils, flora, and fauna. This information can be used directly for site selection; after identification of the desired resource activity, the planner identifies constraints that could inhibit that resource use and looks for sites where the constraints do not exist or are manageable (36).

2. *Land classification-the* objectives of land classification are to identify the resources of a given area, determine appropriate management practices for existing resource uses, and predict the consequences of proposed changes in land use and policies (36). Overlay mapping techniques commonly are used to select sites for particular land uses. One such technique is to produce maps using white, black, or shades of gray to show the suitability of locations for specific types of development. The suitability ratings are combined by superimposing the maps, either manually or by computer, and examining the distributions of shading intensities.

Land classification techniques assume natural system relationships are determined by land physiography. Such techniques can be helpful in resource development planning, but they have limitations. Some systems are oriented toward a particular land use such as agriculture and, therefore, tend to assess suitability for that use rather than overall resource suitability. No single land classification system measures resource productivity directly; this would be too costly and time-consuming. Some techniques are more appropriate for use in ecological studies than for helping decisionmakers with land management questions. None of the techniques identifies the direct or indirect biophysical impacts of land use conversions. Moreover, the techniques neglect gradual changes in biophysical factors that can eventually limit various resource uses. Unless combined with simulation modeling, these techniques do not reflect changes in the magnitude of types of impacts over time (36).

Data on tropical ecosystems, both terrestrial and marine, are insufficient for many planning needs. Resource management and development for sustained yields requires up-to-date baseline data on current resource use patterns and the distribution and status of natural ecosystems. without such information, it is impossible to determine the capabilities of each resource for supporting various types of uses, or to predict the consequences of various resource use decisions on island ecosystems and populations.

Ecological Baseline Surveys

Many jurisdictions rely heavily on environmental impact statements to provide basic information about the condition of natural systems at a given time. However, when subsequent developments are planned in the same area, a new environmental impact assessment is made and much of the same information is gathered again, with resultant duplication of effort (and waste of scarce resources) (2). One alternative would be to design and manage environmental assessments so as to contribute to a central database which could then be used to prepare future EISs, thus minimizing duplication. However, care must be taken to ensure that the information in the central database is updated to reflect changes in land use or resource systems.

A second alternative would be to put increased emphasis on development of ecological baseline surveys which incorporate a "comprehensive appraisal of important natural systems parameters at a given time" (2). Resource inventories which identify natural resources in specific geographic areas and indicate their quality and variety commonly are part of an ecological baseline study. The principal uses of such information are in the preparation of land and water use plans and other program plans, project assessments, environmental impact assessments, area plans, and permit decisions.

The primary obstacle to development of ecological baseline surveys is cost of data collection, storage, and retrieval. The greater the number of variables and the greater the geographic scope, the more expensive it is to measure comprehensive resource data. One way to analyze cost-effectiveness of collection procedures and data parameters is to proceed with a "test case" by: 1) seeking interagency agreement about what parameters to collect, and 2) collecting information for a well-defined geographic area where resource use is high. This makes it possible to examine the utility of the information collected as well as the costs and skill requirements for collection.

Data storage and retrieval systems also may be costly. To avoid costly duplication, a scale must be chosen for mapped data that is appropriate for different users. Detailed mapping of the sort that is useful for permit decisions may result in maps that are too cumbersome for other uses. Some information may be stored and exchanged electronically, but a great deal of advance preparation may be needed to develop formats for storage (25).

Monitoring

Environmental monitoring refers to periodic measurements of natural resources and environmental quality parameters to allow analysis of trends or departures from a standard (usually predevelopment) which result from either natural causes or human activities (2). For many projects, the preproject planning phase is the only time when a substantial effort is made to determine how the project's products and services will contribute to larger development goals (36) and when data are collected on the resources and resource uses that are likely to be affected by the project. Monitoring, on the other hand, takes place during implementation and is intended to meet the needs of day-to-day project management. It can indicate a need to change the timetable, scale, geographic location, resource allocation, or staffing of activities (36). The difficulties in developing and maintaining a monitoring system are comparable to those of developing and maintaining ecological baseline studies.

Data Management

Within many governments, data are collected by more than one agency, sometimes leading to unnecessary duplication. Further, such information commonly is not centralized and may not be exchanged between agencies in the government. Data may be collected in different formats and at different scales, making use of the information difficult without expensive reformatting, In some cases, mapping and data collection are not comprehensive (app. F); and scales are not consistent within a territory, or even within individual agencies in the same territory (31).

An institutional Structure for Data Management

Some opportunities exist for alleviating the problem by reorganizing responsibilities for environmental data collection. A separate department or ministry might be responsible for the environment including setting standards for uniform methods of data collection, scales, and formats, which all other departments would be obligated to follow. The environmental ministry would also be responsible for obtaining and maintaining a national or territorial database, as well as conducting the needed monitoring of key data elements. A second possibility is to organize all environmental data collection under one agency responsible for national mapping. Ministries concerned with specific projects requiring baseline data would then request the national mapping organization to carry out the needed surveys. A third alternative is to leave organizations as they are now but ensure coordination among them and uniformity of environmental information by forming a coordinating committee. It would probably be wise for the coordinating committee to have its own separate staff of a small number of qualified environmental scientists who would advise on methods, techniques, scales, precision standards, and time intervals for collecting data.

An organizational structure that assures that needed data are collected and made available to all agencies, without duplication or nonuniform methods and standards is needed for sustainable resource management. Environmental data are too important and expensive to collect, to let duplication, incompatible formats and scales, and other obstacles hinder the most efficient use of information *(31).*

Resource Data Management Systems

Almost every Federal policy statement, whether legislation, executive orders, or agency guidelines, contains some requirements for data collection and monitoring (l). Most regulatory permit programs also contain data collection requirements. However, few provisions exist for updating or aggregating data. Comprehensive resource planning systems, such as geographic information systems, can centralize the storage and processing of spatial data reducing duplication, and thus, costs (20).

Many States have adopted the map overlay system developed by McHarg in *1969,* in which resources important to the decision to be made are identified, located, and mapped. By superimposing maps, areas containing many valued resources show up as dark-colored areas and areas whose resources are less affected by the proposed development show up as light colored areas. This system, however, depends on the planner's judgment as to which resources are valued and assumes that all are equally important. Much labor, time, and money also are required for map preparation and minor changes in methods or values may often necessitate complete redrafting (24).

In recent years, many local governments have graduated to computerized systems in which the maps are transformed to databases linked to a spatially divided base map. Thus, data can be updated easily, and a great number of variables can be considered in analysis. From these computerized geographic information systems, maps can be "overlain" by the computer with relatively little difficulty to produce composite maps (cf: METLAND system). A computer model can also be used to weigh the various land factors according to some measure of their importance to development to produce a capability map (20)

Feeding inventory and monitoring data into the physical and economic planning process can be relatively simple; in fact, there is a danger of imposing procedures that are unnecessarily cumbersome for island communities. Ideally, a microcomputer could be programmed to process data and present it in simple form to island planners *(11).*

ANALYTIC TECHNIQUES FOR RESOURCE DEVELOPMENT PLANNING

Analytical techniques for resource development planning are methods of manipulating data to generate and analyze information for resource management. Given the current dearth of data and skilled personnel on some U.S.-affiliated islands, analytical resource planning techniques should be inexpensive, should not require a great deal of baseline data, and should not be too complicated or sophisticated *(18).* In addition, the technique should make it clear that resource use decisions will depend on land tenure, needs, skills, available resources to invest, cultural constraints, political goals, and other factors besides biophysical suitability.

Environmental Impact Assessment

The National Environmental Policy Act requires the preparation of environmental impact statements (EISs) for "significant" Federal actions such as the construction of ports and airfields. Some States have additional EIS requirements covering certain land and water uses and/or all uses in select geographic areas.

EISs are preproject reports on possible positive/negative short- and long-term impacts resulting from some public or private policy, program, or project. The central assumption of EIS requirements is that cause and effect relationships between project activities and resource conditions can be identified with sufficient certainty to make them a valuable tool for analysis and decisionmaking. Continuous monitoring and evaluation provide mechanisms for EIS-based planning to deal with uncertainty (14), but these are only rarely practiced in the islands,

Environmental impact statements usually emphasize potential impacts on natural systems, but some jurisdictions require more extensive analysis including potential impacts on publicly funded infrastructure, historic and archeological resources, and demographic and other social and economic conditions. Most environmental assessments contain at least the following elements:

1. a description of the proposed project or activity;
2. identification of selected alternatives to the proposed project or activity;
3. description of the existing conditions (natural, social) at the proposed project site; and
4. identification of the nature and magnitude of possible project impacts at the proposed site.

Some jurisdictions also require identification of trade-offs or possible mitigative actions.

Environmental impact analysis is a short-term investigation of the likely impacts of previously identified policy or project options and, thus, does not permit evaluation of the full range of development alternatives (14). If resource planning began by incorporating the appropriate environmental and resource capability information, EISs might be rendered redundant *(18),*

Resource Suitability Analysis

Resource suitability or capability analyses provide information about the supply of resources at various levels of suitability for various uses. Such analyses generally involve delineating landscape (or seascape) units on a map, or an air photo and assessing the capability of these areas to sustain an array of potential uses without unacceptable degradation and given certain levels of management and technology *(18) (see* fig. *9-1* on p. 342). Land suitability analyses, the most common form, include agricultural classification systems and hazard maps charting flood zones or landslide areas. More complex suitability maps have been developed using multiple land characteristics, but the costs of developing such information are high and the results frequently are mixed.

Resource suitability analysis usually involves several steps:

1. identification of the uses for which suitability is being determined (e.g., agriculture, low-density housing);
2. identification of the biophysical attributes of the area in question that significantly affect suitability (e.g., soil type, slope, depth to bedrock);
3. identification of the significant categories of each attribute (e. g., slopes less than 10 degrees, between 10 and *30* degrees, over 30 degrees);
4. determination of the degree of importance of each biophysical attribute and each subcategory of that attribute to suitability of the resource uses in question;
5. development of a rating system that makes it possible to combine biophysical attributes into an index of suitability for potential land uses on different land or sea areal units; and
6. expression of these indices on maps,

The areal units identified should be part of a hierarchical system of land classification, so that they can be aggregated for general planning purposes, or subdivided for detailed onsite work. In predicting response, and then suitability, levels of most likely management inputs are assumed, and these can be varied for any socioeconomic situation with a cultural context *(18)*.

A central problem in constructing resource suitability maps is in developing methods for combining resource attributes in ways that are practical, technically correct, and easy to understand and communicate. Three basic approaches are used: mathematical combination, regional identification, and logical combination (21). Mathematical combination involves assigning weights to each biophysical attribute and then calculating weighted averages. Because underlying relationships among attributes commonly are poorly understood and do not, in practice, lend themselves to easy application in standard resource management, the mathematical approach generally is not applicable to island resource management. The regional identification approach involves identifying subregions within a larger geographical area that are homogeneous with regard to important attributes, and then identifying the suitability of each type of subregion for various resource uses.

The logical combination approach assigns suitabilities to sets of attributes (rather than single attributes) which are expressed in terms of verbal logic rather than in quantitative indices. For example, a set of simple rules can be derived that take into consideration the interdependence of slope, soil permeability, and subsurface material in determining suitability for hillside residential development. The logical combination approach to suitability analysis would seem to offer the most promise in island contexts; the rules are explicit, can be developed on the basis of known interdependent attributes and are easy to communicate (25).

The task of predicting suitability for an array of uses is the most difficult part of the process. At this stage, it is necessary to incorporate information on prevailing or likely resource management practices of the future users, and the resulting likely output for each array of potentially feasible uses. Assumptions must be made as to the likelihood of remedial measures being instituted to modify land attributes (e.g., terraces to "correct" steep slopes). Such things as custom, economics, skills, innovativeness, likely technology, and institutions come into play in making the rating. Although based in science, these interpretations are certainly partly intuitive (18).

No judgments are made as to which use is the "best" or most appropriate for a given planning unit. No master plan results. Rather, there may be several uses that can be easily sustained on a given unit of the landscape. The decision as to which use will depend on many factors such as resource tenure, needs, skills, available resources, or political plans for development. A change in technology (e.g., a new method of making terraces) may alter the suitability rating as would development of a new market. Thus, resource suitability rating is specific to the general area under planning scrutiny, and may be quite different for similar biophysical units in different watersheds or for ones close to urban centers as opposed to ones in remote areas *(18)*.

Ecologically based planning, if properly done, indicates an array of uses which are suitable and an array of uses which are not sustainable and, hence, not suitable. The specific sustainable use for a unit of land, and the mosaic of uses on several units or an entire watershed will be determined by those close to the land who have more detailed knowledge of their own goals and lifestyles, whether the land is managed by a government office, a cooperative, or a group of individual landholders *(18)*.

Although developing land suitability maps for island resource management may be appropriate and useful, a more immediate application may be ocean and nearshore suitability analyses. The same principles of logical combination of interdependent attributes might also be used for mapping nearshore areas suitable (and unsuitable) for various types of ocean-dependent uses.

Carrying Capacity

Carrying capacity analysis, when extended from its original use in determining the number of range animals capable of surviving on a piece of land to the optimal human population that can be supported at given levels of technology and amenity, has been infrequently applied. Islands would seem to be ideal contexts for application of the carrying capacity concept because the analyst is dealing with relatively closed natural systems.

The basic steps of carrying capacity analyses include:

1. identification of major systems necessary for regional development;
2. identification of geographic areas for application of carrying capacity analyses;
3. definition of limits of "critical systems" (i.e., those systems with capacities that have been exceeded or are close to overload conditions);
4. measurement of current use of critical systems; and
5. determination of the margins for growth.

Carrying capacity studies were performed in Hawaii in the 1970s in response to a legislative resolution requesting that the governor and the Department of Planning and Economic Development establish criteria which could then be used to limit, restrain, or redirect the State's growth (25). In general, these studies were complex and expensive without revealing the "critical thresholds" for resource use. Carrying capacity was not particularly useful in providing a scientifically determined population limit for particular geographic areas although it was somewhat useful in substantiating critical resource use decisions (19,26).

Benefit-Cost Analysis

Benefit-cost analysis originated in connection with the assessment of U.S. Federal flood control projects in the mid-1930s. The technology has since developed to handle more than merely the direct costs and direct benefits of water resources projects. Under the name of extended benefit-cost analysis, the methodology now attempts to encompass the array of secondary and intangible benefits and costs (22). Proponents of extended benefit-cost analysis claim that it can (13):

1. provide an orderly, systematic way to analyze a problem;
2. provide a "neutral" approach;
3. illustrate the benefits and costs of alternative land uses;
4. clarify the question of determining project boundary;
5. attempt to include the benefits and costs of unintended beneficial or adverse effects of the proposed action (externalities);
6. attempt to include intangibles; and
7. raise questions of provision of goods, services, and development options between current and future generations (intergenerational equity) (13).

This method incorporates value judgments regarding unquantifiable variables (e.g., esthetics) and social preferences, thus requiring participation by potentially affected groups as well as experts and decisionmakers. Few guidelines exist for implementing this kind of participatory planning because of the great variation in forms of economies and government, cultural backgrounds, and traditions.

Multi-Objective Analysis

Once information is available on the likely biophysical, economic, and sociocultural aspects of a development project, decisionmakers need some way to judge the relative importance of the findings. Too frequently, decisionmakers avoid confronting trade-offs among conflicting objectives and only consider the most obvious or serious effects. Considerable progress has been made in the last two decades in developing multi-objective techniques that address these trade-offs (4,32).

Multi-objective planning is broader than more traditional single-objective approaches, such as benefit-cost analysis, which require that all the effects of alternative projects be measured in terms of a single unit, usually money. Multi-objective planning attempts to compare effects within categories, but does not force effects into the same measurement units. The techniques also provide formal means for decisionmakers to assign relative values to each category (e.g., number of people employed, reduction in reservoir capacity).

Using multiple objectives in the planning process can improve resource development in at least three ways. First, value judgments are determined by decisionmakers rather than by the analysts. Second, a wider range of alternatives usually is identified, and the relationship between alternatives can be described clearly. Third, the analyst's perceptions of a problem probably will be more realistic if the full range of objectives is considered (4).

During and Post-Project Evaluations

Despite EISs and other preproject assessments, projects sometimes generate unanticipated negative impacts. Ongoing evaluations measure a project's outputs and impacts on intended beneficiaries and assess the project's unintended impacts. Evaluations begin with preproject documentation of potential impact, such as EISs, to assess the predictions of impacts. However, they should be sufficiently broad in scope to examine adverse impacts not revealed in preproject assessments and to trace causal sequences linking project activities with such adverse impacts.

Evaluations performed before project completion can be used to formulate recommendations for changes in objectives, strategies, techniques, institutional arrangements, priorities, and government policies. Their effective use depends on the project's flexibility-i. e., whether it can respond to recommended changes. Such evaluations have a secondary purpose of facilitating communication among persons concerned with the project. Evaluations conducted after a project is complete can:

- identify a need to compensate people adversely affected by environmental impacts,
- suggest followup or complementary projects that build on the original project,
- assist in reformulating broader policies and strategies, and
- provide lessons for planning other projects elsewhere (36).

Post-project assessments frequently are regarded as a luxury that most jurisdictions cannot afford. However, they should be regarded as a necessary supplement to preproject analyses, particularly to environmental impact assessments, to provide information needed to revise and reformulate EIS requirements (25).

IMPLEMENTATION OF RESOURCE PLANNING PROGRAMS

A complex array of resource management programs already exist in the U.S.-affiliated islands. Existing management programs are characterized by four basic approaches: activity management, area management, sectoral management, and integrated management.

Activity management refers to those programs that seek to ensure specific resource use activities are conducted in ways that minimize adverse impacts on resources. 'Dredging, for example, is regulated in the U.S. States, commonwealths, and territories under Section 404 of the Clean Water Act. A private developer or government agency is required to apply for a dredging permit from the U.S. Army Corps of Engineers before dredging can be undertaken. Similarly, the Environmental Protection Agency regulates the discharge of wastewater effluents under Section 402 of the same act. One form of activity management important to island resources is management of activities related to tourism, e.g., siting of hotels and resorts, and tourist transportation facilities.

Activity management is a reactive type of management. Developers propose specific resource uses or activities at a specific site and regulatory agencies must decide whether the proposed uses are appropriate at that site or, if not, whether they can be modified to make them acceptable, In this approach to implementation, the types of resource impacts likely to be associated with the proposed use commonly are well known. The degree and type of analyses associated with activity management vary greatly. However, regulation of activities usually requires some sort of environmental assessment, including formal environmental impact statements.

Area management refers to natural systems management programs that focus on specific geographic areas deemed worthy of special protection. The most common area management programs are parks and protected areas (see "Special Application: Parks and Protected Areas"). Many special area management programs are intended to achieve a single resource management objective, although "multiple-use" and "dominant-use" (in which an area is "zoned" for primary uses) plans are being developed for some protected areas in the mainland United States. Special area management usually requires detailed analysis and planning. Once the purposes of special area management are agreed on (e. g., watershed and habitat protection), the major analytic tasks involve resource surveys, mapping, boundary setting, and the development of standards governing uses of be regulated. Such tasks may require resource specialists.

Sectoral management refers to the management of a single resource such as forests or fisheries. The U.S. Forest Service and the National Marine Fisheries Service are examples of Federal sectoral resource management agencies. At local government levels, sectoral management is exemplified by water management agencies. Sectoral management usually involves substantial analysis of the supply and demand for specific resources. Hence, analytic techniques that provide information on sustainable yields and resource carrying capacity are likely to be most useful.

Integrated resource management refers to multisectoral, multidisciplinary resource management efforts, Integrated resource management plans are anticipatory in the sense of seeking to identify optimal uses of specific resources at specific sites in advance of actual development proposals. They are most frequently expressed in terms of resource maps and detailed use guidelines. Thus, they frequently require a full range of resource analysis techniques.

At the national level, perhaps the best example of an attempt to create an integrated natural systems management program is the Coastal Zone Management Program. The program focuses on a specific geographic area—the coastal zone—and seeks to harmonize multiple management objectives within that zone by providing incentives to States to develop programs that incorporate both resource development and resource protection strategies (see "Special Application: Coastal Resource Management"). Comprehensive community planning efforts at the municipal level have the same multiple objectives and methods.

Participatory Approaches to Planning and Management

The need for public participation is based on several factors. First is the understanding that the local knowledge of an area's natural systems often exceeds or complements scientific knowledge and is needed for decisionmaking. Another is the desire to design actions that respect people's priorities, which requires understanding of those priorities. And finally, the success of any action depends on public support, which is best marshaled by local involvement throughout the course of a project (15), Intensive regulation and enforcement are undesirable because of the adversary relationship they create and also are financially impossible on many islands (16).

Sound resource management requires good understanding of ecological and human use systems. The depth and quality of local knowledge of these can be considerable. Gathering this knowledge can be a cost-effective means for providing the information base needed for resource management projects. In addition, lack of necessary biological and social information is an opportunity to begin to achieve participation objectives by involving local people in the identification, design, and implementation of research activities. Data gathering also is a way to improve the resource users' understanding of the natural systems and processes on which they depend, which can give them greater control over their livelihoods and help them be better able to make informed decisions.

For example, a project supported by the Eastern Caribbean Natural Areas Management Program in St. Lucia had secondary school students carry out, as part of their regular curriculum, a study of charcoal production in the project site (a mangrove area), in which they interviewed the charcoal producers. This simple project provided:

1. information on which to base preliminary decisions about the management of the mangrove and determine additional data needs;
2. an educational lesson for the students in which they learned more about social, natural, and economic systems;
3. a way to inform the resource users about the project, gauge their needs, and solicit their involvement;
4. an experiment in alternative educational techniques for project personnel and the students' teachers; and
5. information which influenced decisions on activities in the mangrove area (15).

Generating public participation in resource management projects can be extremely time-consuming. Because of the common lack of organization of island resource users communities, simply calling public meetings, putting up posters and preparing radio programs is generally insufficient (15; app. F). Considerable effort must be expended in meeting resource users, showing interest in their problems, gaining their trust individually, and bringing them into project activities. Generally resource users are interested in finding viable solutions to local social and resource problems, but are "tired of enthusiastic plans that promise much and do little." Further, projects involving many diverse actors can create dissention and chaos rather than lasting linkages between resource users; the importance of diplomacy to the success of the project cannot be underestimated (15).

In order to tap local sources of information, it usually is necessary to give equally in return. projects that are based on people's priorities and fulfill their needs create trust and cooperation. Commonly those whose needs, as well as dependence on natural resources, are greatest are usually the most "marginalized" from the local society and so the hardest to reach. For these people especially, the need to build confidence and to demonstrate a project's tangible benefits is important. The following conditions have been suggested as guidelines for public participation in resource management:

1. **A long-term presence** to understand a community's structure, build rapport, and foster mutual respect.
2. Local involvement in all aspects of a project from design to implementation, as well as a respect for local input. Seeking ideas and advice and then ignoring them creates animosity rather than cooperation. In order to get active local involvement, project objectives must coincide with or at least include objectives of local users and groups.
3. Local participation in concrete activities from which people can gain tangible benefits.
4. Education and research activities in **which local people are equal partners** with government, project staff, and professionals. When knowledge and information are freely shared, everyone learns and disparate groups gain respect for one another.

The final responsibility for the environment falls on the shoulders of governments and of resource users and the general public. Therefore, to be effective, resource managers must understand local human needs and cooperate with government and community groups to ensure that valuable natural resources are used wisely (16).

Special Application: Parks and Protected Areas

Introduction

Protected areas like national parks and reserves are one approach to the conservation of species and ecosystems. The establishment and maintenance of parks and protected areas may, in fact, be necessary if life-support systems and essential ecological processes are to be maintained, genetic diversity is to be preserved, and use of species and ecosystems is to be sustainable.

Different kinds of protected areas are adapted to different requirements for the use and conservation of resources. In traditional Pacific island cultures, access to scarce resources was restricted through taboo areas (reserves) and temporary closed areas, among other means. Today there is a range of options for designating and managing protected areas. Which option is taken depends on the nature, status, extent, and potential uses of the resource or ecosystem in question.

In a broad sense, setting aside natural areas need not imply setting aside development: it may be a part of the development process, especially when development's objective is to sustain society. Where a species or ecosystem is sensitive to any human interference, however, a strict nature reserve may be appropriate.

Large and small areas where conservation is compatible with recreation and education can be made into national parks and natural monuments, respectively. Where some management is necessary to protect a species or maintain its habitat, managed nature reserves or wildlife sanctuaries can be created. The scenic beauty and traditional resources or lifestyles of inhabited areas can be maintained through designation as protected landscapes, anthropological reserves, or customary protected areas. Temporary resource reserves can be established in areas where decisions on development must await further study.

Marine reserves permit protection and management of important coastal resources. Strict controls over activities in the coastal zone and in adjacent watersheds, together with careful fisheries management and a network of protected areas should permit sustained use of some protected areas such as reefs. The Australian Great Barrier Reef Marine Park Authority has been successfully pioneering the balanced use and protection of coral reef areas. Other areas requiring the careful balancing of different resource requirements such as watershed protection, hunting, and gathering of traditional forest products can be made into multiple-use management areas. The kind and degree of protection can vary to fit almost every local circumstance (11)

Phofo credit Office of Technology Assessment

Multiple use protected areas integrate traditional resource uses, such as traditional subsistence gathering, with conservation.

Protected areas with suitable resources to generate tourism can stimulate the economy and provide employment. In many cases, protected areas result in increased government employment and private sector investment,

Need for Protected Areas and Selection Criteria

On some of the U.S.-affiliated islands only fragments of undisturbed natural areas remain, and many species are endangered. Natural areas serve a variety of economically and ecologically important functions. Forests, for example, provide watershed protection and water catchment, control soil erosion, and contain useful predators that control mosquitoes and other insect pests. While lowland rain forests once covered one-quarter of Puerto Rico, little of this forest remains today. Two-thirds of American Samoa's lowland rain forests have been destroyed, Pohnpei's and Yap's are mostly disturbed, and in Truk no undisturbed areas exist, Only scattered and inaccessible remnants remain on Guam and there are none remaining on the Marshall Islands or the U.S. Virgin Islands. Where such forests remain, some portions could be preserved. Forests might be managed to include protected natural areas, areas used for local wood production and/or agroforestry, and fallow areas where appropriate.

Despite unclear legislation and policies related to protected areas in the former Trust Territory of the Pacific Islands (TTPI), some protected areas have been established in the region (Bikar and Pokak in the Marshall Islands, Ngerukewid in Palau, and Maug and Sariguan in the Commonwealth of the Northern Mariana Islands) (23). Protected areas have been created in Guam and American Samoa through various Federal agencies. A number of National wildlife Refuges have been established in the Pacific, including Howland, Baker, and Jarvis Atolls, Midway Island, and Rose Atoll in American Samoa. protected areas in the Caribbean are well developed. For example, Puerto Rico alone contains 14 State forests and the Caribbean National Forest (Luquillo Biosphere Reserve), and nearly two-thirds of St, John (one of the three major U.S. Virgin Islands) is designated as both a national park and a biosphere reserve.

The concept of the biosphere reserve was introduced in 1971 by the United Nations Education, Scientific and Cultural Organization's (UNESCO) Man and the Biosphere program. Biosphere reserves are part of a worldwide network of protected environments with a primary intent of promoting international scientific cooperation and the study of human interaction with the environment. Ideally, the biosphere reserve integrates conservation with research, environmental monitoring, education, training, traditional landuse, and surrounding socioeconomic needs. Local participation and acceptance is particularly important to the concept of the biosphere reserve (39).

The typical biosphere reserve contains specific areas to accomplish a variety of research, monitoring, and conservation tasks. These areas generally are:

- *core* area—strictly protected from human disturbance, ideally containing much of the biological diversity of the area;
- *experiment] research* area—manipulative research is performed on managed ecosystems;
- *rehabilitation* area—demonstration of recovery of degraded lands;
- *traditional use* area—conservation and study of sustainable resource development practices; and
- *area of* cooperation—managed to foster understanding of the biosphere reserve, such areas may include human settlements, forests, and rangelands.

Ideally, research performed within an individual biosphere reserve can provide important information on natural and managed ecosystems for local use in resource development.

There are three designated biosphere reserves within the U.S.-affiliated Caribbean islands: Luquillo Experimental Forest (Caribbean National Forest) (28,112 acres); Guanica Commonwealth Forest Reserve on Puerto Rico (9,930 acres); and Virgin Islands Biosphere Reserve (15,188 acres) on St. John Island in the U.S. Virgin Islands. The only designated biosphere reserve in the U.S. Pacific islands is located on Hawaii (35,38).

The U.S.-affiliated Pacific islands would likely benefit from creation of biosphere reserves in the region. Sustainable resource development research performed on biosphere reserves could provide useful information for local resource development planning. Potential sites suitable for biosphere reserves would need to be identified and technical assistance probably would be required initially. Although strong local land- and sea-tenure customs in some Pacific islands may pose a major constraint to reserve development, extant parks may prove to be appropriate sites. A regional cooperative effort in developing biosphere reserves may mitigate some of the economic,

Photo credit: Office of Technology Assessment

Ngerukewid Wildlife Refuge (Seventy Islands Park) in Palau, containing considerable open marine areas and unique marine lakes, may offer a potential biosphere reserve site.

staffing, and technical constraints that exist in the islands. The Hawaiian Islands Biosphere Reserve might serve as a model and a source of technical assistance in the development of Micronesia biosphere reserves.

The Virgin Islands National Park was formally designated the Virgin Islands Biosphere Reserve (VIBR) in 1983. The reserve covers nearly two-thirds of the island of St. John and represents many of the areas ecosystems. The U.S. National Park Service (USNPS) manages VIBR and has a declared commitment to institute research, management, and education programs and further to coordinate these programs with other Lesser Antillean institutions. Ongoing VIBR educational outreach activities include environmental programs extended to primary and secondary schools, field trips, and workshops for educators (33).

The Virgin Islands Resource Management Cooperative (VIRMC), established in 1982 through an initiative of USNPS, has a primary goal of bringing local and regional expertise together to solve resource management problems. VIRMC is active in carrying out the objectives of the biosphere reserve on St. John and has performed relevant resource inventories, monitoring, and characterization studies towards that goal. Long-term projects of VIRMC include monitoring of St. John's coral reefs, fisheries resources, and vegetation (33).

Constraints to Designation of Protected Areas

On small islands it is often impossible to maintain an adequate physical separation between damaging human activities and natural systems. Certain activities (i.e., use of pesticides and other toxic chemicals, and certain types of industrial development) may simply have to be strictly regulated, avoided, or prohibited. The establishment and effective management of protected areas certainly can contribute significantly to sustainable use of renewable resources, but may be constrained by such factors as: extreme vulnerability of island ecosystems, lack of trained manpower and money, weak local institutions, increasing demand for limited resources by growing populations, lack of information on the dynamics of island ecosystems, and the deep spiritual and cultural ties of island peoples to ancestral lands (making public acquisition difficult).

Relatively few protected areas exist in many of the U.S.-affiliated islands, suggesting that Federal agencies responsible for establishing protected areas have not been very active or effective in the islands. Part of the problem may be the difficulty of adapting U.S. law concerning different types of protected areas to situations prevailing in smaller islands (11). U.S. provisions for protected areas lack a strong role for local people in planning and management such as would be necessary in many island situations. Primary responsibility for creation of protected areas may have been left to local governments with neither expertise or means to pursue such goals. Flexible programs, such as the National Marine Sanctuary Program, may prove more adaptable to island needs (11).

Local Participation in Protected Area Designation and Management

Modern attempts to protect or preserve island resources, whether through establishment of protected areas or through other means, must consider traditional factors as much as possible. Resource management technologies that reinforce traditional ways or ideas will have a better chance of success than those imposed from outside. For example, resistance exists in the Pacific islands to anything that interferes with traditional cultural practices, such as hunting native birds. On islands where land is limited and has been held in customary ownership for generations, protected areas that exclude people and their activities probably will be difficult to implement. This is even more difficult if populations are approaching or exceed island carrying capacity.

Resource protection will succeed only if it has the support of local populations, particularly resource users, traditional leaders, and the heads of land-owning families. This support can be generated if local people participate from the beginning in their planning and definition. Benefit-sharing arrangements with landowners may also help ensure public support. If enforcement can be left to landowners, protection might be achieved without actual government acquisition.

Protected areas may gain local acceptance more readily if they are carefully chosen and developed to demonstrate the value of parks and preserves to the public and decisionmakers. Interpretive materials can be developed to explain what is protected and why. Parks could become environmental education laboratories for school groups, and increase in number as public understanding and support increase. Traditional knowledge of resource use, management, and conservation remains in many island areas and could form a base for public support of park and protected area development. Parks and protected areas could be demonstrated as a method to preserve island heritage, culture, and traditional practices while protecting island ecosystems. Direction of this type may foster local support for and participation in protected area establishment and management.

The need for protection in some cases can be identified by local people rather than governments. Techniques that allow untrained local people to monitor coral reefs have been developed (12), and similar approaches could be developed for other resources. When local people see for themselves what happens to a resource, they may be motivated to modify their own behaviors if they have options to do so.

Experience in both the Pacific and Caribbean demonstrates that no substitute exists for public support and involvement (15,34).

Conclusion

Without effective protection, further species extinctions and the disappearance of some ecosystems where damage has already been severe are likely on the U.S.-affiliated islands. The broader use of protected areas for resource management will depend on comprehensive island planning and management and on practical experience with different management technologies. There will inevitably be conflicts between measures for the sustainable use of resources and desires for more rapid or immediate development. The resolution of such conflicts will, in part, determine whether the islands maintain a sustainable base for their populations, or slowly decline in productivity and become increasingly dependent on outside sources of support.

Special Application: Coastal Resource Management

Coastal resource management (CRM) is a holistic form of planning and decisionmaking that aims to maximize sustainable multiple uses of coastal resources (28). Little land in the U. S.-affiliated islands can be termed noncoastal, so that coastal resources management is, in effect, island resource management.

Although there is no set procedure for CRM, planning in this context consists of several components:

- a government commitment to CRM;
- a geographical inventory of important resources and resources uses, demands, values and functions; and
- development of policies and guidelines for resource allocation.

Management involves:

- assigning responsibilities for CRM to lead and participating agencies,
- evaluating proposed development and use options for coastal resources against the plan,
- assessing the environmental consequences of a range of options for each development proposal, and
- selecting the alternative that best maximizes economic development and conservation of coastal resources (28).

The planning process should be iterative and open to ensure that communication, understanding, and eventually agreement is established among all individuals with information, claims or interest in the resources.

Under the Coastal Zone Management Act of 1972 (CZMA), the United States provides a maximum of four annual "incentive" grants (Sec. 305) to eligible coastal States and territories to promote timely development of plans. After technical, policy, and legal review and approval by the national office (now the Office of Ocean and Coastal Resource Management of the National Oceanic and Atmospheric Administration [NOAA]), areas with approved plans become eligible for additional funds (Sec. 306) to implement and operate the plan, subject to annual reviews. Grants may also be made to areas to carry out research studies and training required to support CRM programs (Sec. 310).

Regional (State or territorial) governments are charged with the responsibility to develop and administer the CRM plan. This usually involves a geographic inventory of resources; one or more analyses; and preparation of implementation plans, guidelines, or policies applicable to the region designating preferred uses of resources. The CZMA required that an inventory of natural and manmade resources be undertaken and requires that resource use determination be based, in part, on "the capabilities of each resource for supporting various types of uses and the impact of various resource uses upon the natural environment" (37). Other analyses, such as legal-institutional analysis, public attitude-value surveys, and economic and social needs-demands studies also may be performed to fulfill information requirements for developing a coastal resources management plan.

Regional programs may sponsor participation of other State or local government agencies in research and development projects, and plans for areas of particular concern. Also, regional governments review proposed Federal or other development projects to determine consistency with the approved State CRM plan.

Puerto Rico, the U.S. Virgin Islands, and the Pacific flag territories of Guam and American Samoa became eligible for Section 305 funds under CZMA. (The Commonwealth of the Northern Mariana Islands became eligible in 1978.) By 1980, each of these areas had approved CRM plans and became eligible for Section 306 funds. All continue to receive Section 306 funds to help operate and manage their programs. Annual evaluations by NOAA and continued Federal support indicate that all five existing management programs are operating satisfactorily and in compliance with CZMA policies and regulations.

The Trust Territory of the Pacific Islands was not eligible for funds under the original authorization for CZMA. When the act was reauthorized in 1980, the TTPI was made eligible for Section 306 funds but not for Section 305 funds (28). The TTPI could not take advantage of its eligibility for Section 306 funds because they had neither the technical nor financial resources to develop the plans in the first place without Federal assistance. Because of the size of land and ocean areas comprising the TTPI, an acceptable CRM plan would have cost an amount comparable to what was spent on the Section 305 studies for the three Pacific flag territories and Hawaii. Even if initial efforts were limited to district centers, funding would have exceeded the TTPI budget (28). The Compact of Free Association does not include or mention funds specifically directed to development of coastal resource management plans although it allows for provision of technical assistance by U.S. Federal agencies (Article II; Sec. 226).

Under the TTPI, key coastal permitting responsibility was with the U.S. Army Corps of Engineers in accordance with Section 404 of the Clean Water Act. The Corps historically relied on other Federal agencies (e.g., U.S. Fish and Wildlife Service, National Marine Fisheries Service, EPA) and territorial offices for information and advice. Some large construction and piecemeal landfill projects approved in the U.S. Pacific islands have caused significant adverse impacts which could have been avoided with better planning (28).

Freely Associated States' environmental protection boards have had principal environmental responsibility, but their authority appears limited to water quality, sanitation, and the effects of earthmoving. They have been ineffective in compelling applicants to evaluate alternative sites and procedures, and lack authority over aspects of development not strictly dealing with earthmoving. Similarly, planning and marine resource management offices have had little impact on CRM: staffs are small, data are limited, and permitting and project approval authority is essentially nonexistent. Although development plans are prepared and updated periodically for major islands, comprehensive land-use planning and controls (e.g., zoning) are lacking (28).

Provide Financial and Technical Planning Assistance to the FAS

The U.S. Army Corps of Engineers has sponsored a number of coral reef and coastal resource inventories in the tropical pacific since 1978. These projects, with one exception, were supported by Section 22 (Planning Assistance to States) of the Water Resources Development Act. A Corps-managed American Samoan coral reef inventory was sponsored by CZMA funds transferred to the Corps by the American Samoan Government, at the latter's request. The Corps has received further requests to initiate resource inventories in the U.S. Pacific, but continued use of Section 22 funds for original data collection is in doubt.

Coastal resources planning and management might offer a sound means of addressing a number of important socioeconomic and resource conservation issues facing the FAS (table 9-1). These might include identification of important subsistence fishing grounds; planning for small dock, airfield, and water catchment projects in the outer islands; and means to evaluate potential agriculture or aquiculture

Table 9-1.—Selected Socioeconomic and Resource Conservation Issues Suitable for Inclusion in Future CRM Initiatives in the FAS

1. Socioeconomic issues
   A. Outer islands
      - Population density and out-migration
      - Conservation of subsistence lifestyles
      - Small dock and airfield development
      - Water supply and catchment facilities
      - Copra industry development or rejuvenation
      - Other cash crops and handicrafts
      - Commercial fishing
      - Tourism management
      - Aquiculture development
   B. Urban centers
      - Population growth, immigration, and redistribution
      - Land ownership disputes
      - Landuse planning and management
      - Water supply and quality
      - Self-reliance in energy generation
      - College and university facilities or assistance
      - Agricultural and aquiculture development
      - Tourism management
      - Controls over landfilling for houselots and other residential and urban uses
      - Commercial fishing, facilities and permits

II. Conservation of natural resources
   - Conservation of subsistence resources
   - Historic preservation
   - Protection of endangered and threatened species
   - Fishing with explosives and poisons
   - Landfilling of important coastal habitats
   - Water pollution and degradation of important habitats
   - Controls over dredging, filling, and construction in coastal waters

III. Waste management
   - Wastewater and sanitation facilities
   - **Solid waste control and management facilities**
   - Cleanup of hazardous materials and war explosives and debris
   - Contamination from nuclear testing and oil pollution

SOURCE: J. Maragos, "Coastal Resource Development and Management in the U.S. Pacific Islands," OTA commissioned paper, 1986

ventures. In urban centers, CRM planning initiatives could help to identify priorities and sites for future public works projects, especially water supply, wastewater management, energy, and solid waste management facilities. Landuse planning supported by a CRM program could mitigate ecological and public health impacts of urban development. Table 9-2 presents technologies for fulfilling the planning and CRM needs of each area.

In light of the Compact of Free Association, technical assistance for development of coastal resource management plans could be requested by the governments of the Federated States of Micronesia, the Republic of Palau, and the Republic of the Marshall Islands. Each program could be subdivided to address separately the needs of the urban centers and outer islands. Each nation would require a centralized coordinating and planning agency to develop, manage, and enforce CRM programs. Existing planning offices, marine resources offices, and environmental protection boards need substantial upgrading, reorganization, training, and staffing to assume that role, An alternative would be to establish new coastal offices, drawing on the resources of the other offices for support and coordinating with them to develop plans.

Table 9-2.—Potential Implementation of Planning and Management Technologies To Address Selected CRM Issues (identified in table 9-1)

- Public meetings, hearings, and workshops to evaluate needs for CRM in the FAS
- Legislative endorsement and commitment to CRM by legislatures of new countries
- Administrative reorganization to establish a CRM lead office or agency in each new country
- Coastal resource inventories of valuable resources and their uses
  —Urban centers—first priority
  —Outer islands—second priority
- Draft CRM plan development
- Public review and final CRM plan approval
- Implementation of approved plans to meet following goals:
  —promote economic development
  —promote conservation of important resources
  —waste management
  —research and management of areas of particular concern
  —others (e.g., development of institution or facilities for higher education and research)
- Education and training programs on CRM within each new country
- Publication and telecommunication of CRM activities in native languages

SOURCE: J. Maragos, "Coastal Resource Development and Management in the U.S. Pacific Islands," OTA commissioned paper, 1986.

Outside expertise probably will be required, at least initially, for resource inventories, research and development projects, manpower training, planning, and evaluation of specific development proposals. Considerable assistance could come from outside universities with tropical coastal experience, such as the University of Guam, the University of Hawaii and University of the South Pacific (Suva, Fiji).

SUMMARY

Resource planning is a means of strengthening the ecological foundation for future resource management and of putting this information into the decisionmaking process along with economic, social, cultural, and administrative information (18). Planning for sustainable use of resources is not only a scientific technology but has to do with the basic topics of economic development strategy, land distribution and tenure, interagency rivalry in control of resources, peoples' wants and needs, and so forth. It is a "people-problem," extremely political in nature, and must be dealt with from the outset in a manner in which education and training are important, although slow-acting ingredients (18).

Planning and implementation require information and analysis in order to make optimal resource use decisions. Specific analytic techniques have been developed to assist those who make resource use decisions.

In the short run, EISs are likely to remain the primary technique used by island resource managers for natural systems assessment because activity management is currently the dominant approach to resource management and of several "off-the-shelf" approaches to impact assessment make it relatively cheap and easy to implement. A review of current procedures for conducting EISs could help planners identify and develop more "island relevant" EIS procedures. Post-project evaluation would be one way to reveal the strengths and weaknesses of current EIS procedures.

Resource capability assessments have some promise but, because they usually require high levels of expertise and because their value is questionable in the context of small islands, they are less likely to be adopted by island planning offices in the near term. However, the possibility of constructing capability analyses for nearshore waters has considerable potential and should be explored further.

Carrying capacity analysis also has limited immediate potential because of high costs and skill requirements. However on some islands carrying capacity analysis of certain systems, such as water supply, may be useful.

Guidelines for Information Management

The selection of specific techniques for gathering and analyzing information for resource management could be based on several guidelines.

1. *Identification of specific information needs and analytic techniques for resource assessment should be based on analyses of current and projected planning and regulatory information needs.*

A detailed survey should be performed for each island covering what types of resource use decisions are currently being made, the type and quality of information and analysis on which these decisions are based, availability of advisory services, and access to databases in other agencies. Detailed information also is needed about the present scope of data collected, methods of data acquisition, frequency, geographic scale, format of presentation, accessibility, and costs of collection (2).

Current resource management programs sometimes reflect Federal requirements or the availability of funds for management rather than locally perceived management needs. Hence, the survey of planners and resource managers also should address the issues of current resource use problems that are undermanaged and anticipated resource use problems for which information will have to be gathered for management efforts.

2. *Opportunities for sharing existing Federal and local data should be considered prior to gathering more data.*

Agency personnel frequently are unfamiliar with data collected by personnel in other agencies or, if they are aware of data acquisition efforts, commonly there are questions about the quality of the data and difficulties in receiving data on a timely basis, An island-by-island assessment of data collection could be a first step toward identifying opportunities for sharing data and collaborating on the acquisition of additional data. A preliminary study also should identify current incentives and constraints for sharing data. A long-term goal could be interagency protocols for acquisition and sharing of data useful to several agencies in their resource management efforts.

3. *Priorities should be established for the acquisition of new data or the development of an interagency information clearinghouse.*

Few islands can afford a major data acquisition effort. An initial priority for data collection would be to ensure that essential data—those which, if lacking, prevent program implementation—are being collected. After ensuring this, an incremental approach to collecting desirable data can be established. Rural island residents commonly are the best source of information based on intimate, long-term familiarity with an area's resources and trends. Information from these sources can be compiled through interviews, surveys, workshops, and other techniques.

By gathering data on a case-by-case or area-by-area basis, managers can determine what the costs of data acquisition are, what ecological and social parameters are most useful, and what the requirements are for a larger scale data collection effort, Initial data collection efforts could be concentrated in areas where development pressures are the greatest in order to identify baseline conditions from which trends in resource conditions can be determined, and on undisturbed or nearly undisturbed areas which may have species or ecosystems of particular value.

4. *Data acquisition, storage, and retrieval should be based on appropriate technologies.*

The availability and continuing improvement in remote sensing and electronic data processing pose a dilemma for island natural systems managers. These technologies commonly require high levels of skill, and are being modified so rapidly that determining which technologies are most appropriate for island management should be addressed on a case-by-case basis (25). However, satellite information and computerized geographic information systems soon may be cost-effective methods of data collection, analysis, and display (31). The Natural Systems Assessment for Development ecological surveys and monitoring program can be effective in assisting countries to make optimum use of available modern technology (31). Local residents can be used to provide observations which can be used as ground truth data for remotely sensed data, and can provide detailed knowledge about specific areas (27). Again, an incremental strategy of focusing on training and demonstration projects probably is warranted.

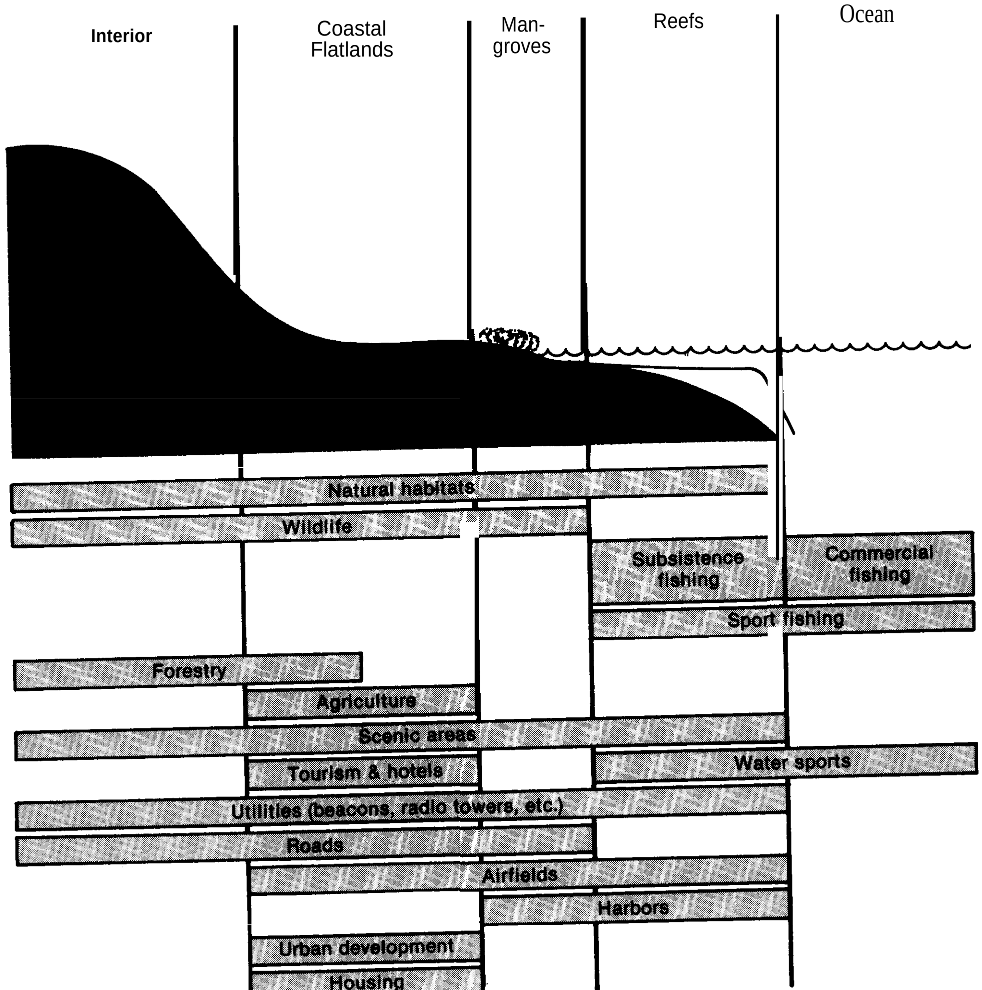
5. *Emphasis should be placed on dissemination as well as acquisition of data.*

Distribution of data to users may be encouraged through preparation of data lists and inventories, reproducing reports, air photos, topographic maps, sponsoring workshops and seminars, and adopting an "open files" policy for other agencies (25). If participatory approaches to planning are adopted, dissemination of information can be more direct.

6. *Training of local data collectors/mappers should be part of basic resource information acquisition.*

Short-course training in resource information collection and mapping techniques is needed to ensure usefulness of resource planning efforts on many U.S.-affiliated islands. Such courses are provided by many U.S. universities. An example of this kind of program is the International Land Use Planning Training Program; its first phase was held by Cornell University in 1983. Perhaps more appropriate for development of land assessment and mapping skills would be on-island training sessions—a traveling workshop. A collaboration of Department of the Interior-U. S. Man and the Biosphere program in training for land assessment, classification, mapping, and suitability rating could be initiated using the East-West Center assessment manual (3).

Figure 9-1.—Typical Siting of Land Uses on U.S.-Affiliated High Islands



SOURCE: N. H. Cheatham, "Land Development: Its Environmental Impact in Micronesia," *Micronesian Reporter*, third quarter, 1975, pp 7-11

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Chapter 10
Issues and Options for the U.S. Congress

CONTENTS

Chapter 10

Issues and Options for the U.S. Congress

INTRODUCTION

In addition to being part of the United States, the U.S.-affiliated islands of the Pacific and Caribbean are of importance to the United States for strategic, economic, and diplomatic reasons, Because of their geographic (small size and isolation) and economic characteristics, economic sectors dependent on the islands' natural resources—agriculture, aquiculture, fisheries, and tourism—have the greatest potential to form the basis of their economies. Growing economies are required to support the islands' growing populations and aspirations, and to assist those that are becoming independent to enter the international economy.

The U.S. Congress, as the primary policy-making body for the U.S.-affiliated islands, has considerable latitude to assist with the sustainable development and management of the islands' renewable resources. Numerous Federal agencies already house expertise and programs that are extended to the islands and others that could be tuned to their needs. However, potential exists for Congress to modify the structure of certain committees/subcommittees in such a way that opportunities for Federal assistance are readily apparent and easily available, In addition, the Department of the Interior's Office of Territorial and International Affairs, which has been designated as the major point of contact between the insular governments and the U.S. Congress, could strengthen its role in agency coordination and technical assistance. These underlie the first options for the U.S. Congress.

Further options are categorized by major area of public sector involvement in management and development of renewable resources:

- data collection and information management,
- planning,
- education,
- research,
- extension and training, and
- regulations and incentives,

Little can occur without the necessary information: both problems and opportunities may be overlooked. Not only is the appropriate data necessary, management systems that allow easy access and manipulation for various needs are necessary to put that information to use. Planning of resource and economic development takes that information one step further—social, cultural, and political considerations must be integrated.

Education provides the personnel interested and, perhaps, skilled in the disciplines and technologies needed for sustainable resource management on islands. Research is the source of those technologies and extension and training provide the means to deliver them to the eventual practitioners. Finally, regulatory measures and incentives are needed (or disincentives need to be removed) in order to encourage those practitioners to adopt new technologies and activities,

Within the above categories, opportunities exist for improved and expanded Federal agency support for agriculture, forestry, aquiculture, and nearshore fisheries development appropriate to the tropical insular environment. While the structures of both Federal and local government agencies tend to follow the separate resource-related divisions (agriculture, etc.), tropical insular resources need to be viewed as a single system in order to make resource development and management productive and sustainable. Thus, programs designed to develop and manage island resources would benefit from improved coordination of those agencies dealing with single resource systems.

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CONGRESSIONAL OVERSIGHT

This study shows the importance of renewable resource development to increasing self-reliance on U.S.-affiliated islands and the important linkages that exist among renewable resource use, environmental protection, island cultures, population growth, political systems, and economic development. These relationships or linkages underlie integrated renewable resource management on U.S.-affiliated insular areas. In addition, it is clear that the picture that develops from these relationships is not typical of the 50 U.S. States, especially because all of the islands lie within tropical climates.

The U.S. Department of Agriculture (USDA), National Oceanic and Atmospheric Administration (NOAA), and Department of the Interior (USDOI) probably comprise the agencies having the greatest number of Federal programs bearing on integrated renewable resource management and planning within the islands, although some resource-related activities are undertaken within other Federal agencies such as the Departments of State and Energy. However, activities related to the U.S.-affiliated islands are spread among a large number of programs within these institutions, hindering congressional oversight of Federal agency activities specifically designed for or conducted within the islands.

Today, no single subcommittee of the House Committee on Interior and Insular Affairs or of the Senate Committee on Energy and Natural Resources is structured to deal with all of the related aspects of integrated renewable resource management as they relate to the U. S.-affiliated islands. Further, the emerging Freely Associated States have no direct representation in Congress. For Congress to take advantage of the OTA study and to oversee the network of diverse activities and efforts underway in executive branch agencies dealing with island renewable resource issues, mechanisms to facilitate congressional oversight probably are needed.

Option: New Congressional Subcommittee(s)

Congress could establish new subcommittees in the House and Senate committees listed above that would focus on improving self-sufficiency in the U.S.-affiliated islands through an integrated renewable resource approach.[1]

Positive responses have been common from U.S.-affiliated island residents to the leadership Congress has shown in requesting this study. Having new subcommittees designed to deal specifically with these island resource issues probably would expedite congressional actions for taking advantage of opportunities to work toward increasing island self-sufficiency. Island officials would have focal points within the two congressional committees where integrated approaches to island resource development could be handled easily and effectively.

In addition, convictions are growing that the U.S.-affiliated islands are likely to become increasingly important in matters of national security in the next decade. Having subcommittees accustomed to dealing with island resources, and their associated cultural, economic, and political aspects, and capable of dealing with issues of overall U.S. security might strengthen existing links between the U.S. Government and the U.S.-affiliated islands.

Reorganizing committee structures would take time from other committee activities and the new subcommittees may require additional staff. Thus, this reorganization might be viewed unfavorably.

[1]Moving in this direction the House Interior and Insular Affairs Committee recently established the Subcommittee on Insular and international Affairs, chaired by the USVI delegate Ron deLugo.

Option: Joint Territorial Policy Study Group

Congress could establish a Joint Territorial Policy Study group to produce analyses of island matters to require congressional action related to the U.S. insular areas and could provide initial territorial impact analyses of current legislation affecting the islands.

The Joint Territorial Policy Study Group would be composed of congressional committee staff who have demonstrated a continuing interest and knowledge of the U, S.-affiliated Pacific and Caribbean islands. This group could request assistance from two very active bipartisan congressional caucuses serving the House and Senate: the Congressional Clearinghouse on the Future and the Environmental and Energy Study Conference, both of which address long-term issues and the impacts of possible new legislation.

Option: Review Effectiveness **of** Federal **Is**land Programs

Congress could direct USDA, NOAA, and USDOI **each to** evaluate **the** effectiveness **of its own agency's** programs related **to** integrated renewable resource management **and planning designed for the islands and implemented therein. Congress could have the three executive agencies appear at oversight hearings related to island resource management and planning issues.**

Alternate Option: Federal Island Program Reviews by the General Accounting Office (GAO)

Congress could direct GAO to conduct the above reviews that could be used later in congressional oversight hearings related to island issues.

Many individual programs of these agencies receive favorable comment from island resource managers, planners, and government representatives; some do not. Agency reviews could be useful to Congress and the agencies themselves in determining which approaches have worked best in the islands and which ones might be modified to improve their chances of success.

The agencies know the details of their programs and could probably conduct the review with minimal delay. Congress on the other hand may feel that outside eyes may be the most revealing and, therefore, choose GAO to conduct the evaluations.

COORDINATION OF FEDERAL AGENCY ACTIVITIES

The Department of the Interior's Office of Territorial and International Affairs (OTIA), under the Assistant Secretary, is responsible for promoting the economic, social, and political development of the U.S.-affiliated islands. In addition, OTIA is responsible for analysis, development, coordination, and review of the department's policy and programs pertaining to international activities and opportunities for support of U.S. foreign policy through the use of the department's natural resource and environmental expertise.

The extensive mandate of OTIA may hinder regular coordination of Federal agency activities in the U.S.-affiliated islands. No other formal mechanism exists to coordinate the large number of Federal programs and policies extended to the islands. Oversight hearings might provide an initial means of evaluating OTIA capabilities to coordinate Federal activities and to review new island activities that any of the executive agencies plan to undertake. These hearings may indicate where alternate or supporting coordinating activities are needed.

Option: Designate an Interagency Coordinating Group on Resource and Economic Development in U.S.-Affiliated Islands

Congress could authorize the creation of an interagency coordinating group on U. S.-affiliated islands, designating the Department of the Interior as the lead agency, that would provide policy guidance to Federal departments and agencies on extension and

modification of programs to assist in island resource management and development.

Members of the interagency coordinating group should represent USDOI/OTIA; Department of State; and resource-related offices of NOAA (e.g., Offices of Sea Grant and Coastal Resource Management, National Marine Fisheries Service); USDA (e. g., Soil Conservation Service, Agricultural Stabilization and Conservation Service, Forest Service); USDOI (e.g., U.S. Geological Survey, Bureau of Reclamation, Park Service, Fish and Wildlife Service); Department of Energy; Environmental Protection Agency; Small Business Administration; and Economic Development Administration.[2] This group should be closely associated with the Interagency Group on Freely Associated States' Affairs authorized in the Compact of Free Association (Public Law 99-239).

The first responsibilities of the interagency coordinating groups might be to: 1) identify programs for which the islands are currently eligible and their rates of participation, and 2) to solicit information regarding the suitability of Federal programs to the islands. Second, the interagency y coordinating group could identify means for integrating programs within and among the agencies into packages that might allow for simultaneous or sequential development of: 1) insular resource management and planning institutional capabilities; and 2) private sector activities in management, production, processing, and marketing of insular products, Third, the coordinating group could suggest funding priorities for the agencies' technical assistance programs to the Territories, Commonwealths, and Freely Associated States (see Public Law 99-239, Sec. 105(1)). Fourth, representatives from these agencies to the interagency coordinating group could serve as insular government contact points to the Federal agencies.

Such an interagency coordinating group probably would need one or more full-time staff from each office, and a budget allowing travel to each of the island areas. These additions seem problematic during the current period of budget reductions.

Alternate Option: Designate U.S. Man and the Biosphere program (U.S. MAB) as Lead Coordinating Agency for Federal Resource-Related Activities on Islands

Congress could identify the U.S. MAB in the Department of State as a lead coordinating agency for Federal resource-related activities in the U.S.-affiliated islands, appropriate funds specifically for the U.S. MAB program and encourage increased coordination between U.S. MAB Islands Directorate, the Department of the Interior's Office of Territorial and International Affairs, and other appropriate Federal agencies.

Federal agencies already supporting U.S. MAB include the Department of State, U.S. Forest Service, National Park Service, National Ocean and Atmospheric Administration, and the National Air and Space Administration. U.S. MAB also collaborates on a bilateral and multilateral basis with other MAB national programs as well as the United Nations Educational, Scientific, and Cultural Organization's International MAB program, the U.N. Environment Program me, and the U. N. Conference on Trade and Development. However, funding for U.S. MAB has been low, and the U.S. MAB Pacific Islands Directorate has been inactive.

In 1985, the U.S. National Committee for MAB identified small island ecosystems as a priority for U.S. MAB support, emphasizing "ecology and rational use of island ecosysterns." U.S. MAB has funded such research projects as oil spill contingency planning for small Caribbean islands, a workshop on Management of Marine protected Areas in the Caribbean and one on Planning for World Small Islands Environmental Management and Development. U.S. MAB also has organized a global meeting known as "Interoceanic Workshop on Sustainable Development and Environmental Management of Small Islands" (3). Issues such as environmental and socioeconomic changes associated with tourism and industrial development also are being examined. A major U.S. MAB Caribbean Island Ecosystems ef-

[2]This list is not intended to be exhaustive, but only representative of the types of agencies, bureaus, and offices that might be involved.

fort has been to encourage the designation of a Decade for Small Islands (1990-99) to organize a lo-year concentrated program of studies related to development of small islands (l).

Increased support for the U.S. MAB islands program could allow them to expand their research, coordination, and training functions in the U.S.-affiliated islands, especially in the Pacific, and might improve coordination of federally supported resource-related island activities. Increased coordination between U.S. MAB and USDOI/OTIA might assist U.S. MAB-supported research and training projects designed for Caribbean and Pacific Basin countries to be applicable to U.S.-affiliated islands.

To undertake such a leadership role, the U.S. MAB program would need to be upgraded and strengthened substantially. In addition, identifying the U.S. MAB as the primary coordinating group could be seen to be in conflict with the mandate for OTIA.

EXTENSION OF TECHNICAL ASSISTANCE TO THE ISLANDS

OTIA's Technical Assistance program has responsibility for extension of technical assistance grants to insular governments and individuals to support the development of local institutional capability and private sector enterprises. This program has been referred to as "the most effective utilization of United States dollars in the Pacific Basin" (2). The staff is competent in its island-related work, but is small and its budget is declining.

Option: Strengthen OTIA Technical Assistance

> Congress could direct the OTIA Technical Assistance program to prepare reports on development of local institutional capability to foster private sector development in renewable resource enterprises (production, processing, and marketing) in each island area, and to establish priorities for its technical assistance program that reflect insular needs. In addition, Congress could appropriate additional funds as needed to allow expanded technical assistance to insular resource management institutions and entrepreneurs.

Preparation of the "Capability Reports" should be carried out in close coordination with the insular governments and should be readily available to insular governments and entrepreneurs. Regular updating of these reports could allow continued modification of technical assistance programs to match insular needs.

These reports could be used to redirect Federal agency programs as well as to provide guidelines for technical assistance. Further, technical assistance programs developed from these reports could be used to link production, processing, and marketing enterprises on the islands.

Data needed for preparation of the Capability Reports may be difficult to collect or unavailable, requiring that this effort be postponed until improved statistical collection programs are implemented. Further, preparation of such reports does not guarantee that future grant proposals submitted to OTIA will reflect identified insular needs or that coordinated resource development follows.

FEDERAL/INSULAR INFORMATION SHARING

U.S.-affiliated islands have difficulty in identifying what Federal data/information and programs exist that are relevant to island needs in integrated renewable resource planning and management. Much information does exist but it is scattered through the various Federal agencies and sometimes is not associated directly with island needs. An examination of agency data/information and programs, an assessment of their relevance to island needs, and making this information known to island governments would be an important step in improving island natural resource planning, management, and development.

Option: Interagency Task Force on Federal Information

Congress could direct the Department of the Interior to lead an interagency task force charged with assessing the data/information and programs that exist in each relevant Federal agency related to integrated renewable resource management and planning that is likely to be of benefit to island governments.

The task force would make a summary of this information available in published form to Congress in one year to serve as the substance for a congressional hearing on the topic. Island representation would be included in the task force activities. Each agency could establish an "island desk" that could act as a contact point for island liaisons during and after the task force activities.

Identification of such data/information and programs in existence could eliminate the possibility of unwanted duplication and could make Federal information (such as the Pacific Island collection housed in the Smithsonian Institution—currently an unorganized, largely inaccessible library) more readily available. In addition, it could help expedite island activities that rely on such data/information and assure the island governments that Federal programs that could be applied appropriately to the islands are not overlooked. Nevertheless, a task force of this sort can consume a significant amount of time at each participating Federal agency as well as initiate additional associated costs.

Option: Establish Regional Information Clearinghouse(s)

Congress could establish or support one or more existing regional island centers to act as a clearinghouse for relevant island information produced at national and international levels.

Such information could include: Federal Government announcements on new programs pertaining to the islands; island government announcements; similar international program information; market information on agriculture, mariculture and aquiculture; and information on island experts, their specialties, backgrounds and availability. Such a clearinghouse(s) would gather such information, assess, and disseminate it to island governments. In addition, the clearinghouse(s) could maintain directories of Federal, regional, and international programs related to island resource development and provide assistance with grant proposal preparation. Congress might choose to strengthen and broaden the scope of one or more of the following centers to handle this role: Pacific Basin Development Council, East-West Center, Micronesia Area Research Center's Information System, Island Resources Foundation or Eastern Caribbean Center.

Communications among U.S.-affiliated islands and with the continental United States are slow but particularly so in the Pacific. A clearinghouse(s) for island information is very likely to improve this situation and may in fact improve communications between the Pacific and the Caribbean islands. However, establishing a new center(s) or strengthening others will require additional funding at a time when such funding is scarce. Further, startup costs for establishing a new center(s) will be higher than strengthening an existing institution(s).

INSULAR DATA COLLECTION, INFORMATION MANAGEMENT, AND PLANNING

Insular governments, like governments anywhere, need a natural resource database on which to base their land-use plans and decisions for future actions. Clearly, adequate data for these purposes seems wanting on most U. S.-affiliated islands. In addition, no consistent source of economic and social data exists from which informed judgments on future island development and conservation can be made. It is important to have not only adequate and appropriate data but also the technology for effective data management and analysis and the skilled staff to carry out these tasks. The day-to-day needs of local governments necessitates that the data are easily accessible and that they can be manipulated in useful combinations quickly and accurately.

Many of these data will pertain to the island locality whereas other data may have a Federal, regional, or international flavor. All of these data types are useful to island planning and terrestrial and marine natural resource management, monitoring of environmental changes, and development of strategies for sustainable development. With the modern, reasonably inexpensive, computer systems available today, data storage, analysis, synthesis, and dissemination no longer seem insurmountable problems. Still, many of these problems exist in the U.S.-affiliated island governments.

Option: Analyze the Adequacy of Island Information Management Systems

> Congress could direct the Department of the Interior to take the lead role in an interagency task force including island representation to determine the adequacies and inadequacies in natural resource, economic, and social databases for the various U. S.-affiliated islands as well as the means to handle the data.

The task force should prepare a report for Congress on the status of these databases as well as an assessment of the island needs to manage this information resource effectively. The assessment should include an analysis of the adequacy of local government computer facilities and the personnel to maintain, manage, analyze, and interpret such data. Consideration should be given to ongoing training for government users of these data, training quality, and needs. This report should be produced in an expeditious manner and should serve as the basis for congressional hearings wherein Congress can determine appropriate further actions.

Such an analysis could provide an islandwide basis for a coordinated, effective action on improving island data needs and data management, thus, filling a long overdue gap. The process would raise the awareness of the islands' needs, problems, and opportunities and may provide improved linkages between the Federal agencies and island governments. Conversely, this may be viewed as just "another study" and further wasted time. Such an assessment may take one year or so to complete, whereas some people may feel that direct action to collect the needed data on the islands should begin now,

Option: Training Programs for Data Managers and Users

> Congress could direct the Department of the Interior in cooperation with the Department of Agriculture to arrange for periodic training programs on manual and computerized data management techniques and analysis for the islands.

The training programs could be held at the land-grant institutions on U.S.-affiliated islands in the Caribbean and Pacific and on Hawaii for appropriate data managers and users from the island governments. USDOI and/or USDA could provide technical assistance grants to eligible island governments for the integration of currently held databases.

Where no local data collection expertise is available, U.S. agencies also could allocate funds for a local person to work side-by-side with Federal data collectors to provide some on-the-job training and improved understanding of eventual interpretations of data,

Such courses could expand the usefulness of island databases as well as the number of data users in government service, Carrying out such training at island land-grant institutions in turn may help strengthen the institutions' training and education programs. Such training could begin even as extant computerized data management systems were being evaluated for improvement, although for training to be effective, the computer hardware and software systems used in training and on-island should match. In order for a government employee, however, to take advantage of such training he/she will be required to be away from his/her job and probably off-island for certain periods. During the initial training periods, data management in the island government, therefore, may be slowed down.

An on-the-job association would increase the understanding of technical data collection techniques, increasing the potential for future updating of data. In addition, eventual usefulness of data in decisionmaking may be improved. Conversely, this may slow data collection efforts and increase the costs of data provision to the islands.

Agriculture and Forestry

To accelerate agriculture development, there is a need to understand the socioeconomic situation of small farmers and to diversify islands' agricultural bases to avert the "boom-and-bust syndrome."

Option: Reactivate USDA Minor Economic Crops Computer Database

Congress could direct USDA to reactivate, update, and maintain their computer file on minor economic crops.

A summary of the contents of the database could be made available to island governments so they can use the information in agricultural activities. Further, island governments should contribute suggestions on how to improve the database for their use by identifying crops not yet included, as well as important measurable properties and characteristics of plants and environmental aspects needed to assure crop success.

USDA previously maintained a computer database on minor economic crops, many of which would grow in tropical climates, but no longer keeps this computer database active. Data included in it cover important and diverse topics: the climate and soil conditions necessary for growing various crops, yield information, the climatic range over which a plant would grow, nutrition data, medicinal use, pesticidal properties, food crops that grow well when intercropped with others, and agroforestry. This database contains important agricultural information relevant to ecosystems of the U.S.-affiliated tropical islands. No other similar database is known to exist.

The information included in USDA's minor economic crops database has taken many years to accumulate and check and, therefore, is a valuable resource. The database also provides a mechanism of linking island agricultural data from the Caribbean with that of the Pacific, thus, providing both with additional important information. Should USDA reactivate this database, it would incur additional operational costs. Because maintaining this database historically was of small cost to USDA, it seems unlikely that the cost of reactivating it would be prohibitive.

Option: Have USDA Develop Small-Scale Island Farmer Profiles

Congress could direct USDA Extension to gather the necessary data to prepare "small-scale island farmer profiles" for U.S.-affiliated islands in the Caribbean and the Pacific to be used in the process of identifying agricultural technologies that will be economically beneficial to the farmer and will sustain the productivity of the natural resource base.

In order to determine which food/fiber/fish technologies have the greatest possibility for ready and profitable adaptation, a need exists for additional specific information on:

- how smallholder subsistence and semi-commercial farmers actually distribute their labor and capital resources in their farming effort,
- which activities are part-time v. full-time, and
- how much output is consumed, etc.

Farm economic information is needed on, for example: the farmer's sources of income and labor effort; patterns of planting, cultivating, fertilization, harvesting, and storage; nonfarm resources used; and home consumption v. market sales, in order to assess the farmer's adaptability to change, and the system's openness to modification, Access to such information may help farmers and others avoid mistakes made in past technology selection. Technologies were promoted in certain instances which were not accepted by the farmer because the technology did not readily and profitably fit the existing agricultural system,

Introduction of inappropriate agricultural technologies can be economically detrimental to the farmer and ecologically detrimental to the farmer's land. Minimizing such failures obviously is cost-effective over the long term, Yet, to minimize these costs requires the expenditure of funds for developing the needed database to develop the small-scale island farmer profiles. While such profiles are being developed, agricultural technologists on the island may have a tendency to slow down the rate of new technological implementation, Then too, there is the question of the future role of the Extension Service at a time when it is under possible severe budget cuts. It seems likely that the Extension Service's new role may be largely in assisting the small and part-time farm operator. This may be an opportune time to have them expand their work with the U.S.-affiliated island governments.

Aquaculture and Nearshore Fisheries

In the U.S. Caribbean, local departments of marine resources collect aquatic and fisheries data, and share it regionally through the Gulf and Caribbean Fisheries Association and the Caribbean Coastal Marine Productivity Program. The U.S.-affiliated Pacific islands, however, have no such data collection and aggregation structure.

In 1974, a private nonprofit corporation—the Pacific Fisheries Development Foundation (PFDF)–was established to carry out the directives of the Central, western and South Pacific Fisheries Development Act (authorized in 1972), The Western Pacific Fishery Management Council was created by the Magnuson Fishery Conservation and Management Act of 1976, to manage the fisheries within the 200-mile zone around U.S.-affiliated Pacific islands. In 1983, the National Marine Fisheries Service acknowledged that the island fisheries differ significantly from mainland fisheries and established a special set of priorities for Saltonstall-Kennedy funding of projects in the Pacific Basin.

The PFDF, the Pacific Basin Development Council, and the Western Pacific Fishery Management Council subsequently established a set of priorities for fisheries development in the Pacific, based around:

- stabilizing island fisheries,
- emphasizing and improving quality in island seafood production,
- expanding domestic harvesting of underutilized species and stocks, and
- developing fisheries resources in harmony with non-American Pacific island neighbors.

The emphasis is on coordination of nearshore and offshore fisheries development, considering both conservation and development objectives, and development of an ordered, incremental program of assistance.

Option: Fisheries Statistics Collection

Congress could provide funding to the Pacific Fisheries Development Foundation for Freely Associated States island fisheries statistics collection programs.

Collection of statistics should focus on determination of stock levels and estimates of maximum sustainable yield for economically important fisheries, as well as identification of current catch levels. Funding could be appropriated under either the Saltonstall-Kennedy grant program or appropriations to the Central, Western, and South Pacific Fisheries Development Act, This information should be integrated with the WESTPACFIN database on fisheries maintained for Hawaii, American Samoa, Guam, and the Commonwealth of the Northern Marianas by the Southwest Fisheries Center.

Collection of baseline data often is costly. Because most insular nearshore fisheries are artisanal, and markets are informal, collection of catch statistics may be difficult, Data collection might be facilitated by development of small fish-markets to centralize sales and statistics collection. Similarly, identification of particularly favored fisheries areas near islands (such as near fishery aggregation devices) could aid collection of subsistence fishery statistics. Development of such a program also will require development of a local institutional capability to collect, organize, and manipulate data requiring skilled individuals who may not be available on some islands.

Option: Develop Sea Resource Atlases

Congress could direct the U.S. Army Corps of Engineers and the Sea Grant Marine Advisory Service to develop sea resource atlases for each of the U.S.-affiliated islands.

Sea resource atlases (similar to land capability assessments) could identify marine areas with particular fisheries or tourism value, areas of current or probable future resource degradation, and areas suitable for certain forms of marine development, such as marinas, marine parks, or mariculture enterprises.

Funding could be derived from Section 22 of the Water Resources Development Act, although changes in legislative language maybe required to allow this. Atlas preparation should be closely coordinated with or performed jointly with insular Coastal Zone Management programs. For most effective use of atlases in marine resource development, the Sea Grant Marine Advisory Service could conduct training programs for marine resource managers following completion of the effort on each island or island area.

Development of atlases may represent a reorganization of information already available to some U.S.-affiliated islands, requiring little effort or funding and potentially little additional benefit. In other cases, particularly for remote outer-islands, little baseline information or maps may be available, requiring substantial and potentially costly data collection programs.

Option: Artisanal Fisheries Profiles

Congress could direct the Sea Grant Marine Advisory Service to develop Artisanal Fisheries Profiles.

These profiles, similar to the smallholder farmer profiles described above, would characterize artisanal (subsistence and semi-commercial) fisheries in the islands. They could be used, in conjunction with sea resource atlases, fisheries statistics, and estimates of maximum sustainable yield, to determine technologies potentially suitable for introduction to the islands.

Unless this effort is coordinated with extension of the Sea Grant Advisory Service to U. S.-affiliated Pacific islands beyond the current representative on Guam, this will require increased funding to the University of Hawaii Sea Grant Program to cover travel and other costs.

Option: Marine Resource and Aquiculture Database

Congress could direct USDA's National Agriculture Library to provide assistance to the Micronesia Area Tropical Agriculture Data Center (MATADC) at the University of Guam to include appropriate tropical aquiculture information developed locally and culled from USDA's Aquaculture Information System. Similar information on warmwater aquiculture could be provided to the University of Puerto Rico.

MATADC maintains a computerized database of published and unpublished documents produced in Micronesia concerning tropical agriculture and related subjects, and provides bibliographic information retrieval and document dissemination services. In addition, MATADC maintains a database of scientists and current research to assist with location of experts in various resource-related fields. Expansion of these databases to include information on warmwater aquiculture, tropical marine resources and resource uses, and scientists with expertise relevant to the islands could provide valuable, additional benefits from this program in supporting local research and resource development.

Because bibliographic information on aquaculture already is collected and organized in USDA's Aquiculture Information System, this effort should be inexpensive and readily accomplished. To maintain its usefulness, regular information updates should be provided under a continuing program.

EDUCATION

Future development of sustainable, renewable resource development programs and projects and maintenance of esthetic, productive environments depend heavily on: 1) the availability of an ecologically aware public, 2) technologically capable practitioners, and 3) scientifically skilled entrepreneurs and managers. Education underlies the development of these cadres of people.

Issue: Traditional Knowledge and Skills

Traditional knowledge and skills are eroding as older generations cease to teach younger islanders and as island youth increasingly look to emigration or professional education for "white-collar" employment opportunities.

Many traditional island renewable resource uses and products can be considered manifestations of cultural identity and, thus, their preservation is of importance to island cultures. Some traditional resource use systems, when incorporated with modern techniques, may form the basis for development of sustainable technologies. In addition, traditional insular resource-related knowledge could be of considerable value to island renewable resource management and development. Traditional products might form the basis of local industries, such as handicrafts industries. Similarly, traditional skills could provide the basis for nontraditional small industries development, such as carpentry.

Option: USDOI Historic Preservation Evaluation

Congress could direct USDOI to reexamine its historic preservation activities on the U.S.-affiliated islands, especially regarding the preservation, oral or otherwise, of islanders' knowledge of resource systems and of skills related to sustainable uses of renewable resources.

USDOI could evaluate and report to Congress the effectiveness of current historic preservation activities in fostering local awareness of the importance of maintaining traditional knowledge and skills and on making use of the information and skills in resource and economic development.

Option: Preserve and Support Traditional Skill Education Programs

Congress could support National Endowment for the Arts (NEA) educational programs designed to transfer traditional knowledge and practices using island renewable resources to island youth.

The Palau Museum's Master-Apprentice program, supported by a grant from NEA, allows master carvers to pass on their knowledge to unemployed but talented youth. A second NEA project in American Samoa supports master carvers in rotating employment. Tapa artists visit schools on the island to instruct students in their craft. Other traditional skill studies are occasionally inserted into school curricula, but this varies with administrative policies and funding, and such studies are considered secondary to academic studies. Through NEA, the Federal Government could encourage more of this activity throughout the Pacific and Caribbean regions.

Issue: Environmental Education

While the island areas each have well-developed educational systems, few curricular materials are available for primary and secondary schools developed specifically to educate students on island land and sea ecology, on the relationships between environment and development, or on the relationship of traditional culture to resources. In addition, most U.S. Pacific colleges are 2-year institutions, necessitating study off-island to complete graduate-or college-level educations.

Option: Develop Environmental Education Programs

Congress could direct the U.S. Department of Education's Office of Education Research and Improvement, in cooperation with lo-

cal government Departments of Education, Coastal Resource Management programs, and other programs already interested and involved in environmental education, to assess ecology curricula materials for island environmental education programs.

Educational materials developed by regional and international organizations for small tropical islands (e.g., the South Pacific Regional Environment Program) should also be assessed. where appropriate, financial assistance could be provided for dissemination of identified materials, and for development of materials suitable for primary and secondary schools.

Improvements in ecological education programs in primary and secondary schools could assist development of an island environmental ethic, that eventually could reduce the need for regulatory and incentives programs and could contribute to the maintenance of environmental quality. In addition, such programs could increase students' scientific knowledge and interest and stimulate them to seek further education in resource-related areas.

Option: Assess Island Manpower Needs and Skill Requirements for Resource Development

Congress could direct USDOI to assist island governments in analysis of manpower needs and subsequent education requirements to fulfill insular development plans.

These analyses could be carried out in cooperation with local government agencies, and reports made available to Congress for consideration annually or with evaluation of each 5-year development plan required under the Compact of Free Association (Public Law 99-239).

RESEARCH

Improvement in the fit between present and future Federal programs for U.S.-affiliated islands relating to integrated renewable resource management and planning and island economic development is a key element to a program's success. Many Federal programs extended to the u. S.-affiliated islands are based on research conducted in the temperate continental U.S. environment. This environmental misfit in some cases causes programs to fail and may even cause hardships to island inhabitants. Yet research results potentially applicable to the U.S.-affiliated islands are housed in certain Federal, regional, and international agencies and opportunities exist for improved transfer of that information to the islands.

Programs exist in certain Federal agencies that commonly are designed with a tropical environment in mind; these programs relate mostly to renewable resource management in tropical developing countries. For example, the U.S. Agency for International Development (AID) supports resource-related research and development in many developing countries. In certain cases, this AID research as well as other U.S.-funded research conducted by the Food and Agricultural Organization of the United Nations, and the World Bank, is directly applicable to tropical insular resources. The islands benefit little from this relevant agricultural and renewable resource research.

Option: Screen U.S. Development Assistance Research for Its Application to U.S.-Affiliated Islands

Congress could direct USDA's Office of International Cooperation and Development, and Forestry Support Service, which work closely with AID, to screen U.S.-funded research results on agriculture, forestry, and other renewable resources in tropical developing countries for its applicability to U.S.-affiliated islands, and to provide the information for island use in an appropriate published form.

AID has had about 25 years of on-the-ground experience in working with the developing countries of the tropics worldwide. This wealth of experience and the associated research provide a storehouse of information on renewable resource management, planning, and development in the tropics, large parts of which may benefit the island governments. USDA, with its great diversity of technical skills, would be in a position to adapt this information for island needs. The cost to the United States for this development assistance information is large, yet the cost for making it available to the islands would be small.

Agriculture and Forestry

Option: Link Tropical and Nontropical Land-Grant Institutions

Congress could direct AID to develop a mechanism whereby nontropical U.S. land-grant institutions could link their research activities, funded under Title XII of the Foreign Assistance Act of 1966, with the research activities of tropical land-grant institutions on U.S.-affiliated islands.

Such arrangements would allow for testing of the applied research of the continental land-grant institutions for suitability in a tropical environment prior to transfer to developing countries, This linkage would very likely strengthen the island land-grant institution's activities in integrated renewable resource planning and management.

This Title XII-funded research arrangement ultimately could improve U.S. development assistance efforts in developing countries. In addition, it should strengthen overall U.S. competence in tropical natural resource management.

Because of the travel that would be required from the continental research institutions to the islands, larger amounts of the overall Title XII funds would go for travel, thus reducing the funds for research.

Option: Extend Section 406 Programs and Funding to All Tropical Land-Grant Institutions

Congress could extend Section 406 of the Food for Peace Act of 1966 to cover all tropical land-grant institutions and provide the necessary funding to pursue the goals of the section.

Tropical land-grant institutions are: the University of Guam, American Samoa Community College, the College of Micronesia, the College of the Northern Marianas, the University of Puerto Rico, and the College of the Virgin Islands.

Section 406 of the Food for Peace Act of 1966 directs USDA to develop research contracts and agreements with American institutions in the field of tropical and subtropical agriculture, and that USDA should make the results available to friendly developing nations. The goals of Section 406 are twofold: 1) to provide USDA and land-grant scientists with tropical experience and training, and 2) to provide foreign nationals with a place to learn techniques and methodologies from U.S. specialists under tropical conditions. The University of Hawaii and the University of Puerto Rico were the two original tropical institutions to receive research funds under Section 406. Today, five additional tropical land-grant institutions exist in Guam, American Samoa, the Federated States of Micronesia, the Commonwealth of the Northern Marianas, and the U.S. Virgin Islands.

This congressional action would very likely result in a substantial increase in the total tropical agricultural research in the United States and its territories. Island residents and particularly college-level students would have access to training that they commonly have to travel thousands of miles to obtain. Many of these institutions are small and will need funds to equip research and training facilities to complement Section 406 funds. Population growth rates on most of the islands are high and, therefore, it seems probable that the new tropical agricultural research will quickly show benefits in expanding sustainable agriculture on the islands. Because of the proximity of foreign countries to many of the island land-grant institutions, it may be likely that these institutions will strengthen linkages between the United States and countries neighboring the islands.

Education and research are costly, and providing funding at the early stages of development of many of these institutions may be viewed as wasteful. It may take many years for these schools to reach productivity levels comparable to the Universities of Hawaii and Puerto Rico.

Option: USDA Island Screening Committee for Agriculture Research

Congress could direct USDA to establish a small screening committee within USDA charged with reviewing USDA-funded proposals, and research results for their applicability or possible applicability to agriculture on U.S.-affiliated islands.

The screening committee could use USDA Current Research Information System computer data on research being planned or research that is underway to identify points of opportunity for the research to benefit the islands. The screening committee could suggest to appropriate researchers possible ways that the research projects might incorporate certain aspects of importance to U.S.-affiliated tropical islands. The individual researcher would make the final decision whether the research design should be modified or not.

The USDA funds important, major agricultural research across the United States. However, much agricultural research sponsored by USDA does not specifically consider its applicability to the tropical environments of the U. S.-affiliated tropical islands. Inadvertently, opportunities to apply the results of the research to this special environment may be missed. Certain small modifications made in research plans at the start of projects designed for continental, temperate lands may have significant payoffs later to tropical island agriculture if the researchers have kept island agricultural problems in mind.

This probably is an inexpensive way to "piggy back" island agriculture research. Because the researcher would have the final decision, it seems unlikely that having a screening committee suggest possible changes would adversely affect the researcher or his/her project. Researchers like challenges and some might welcome the chance to approach the research in a different light. Because tropical agricultural scientists probably are few overall in USDA, it may bean unduly heavy additional load to place on these few specialists.

Option: Expand Tropical Agriculture and Forestry Research Stations

Congress could direct USDA to evaluate research priorities and increase support for applied research in agriculture and forestry development on U.S.-affiliated islands conducted by the Tropical Agriculture Research Stations, and Institute of Tropical Forestry in Puerto Rico, and the Institute of Pacific Islands Forestry in Hawaii.

Examples of areas in which applied research might be expanded are:

- research on traditional farming systems;
- crop interactions and mechanisms governing productivity and stability in tropical agriculture systems;
- identification, maintenance, and increased use of superior varieties of local cultivars;
- sustained-yield mangrove forestry practices; and
- stable agroforestry systems for montane watersheds.

Aquaculture and Nearshore Fisheries

While insular research centers in tropical agriculture and island forestry have been established, no corresponding organization exists for warmwater or tropical aquiculture. The universities of Puerto Rico and Hawaii have been designated as Sea Grant institutions, and a Sea Grant representative is based at the University of Guam. However, funding for Sea Grant research has been declining and the representatives have little capability to direct research towards the needs of other islands.

Option: Establish an Institute of Tropical Aquiculture Research

Congress could direct NOAA to establish one or more Institutes of Tropical Aquaculture Research, based in the U.S.-affiliated islands, which could serve as a center of excellence for tropical aquiculture technology development.

The Institute(s) might profitably be associated with established Sea Grant institutions, but should have the mandate and capability to serve other U.S.-affiliated islands. Like the other federally funded tropical research institutions based on the islands, the Institute(s) would be a relatively small cadre of experts performing relevant research and could serve as a facility supporting graduate and post-graduate study. It also could serve as an information clearinghouse and assist in identification of U.S. warm-water aquiculture experts for private firms, tropical universities, or government agencies interested in collaborative work and by identifying sources of funding for these kinds of exchanges.

Development of such an Institute would require funding for development of facilities and probably would take several years. Increased support for development of Sea Grant Program and/or insular government research capabilities might achieve virtually the same goal, potentially in a shorter time. Thus, alternatively, Congress could increase support for NOAA Sea Grant basic and applied research in such areas as aquiculture, fisheries, marine biotechnology, seafood quality, and seafood processing and marketing.

Local and Regional Cooperation in Research

While U.S. Federal research organizations have considerable expertise in resource-related fields and technologies, little of this research is expressly oriented to tropical environments, and still less is aimed at the social and cultural conditions found on the U.S.-affiliated islands. In addition, island governments have limited capability to conduct research on other than critical local needs.

Local and Federal research could be supplemented by taking advantage of research performed by regional and international organizations, and at similar institutions on neighboring islands. Research conducted by the South Pacific Commission, South Pacific Regional Environment Program, the Caribbean Agriculture Research and Development Institute, and other regional research institutions can provide useful information.

Option: Increase East-West Center Activities in U.S.-Affiliated Pacific Islands

Congress could direct the East-West Center to increase resource-related research and analysis for the U.S.-affiliated Pacific islands and provide increased funding for such activities.

Activities could include increased support of the Research and Information Network of the South Pacific Regional Environment Program, which includes the U.S.-affiliated islands.

The East-West Center, established by Congress in 1972, is mandated to provide analysis of social, political, and other issues for Asia and the Pacific. However, the Environment and Policy Institute often has to work where the larger populations and matching resources can be found (i.e., Southeast Asia and South Asia). Similarly, the Pacific Islands Development Program research and training activities in Micronesia might be expanded.

Option: Support Development of the Eastern Caribbean Center

Congress could extend continued support and appropriate funds through the Department of the Interior and/or the Department of State to accelerate development of the Eastern Caribbean Center.

A regional research and information dissemination center for the eastern Caribbean, based at the College of the Virgin Islands, has been modeled on the East-West Center. The Eastern Caribbean Center was proposed to serve as a link between the United States and the island nations of the eastern Caribbean. The center's areas of study include:

- agriculture and aquiculture technology needs assessment,
- insect and disease distribution,
- food production research,
- food processing,
- water research inventory,
- data systems improvement,

- professional and midmanagement training, and
- telecommunications.

This center would expedite two-way exchange of information relevant to sustainable resource management on small Caribbean islands.

Option: Establish Cooperative Relationships With Regional and International Research Organizations

Congress could direct the U.S. Department of State to assist the insular government research organizations in establishing cooperative relationships with regional and international research institutions or major universities that can help with broad strategic and basic research.

For the most part, Department of State assistance could take the form of identification of such organizations and of expertise relevant to islands within the organizations. For the Freely Associated States, assistance also could include funding for informal participation in international conferences or meetings relevant to sustainable resource management and development on the islands.

These efforts would cost little, but may require that Department of State staff be increased or redirected to allow timely response to insular requests, potentially detracting from other programs.

EXTENSION AND TRAINING

Even where research has been conducted, where information is available, and technologies have been deemed appropriate to island conditions, few technologies will be widely adopted without: 1) extension of that information to potential practitioners, 2) demonstration of the associated technologies, and 3) training of the practitioners to develop any new skills needed for implementation. Most local government departments of agriculture and marine resources have designated extension staff, but these offices tend to be small, underfunded, and to have numerous responsibilities, hindering their effectiveness in transferring technology to practitioners.

Option: Joint Extension Programs

Congress could direct USDA, NOAA, and USDOI to have the major Federal resource-related agency extension programs—Cooperative Extension Service, Marine Advisory Service, State and Private Forestry, and Fish and Wildlife Service—in cooperation with local department extension services to hold jointly conducted training workshops for field extensionists in the islands.

Goals would be to improve local extension skills and to assist extensionists to understand the assistance opportunities offered by Federal agencies and local departments of agriculture, marine resources, and fish and wildlife agencies. This could improve the efficiency of extension on limited budgets.

They might also establish regular joint programs to assist island practitioners in locating and communicating with island resource extensionists, given that most islanders are not solely farmers or fishermen, but engage in multiple enterprises.

Agriculture and Forestry

Each island area has a designated Land Grant college or university with an associated joint USDA Extension Service/Land Grant College/territory government Cooperative Extension Service. While this system is a uniquely in-

[3] The College of Micronesia, with headquarters on Pohnpei, serves the Federated States of Micronesia, the Republic of Palau (the Micronesia Occupational College) and, when the Nursing School is relocated from Saipan to Majuro, the Republic of the Marshall Islands.

tegrated Federal Government/local government/academic system designed to educate and assist agriculturists, the isolation of populations and travel difficulties create special conditions in the U.S.-affiliated Pacific islands, Neither the local colleges nor the local governments can supply adequate funds to maintain the extension staff needed to reach remote rural and outlying populations.

Option: Increase Support for Island Extension Services

Congress could direct USDA to increase support of insular agricultural extension programs to allow expansion of programs to reach remote populations.

This would coincide with the emphasis in the 1985 Farm Security Act on support for small-scale farms. However, this would require that monies be increased despite the current Administration's efforts to eliminate the program, or that funds be diverted from other extension programs for the continental United States during a period of decline in moderate- and small-sized farms, and may only be achieved within the framework of a general reorientation of the USDA Extension Service.

Aquaculture and Nearshore Fisheries

The University of Hawaii and University of Puerto Rico Sea Grant programs have established Marine Advisory Services to extend to practitioners information and technology for aquiculture, fisheries, and related marine-resource management, While these organizations have had a long-term interest in working with the other islands in their regions on problems pertaining to marine resource development, staffing and funding levels hinder the extension of Marine Advisory Service to U. S.-affiliated islands other than Guam.

Option: Expand Sea Grant Marine Advisory Service Activities in Islands

Congress could appropriate funds and direct NOAA to increase Sea Grant assistance in training and extension for aquiculture, fisheries, and marine resource management for islands having Sea Grant representatives and to make such services available to the other U.S.-affiliated islands.

Additional Marine Extension Agents could serve the various island groups, either as on-island Sea Grant representatives or from bases at the Universities of Puerto Rico and Hawaii with travel funds provided to allow extension of information and technologies to other islands.

The infrastructure for the administration of the program already exists, but appropriate new personnel need to be identified and funded to serve islands presently without Sea Grant representatives, These people could be immediately tied into the existing Sea Grant System at universities that have the expertise to address the various problems, Training in key areas could then be more readily accessible to islanders wishing advanced technology or degrees.

Issue: Species Introductions

A need exists on the U.S.-affiliated islands for expert advice on proposed species introductions for aquiculture development and biological pest control and their likely impacts on island ecosystems, Without such expertise the islands run the risk of inappropriate species introductions with possible harmful effects on resources.

Option: Resident Fish and Wildlife Service Scientists

Congress could direct the U.S. Fish and Wildlife Service (perhaps jointly with NOAA Office of Sea Grant) to provide a resident scientist to the regions.

The scientist could provide advice on ecological aspects of agriculture and aquiculture, especially on introduction of aquiculture and biological pest control species and recovery of endangered species, and to conduct the necessary research to backup the advice. The resident scientist could be located at a certain land-grant institution within the islands, and provided with a budget to allow extension of this service to islands throughout the regions,

INCENTIVES

Some amount of regulatory measures and incentives are needed to prevent resource and environmental degradation in the short term until island residents become predisposed towards maintenance of resource productivity and environmental quality. In addition, incentives may be necessary to encourage people to undertake new or potentially high economic risk activities.

Initial incentives are availability and knowledge of potentially profitable technologies (provided by research and extension) and ability to implement them (provided by training). In some cases, where the social benefits are perceived to be higher than the private benefits, incentives or removal of disincentives maybe needed to encourage undertaking of appropriate activities. Incentives can be technical (e.g., marketing assistance) or financial (e.g., cost-sharing programs).

Issue: Marketing Assistance

Increasing agricultural productivity and establishing new island crops for export is important but only part of what is needed. Agriculture producers must have accurate, thorough information on markets for their products, and may need assistance in accessing those markets. Identifying markets and potential markets needs improvement in U.S.-affiliated islands.

Option: Agricultural Marketing Service Assistance

Congress could direct USDA's Agricultural Marketing Service to assist insular governments through three major programs: 1) the Federal-State Marketing Improvement Program, 2) provision of market news, and 3) agricultural product grading.

The Federal-State Marketing Improvement Program provides funds to States to solve marketing problems at the State and local level through Federal-State cooperation. *Market News* provides timely information on prices, demand, movement, volume and quality of all major agricultural commodities. Agricultural Product Grading provides the producer and marketer of agricultural commodities with meaningful grades indicative of product quality.

Although the Federal-State Marketing Improvement Program probably has the greatest latitude for serving insular needs, *Marketing News* and the Agricultural Product Grading programs can be directed to provide information on major tropical agricultural commodities, such as fruits, to the insular governments. This may require expansion of their current programs.

Option: Sea Grant Evaluation of Aquacultural Marketing and Economics

Congress could direct the Department of Commerce to have NOAA's Office of Sea Grant programs conduct an assessment of aquacultural marketing and economics issues for island aquiculture development.

NOAA does not have a marketing assistance program corresponding to that of USDA described above. However, identification of potential markets is integral to the development of successful aquiculture enterprises. An assessment of local and export markets for aquiculture products that could be grown on the islands could provide an improved basis for estimating the potentials for aquiculture development on the islands, and might serve as an indicator of research needs (e.g., if a substantial market is identified but the present culture technology is unsuitable for implementation in the islands). Such an assessment might also identify barriers and means to overcome the barriers to exporting products into non-U.S. islands and nearby countries, such as Japan.

Issue: Conservation Cost-Sharing Programs

In recent years, cost-sharing and other incentive/assistance programs have been reduced in favor of U.S. Federal income tax incentives. However, such incentives programs have, in some cases, formed the basis for local government activities to develop resource enterprises.

Because the islands do not participate directly in U.S. Federal income tax structures, tax-based incentives are an ineffective means to encourage participation in sustainable resource-related activities. For example, despite a recent resurgence in forest planting and management in Puerto Rico, further reduction or elimination of the USDA Forestry Incentives Program (FIP) (which offers up to 70 percent of forest establishment costs) may bring local planting to a standstill.

Option: Establish Insular Resource Management Cost-Sharing Programs

Congress could authorize and appropriate for a new USDA program to provide cost-sharing and technical assistance to insular individuals undertaking approved agriculture, soil and water conservation, forestry activities (such as those offered by the current Agricultural Stabilization and Conservation Service's Agricultural Conservation Program and Forestry Incentives Program), and fisheries and aquiculture activities.

To ensure that activities are appropriate to maintain island resource sustainability and productivity, individuals' development plans might require approval by an appropriate Federal agency representative (as FIP participation requires plan approval by the U.S. Forest Service). Local government agencies, regional centers of excellence or similar agencies might be designated to administer the programs to mitigate travel costs and similar problems.

Issue: Impacts of income Support and Food Programs

A high percentage of island populations are eligible for and participate in U.S. income support programs. Some analysts argue that this reduces the incentives to invest money and labor in resource-related enterprises.

In addition, USDA and the Department of Health and Human Services (DHHS) food programs operate in most U.S.-affiliated islands. For example, some 1 million pounds of food is imported each year into the U.S. Pacific islands under the School Lunch Program. Locally grown island commodities, in some cases, account for 15 percent of program lunches. Increased use of locally grown foods in such programs could provide markets and incentives for expanded island agricultural activities and, as such, increased economic benefits to the islands.

Option: Analyze Income and Other Support Programs

Congress could direct USDA and HHS to perform a joint analysis of eligibility formulae, nutritional and other impacts of U.S. income and other support programs.

Should such an analysis indicate a high level of "marginal participants" (i. e., those participating in but not substantially benefiting from such programs), support funding could gradually be reduced or a proportion of such funding could be redirected to cost-sharing assistance programs.

Option: USDA Analysis of Island Contributions to the School Lunch Program

Congress could direct USDA to prepare a report assessing the current and potential role of locally grown island food in island School Lunch Programs.

USDA should address questions of nutrition, and the beneficial or adverse economic impacts on the island economies from increasing locally grown food in the program. Also, USDA should recommend a target level for incorporation of island grown food in the program and in proposing the target level, examine whether the locally grown food's contribution to the program should, for example, be measured as a dollar percent, a weight percent, a volume percent, or as a percent of the total nutritive value of the lunches. Other USDA/DHHS food and nutrition programs such as Women, Infants and Children; Nutrition Program for the Elderly and derivatives of the Food Stamp Program could also be assessed.

Locally grown island foods may find greater acceptance among school children than certain imported items because of the familiarity with the local crops. However, local storage and refrigeration facilities may not be adequate to assure schools of delivery on a regular basis. Increased purchase of local food to supply these programs may have deleterious effects on the availability or price of food available on open markets.

CHAPTER 10 REFERENCES

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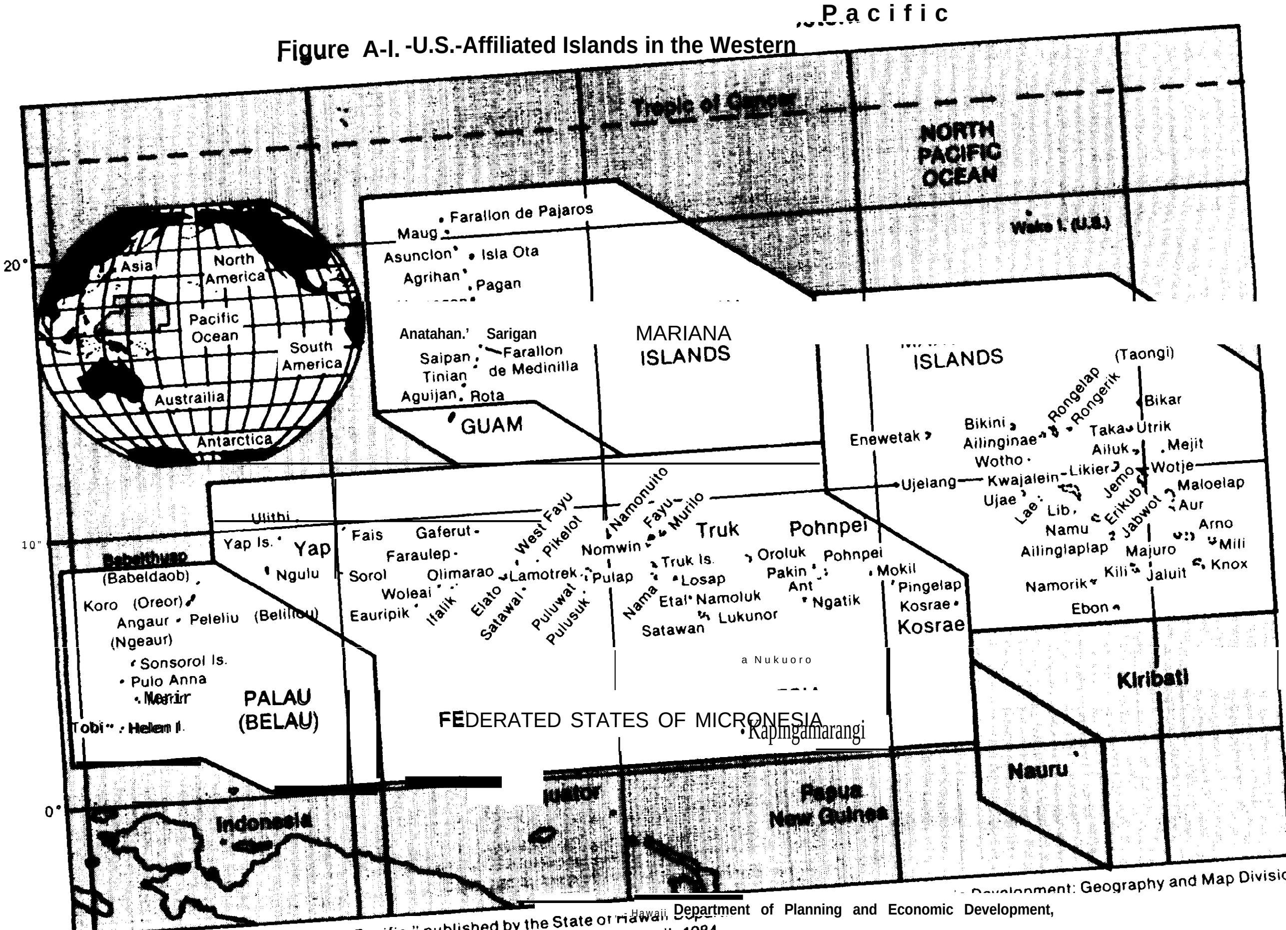
2. de Bruin, O., *Hearings,* statement before the Subcommittee on the Department of the Interior and Related Agencies, Committee on Appropriations, Apr. 29, 1986.
3. U.S. MAB Bulletin, Highlights *From the Directorates: Caribbean Island Ecosystems (MAB-7), 8(1):5,* July 1985.

Appendixes

Appendix A

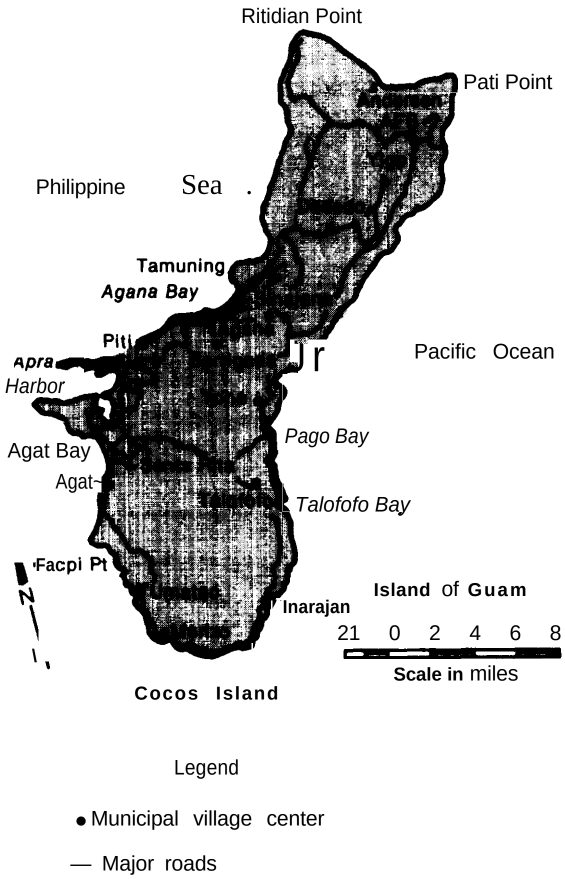
Maps of the U.S.-Affiliated Islands

Figure A-1.—U.S.-Affiliated Islands in the Western Pacific



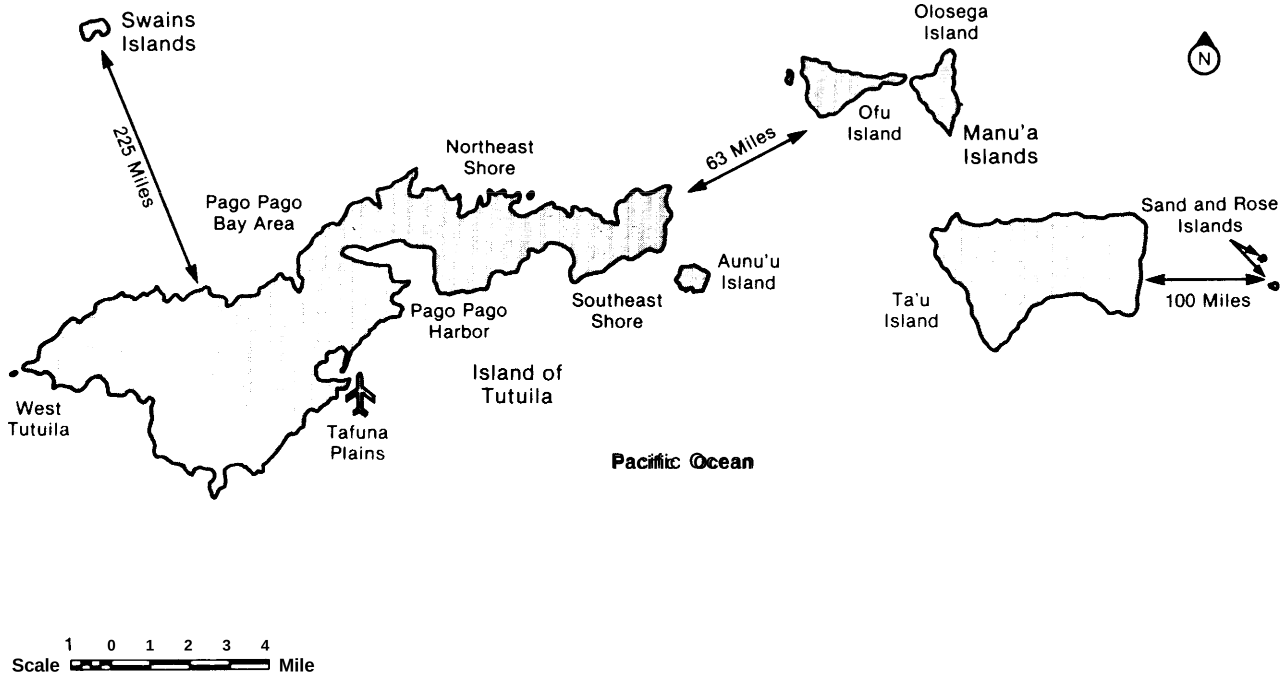
SOURCE: Adapted from map of "The New Pacific," published by the State of Hawaii Department of Planning and Economic Development, Geography and Map Division Bernice P. Bishop Museum; and The Pacific Basin Development Council, 1984.

Figure A-2.—Island of Guam



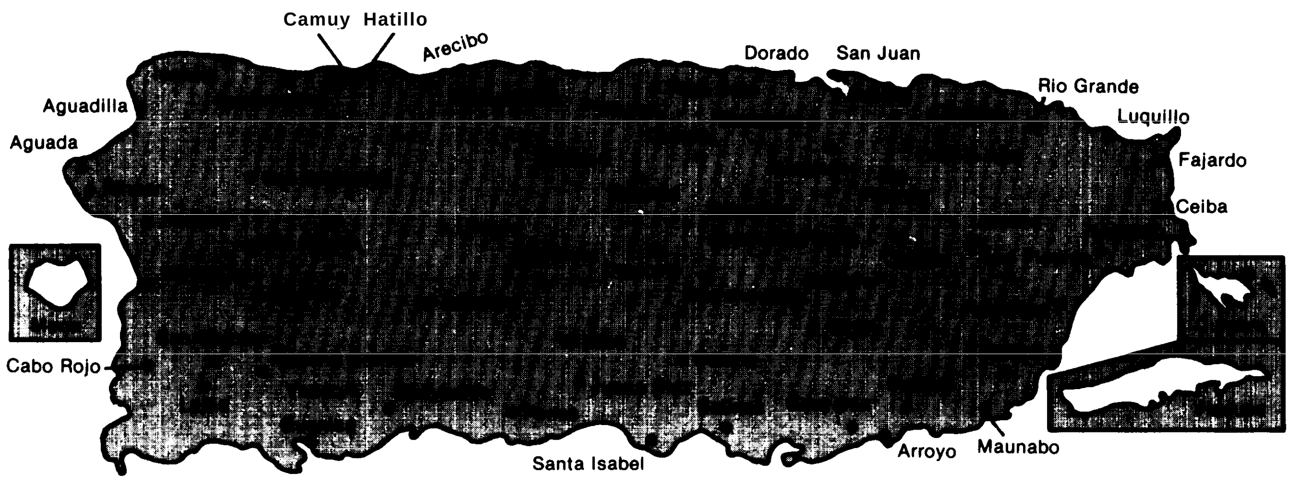
SOURCE: U.S. Army Corps of Engineers, Pacific Ocean Division, Honolulu, HI in J. Maragos, "Coastal Resource Management and Development in the U.S. Pacific Islands," OTA commissioned paper, 1966.

Figure A-3.— Islands of American Samoa



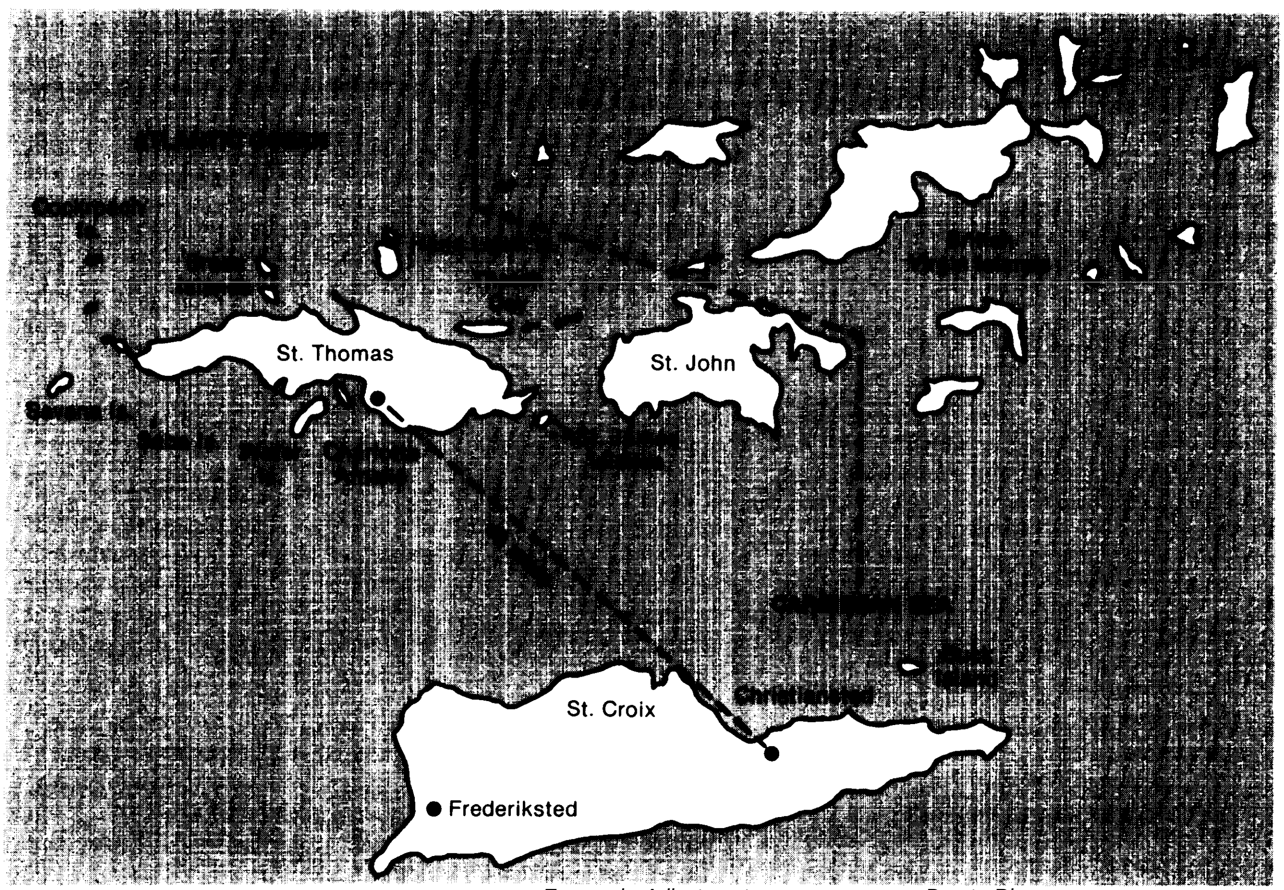
SOURCE. U S. Department of Commerce, National Oceanic and Atmospheric Administration, American Samoa Coastal Management *Program and Final Environmental Impact Statement,* **Office of Coastal Resource Management, NOAA, Washington, DC, 1980**

Figure A-4.—Major Islands of Puerto Rico



SOURCE: Adapted from R. Pico, The Geography of *Puerto Rico* (Chicago IL: Aldine Publishing Co, 1974)

Figure A-5.—Major Islands of the U.S. Virgin Islands



SOURCE: Adapted from President's Economic Adjustment Committee, *Economic Adjustment* Program for Vieques, *Puerto Rico* (Washington DC: Office of the Secretary of Defense, The Pentagon, November 1985).

Appendix B

Other U.S. Island Possessions in the Tropical Pacific[1]

Introduction

There are eight isolated and unincorporated islands and reefs under U.S. control and sovereignty in the tropical Pacific Basin. Included in this category are: Kingman Reef, Palmyra and Johnston Atolls in the northern Line Island group; Howland, Baker and Jarvis Islands in the southern Line Island group; Midway Atoll at the northwest end of the Hawaiian archipelago; and Wake Island north of the Marshall Islands. Evidence indicates that some of these islands were not inhabited prior to "Western" discovery; and today some remain uninhabited.

These islands range from less than 1 degree south latitude to nearly 29 degrees north latitude and from 162 degrees west to 167 east longitude. The climate regimes range from arid to wet and equatorial to subtropical. Wildlife resources are similarly varied, with endemic threatened and endangered wildlife species existing on several of the islands. The geographic area covered by these islands has made many of them nesting areas for seabirds and habitat for some rare mammal species such as the Hawaiian monk seal. Several of these islands are of extreme scientific interest because of their age, with origins in the Mesozoic era, and the majority are designated wildlife refuges or contain designated wildlife refuges.

Both Wake Island and Midway Island figured prominently in World War II, as did many other U.S.-affiliated Pacific islands. The Battle of Midway frequently has been called the "turning point" of World War II. Today, military installations remain on Midway, Wake, and Johnston. Johnston Atoll, an important site during the era of nuclear testing, remains a storehouse for chemical munitions and defoliants. During the storage period, some of the storage drums leaked chemicals into the ground; the U.S. Army is currently taking remedial actions to restore the island.

[1] Condensed from "Coastal Resource Development and Management in the U.S.-Affiliated Islands," J.E. Maragos, OTA commissioned paper, 1986.

Howland, Jarvis, and Baker Islands

Howland, Jarvis and Baker are arid coral islands in the southern Line Island group (figure B-l). Aside from American Samoa, Jarvis Island is the only other U.S.-affiliated island in the Southern Hemisphere. These islands lie within one-half degree from the equator, in the equatorial climatic zone.

During the 19th century the United States and Britain actively exploited the significant guano deposits found on these three islands. Jarvis Island was claimed by the United States in 1857, and subsequently annexed by Britain in 1889. Jarvis, Howland, and Baker Islands were made territories of the United States in 1936, and placed under the jurisdiction of the Department of the Interior. The islands currently are uninhabited.

These atolls were used as weather stations and military outposts during the World War II years and debris from military presence during the war remains on the atolls. The U.S. Army Corps of Engineers presently is investigating whether to clean debris, drums, and discarded fuel from the islands as part of its responsibilities under the new Defense Environmental Restoration Account. Presently, all three are National Wildlife Refuges administered by the U.S. Fish and Wildlife Service.

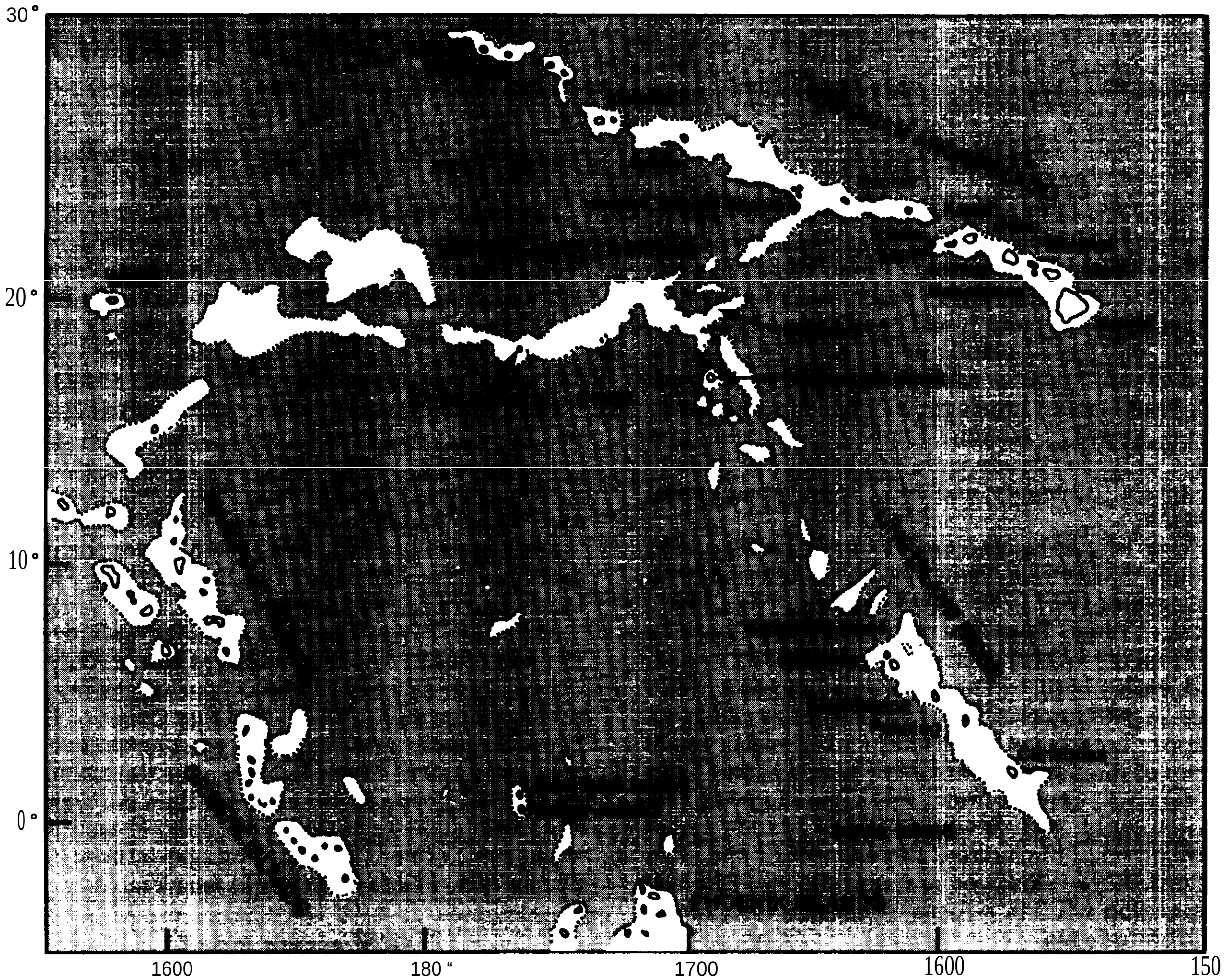
Kingman Reef

Kingman Reef is in the northern Line Islands; its land area is exposed only at low tide and is essentially a coral reef and shoal. The U.S. Navy currently has jurisdiction over Kingman Reef.

Midway Atoll

Midway Atoll is at the northwest end of the Hawaiian archipelago and consists of two main islands, Sand and Eastern, and surrounding reefs (figure B-l). There is no evidence of prehistoric human occupation at Midway prior to its discovery in the last century. Midway was claimed for the United States in 1867. Soon the atoll became important as a link in the first global communication system; later as part of a trans-Pacific flight route and as a quarantine station to control the introduction of exotic and pest species to Hawaii.

Figure B-1 .—Other U.S.-Affillated Pacific Islands



NOTE: Names in parenthesis depict individual or chains of seamounts far below sea surface and therefore lacking living reef corals.

SOURCE: J. Maragos, "Coastal Resource Management and Development in the U.S. Pacific Islands," OTA commissioned paper, 1986

Midway was bombed by the Japanese in 1941 on the return from the Pearl Harbor raid. The successful U.S. defense of Midway during World War II was a turning point in the war and arrested the Japanese attempt for broader control of the Pacific. Presently, the Navy maintains a Naval Air Station at Midway, including airfields and a deep draft harbor.

The severe reduction of Midway's seabird population by plume and feather hunters resulted in the designation of the Leeward Hawaiian Islands, including Midway, as part of a National Wildlife Refuge. Large populations of migratory and nesting sea- and shorebirds remain one of Midway's most important natural resources; at times the seabird populations approach one million birds, and over 60 species have been recorded. Fishery and coral reef resources have also been the subject of study in recent years, and for a time commercial fishing interests were allowed access to the island for refueling; however, this arrangement was terminated after a few years. Several rare or endangered species inhabit Midway including the Hawaiian monk seal, short-tailed albatross, green sea turtle, and possibly the hawksbill sea turtle.

Significant environmental issues at Midway include: 1) the high incidence of seabird mortality due to air strikes with planes and collisions with radio antennas; z) the continued vulnerability of the monk seal to human induced disturbances; and 3) the occurrence of ciguatera fish poisoning which is believed to be linked to dredge and fill activities.

Wake Atoll

Wake is an isolated atoll island located north of the Marshall Islands and consists of three islets and a reef enclosing a shallow lagoon (figure B-l). The written historical record provides no evidence of prehistoric populations on Wake Atoll. Marshall Islanders occasionally visit Wake, have given it a Marshallese name (Enenkio), and also occasionally claim it, The atoll was claimed by the United States in 1898, and annexed in 1899. Prior to the 1930s the only visitors to Wake were scientists and survivors of shipwrecks. The Navy received administrative control of Wake in 1934, and a Naval air base was established on the atoll in January 1941.

Wake Atoll was bombed at the beginning of World War 11 by the Japanese on their return from the Pearl Harbor raid. Shortly thereafter the Japanese invaded and took control of Wake after heavy fighting. Heavy bombardment by United States forces throughout World War II neutralized Wake's strategic importance. Considerable damage to the resource base occured as a result of bombing and port dredge and fill activities. Seabird populations were severely decimated during World War II and an endemic bird (the Wake rail) became extinct during this period as well.

The United States reoccupied the atoll after the war and administrative authority was held by the Federal Aviation Administration until 1962, At that time, authority was transferred to the U.S. Department of the Interior which in turn assigned authority to the U.S. Air Force.

Significant coastal resources include nesting seabird populations and coral reefs. Periodic storms have shaped the geomorphology of the atoll considerably and the lagoon is very shallow, having a maximum depth of 15 feet. The green sea turtle and the hawksbill turtle occasionally may visit Wake to feed but there is no documented nesting activity, *Lepidium wahiense,* a rare plant species found on Wake, has been proposed for listing as an endangered species by the U.S. Fish and Wildlife Service. The nesting seabird populations are protected under the Air Force base regulations,

Palmyra Atoll

Palmyra is a wet atoll located in the central Pacific and is comprised of three sub lagoons and over 50 separate islets totalling some 1,800 acres (figure B-1), Palmyra was discovered by Western man in 1802 by Captain Sawle, and in 1859 it was claimed by the American Guano Company. Palmyra officially became part of the Hawaiian Kingdom in 1862, and in 1911 became privately owned. When Hawaii became a U.S. territory in 1899, Palmyra was officially included; however the island was explicitly excluded from the Hawaii Statehood Act of 1960. All land titles (except those for a few small islands at Palmyra) were transferred in 1922 to private ownership, which still continues. Although there is no direct evidence of prehistoric occupation of Palmyra, the presence of coconut palms on Palmyra and a Polynesian ceremonial platform on nearby Fanning Atoll suggest the early Polynesians may have visited Palmyra.

A seaplane base and other defense facilities were constructed on Palmyra in the late 1930s in preparation for possible war. The extent of World War II involvement was the Japanese bombing of the atoll in December of 1941. The atoll was continuously occupied by the U.S. Navy or other Federal installations after the war until 1949 and was also occupied during nuclear testing programs in 1962. The Navy attempt to regain control of Palmyra after World War II ended with a U.S. Supreme Court decision to return the atoll to the present owners.

Palmyra has some unique ecological resources due to its wet climate and equatorial location. A variety of seabirds nest there, and coconut crabs, and land crabs are common. The marine populations, though only partially sampled, seem large. The lagoon is brackish and estuarine, Construction activity has resulted in major impacts on reefs and lagoon environments, which to date have only partially recovered.

Johnston Atoll

Johnston is an open atoll in the north central Pacific Ocean approximately 800 miles southwest of Honolulu. The atoll platform and lagoon measure about 15 miles east-west and 7 miles north-south. The atoll's islands and most shallow reefs are found in its northwestern quadrant. Until the 1940s there were only 2 islands (Johnston and Sand), but by 1964 massive dredge and fill operations had expanded Johnston Island to over 600 acres, doubled the size of Sand Island, and created two rectangular fill islands, Akau and Hikina, of approximately 20 acres each.

Johnston Atoll was formed in the late Mesozoic era, and aside from Wake is the only shallow-water atoll along the Marcus Necker submarine ridge. A barrier reef is located along the northwestern quadrant rim which in addition to the islands and shoals to the south partially protect Johnston lagoon from heavy wave action. Elsewhere the lagoon is semi- or heavily exposed, and subject to open seas.

Johnston was discovered in 1796 and claimed by Hawaii and the United States in 1858. When Hawaii became a U.S. territory in 1898, authority over Johnston clearly belonged to the United States. Early scientific expeditions indicated that only two species of plants originally grew on the islands and that the atoll had never been inhabited. Guano deposits found on the island were exploited for a short period in the 19th century. An Executive Order (No. 6935) in 1934 transferred jurisdiction over Johnston Atoll to the Department of the Navy, where it remains today.

Johnston played a central role in the U.S. atmospheric nuclear testing program. In 1963, when the atmospheric nuclear test ban Treaty was signed, it retained the basic capability to resume key atmospheric testing on the atoll. This Safeguard "C" status was further relaxed, and Johnston has been reduced to a caretaker status. It now serves as a refueling stop for air traffic between Hawaii and Micronesia.

Johnston has served as a temporary repository for chemical defoliants and chemical munitions since the 1970s. Some of the storage drums have leaked, possibly contaminating both the ground and groundwater with dioxins. The extent of contamination has been analyzed and remedial actions have begun.[2] The Army is constructing an explosive-proof facility on Johnston and upon completion, plans to incinerate the stored chemical munitions.

Johnston was designated as a bird refuge in 1926 and later upgraded to a National Wildlife Refuge administered by the U.S. Fish and Wildlife Service. Johnston's principle protected resources are nesting seabirds and coral reefs, and the green sea turtle, Johnston's extreme geographic isolation and age make it of scientific interest. Recent expeditions have yielded a greater understanding of the ecology, geology, and marine environment of Johnston.

[2] Ramsey, C., U.S. Department of Defense, personal communication, September 1986.

Appendix C
U.S. Military Presence in U.S.-Affiliated Islands[1]

The U.S.-affiliated islands are of considerable importance to national security, and the United States is committed to their defense and to maintaining lines of communication to and through them. Individual islands vary in strategic importance.

Military Installations and Activities in the U.S.-Affiliated Islands

Pacific

Military installations occupy about one-third of Guam. Military personnel and their families comprise about 20 percent of Guam's population. Andersen Air Force Base (AFB) is a major Strategic Air Command (SAC) transport hub between Hawaii and the Philippines and a base for weather surveillance units and satellite communications. Guam also houses naval facilities such as a naval air station and a submarine tender (to be phased out when the Trident submarines are deployed).

Currently, about 200 active duty military personnel are employed in the former Trust Territory, most at the 3,500-acre Kwajelein Missile Range (KMR) and making up five Civic Action Teams (CATS) operating in the Federated States of Micronesia (FSM) and Palau. The CATS are modeled after the Navy Seabees of World War II, and began operating in Micronesia at the request of the Secretary of the Interior in 1969, to help in the construction of public infrastructure, mainly schools and roads.

CATS have been a tremendous success in Micronesia, both politically and economically. Although these teams probably cannot make a significant difference in the pace or ultimate progress of economic development on the islands, they do provide excellent training for local apprentices and are a strong symbol of continued U.S. interest in the welfare of the Micronesians. Under the Compact of Free Association and subsidiary agreements, the Department of Defense (DOD) will continue to make CAT services available to the FSM and Palau at shared costs.

Navy, Marine, and some Army and Air Force units also are active in the Commonwealth of the Northern Mariana Islands (CNMI), Units totaling less than a brigade in strength conduct periodic maneuvers on Tinian, where DOD has nonexclusive use of some 18,000 acres—about two-thirds of the island. Marine Engineer and other tactical units periodically exercise there and conduct certain civic action projects. These have included repair and renovation of local buildings, assistance in the installation of water lines, and installation of power distribution to the Marpo farming area. Finally, Farallon de Medinilla, an uninhabited, small volcanic island north of Saipan, is used sporadically as a bombing and gunnery target by U.S. naval forces in the Pacific and by the U.S. Air Force tactical air squadron on Guam.

Caribbean

The U.S.-affiliated Caribbean islands are of special significance because of their close proximity to the United States and the importance of achieving a stable security situation in the Caribbean. Most of the major Air Force and naval units operating or available for operations in the Caribbean are based in Florida, Virginia, Panama, or at Guantanamo, Cuba. Puerto Rico, which is situated on major routes of communication, also has a major naval installation at Roosevelt Roads with permanent air and surface forces. Roosevelt Roads supports the bombing gunnery range of Vieques Island and provides the principal backup for the U.S. base at Guantanamo. There are no permanent military installations in the U.S. Virgin Islands (USVI), and only sporadic naval or air surveillance or training activities in nearby waters or airspace,

Projected or Planned New Installations or Activities

All of the above described bases and activities are scheduled to continue through the foreseeable future, Military patrols in the Caribbean may intensify if DOD gets more deeply involved in anti-drug operations. Otherwise, there are no known plans to expand or radically change the U.S. military presence there,

Three potentially significant changes may affect the western Pacific:

1. Approval of the Compact of Free Association between the United States and Palau may give

[1]This section was summarized from S. Loftus, ''Impacts of U.S. Military Presence on U.S.-Affiliated Islands, " OTA commissioned paper, 1986.

the United States rights to convert certain well-defined areas in Palau into bases or training areas. Implementation of such plans presumably depends on the evolving situation in the Philippines and/or the pace and level of Soviet military activities in the area.

2. A major air base for dispersed operations may be constructed on Tinian as a backup to Andersen AFB on Guam. However, there are no indications of any serious moves by DOD to do this over the next several years.
3. KMR might be expanded or an alternative range developed to allow testing of the MX missile. preliminary surveys during the late 1970s identified the CNMI as a possible site for a "mini-KMR." As yet there is no evidence that DOD plans either action.

Ecological and Economic Effects of the Military Presence

Views regarding the effects of the U.S. military on the islands are mixed. Many islanders welcome the economic and job benefits derived from the presence of military bases. Others cite the loss of valuable lands, negative cultural impacts (e. g., undermining of traditional values), attraction of undesirable elements, inflation, overcrowding of schools, degradation of water quality, and restrictions on economic growth,

Pacific

Guam's local government concedes the critical importance of bases thereto U.S. security interests, but contends that much of the land presently occupied is redundant to principal missions. U.S. military authorities strongly disagree, citing the need to be prepared for several major contingencies, including the phasing down or replacement of key facilities in the Philippines, DOD currently is reassessing its land requirements on Guam, but is unlikely to recommend a reduction of these requirements, However, some lands held for military purposes contain large areas of natural habitat, for which DOD ownership has provided de facto protection to wildlife populations.

The operations at KMR have a profound effect on local inhabitants and ecology. Water availability, quality, and wastewater disposal all pose problems, The concentration of 8,000 Micronesians on the 66-acre island of Ebeye is an extreme example of the U.S. military's impact. Ebeye is severely overcrowded; acute socioeconomic problems and substandard housing, medical facilities, schools, and related amenities have resulted.

Most of the residents of Ebeye migrated there from the "outer" Marshall islands, drawn by well-paying jobs at KMR or because relatives work there. Most are denied access to base facilities, although these restrictions have been relaxed over the past several years, Ebeye has been the recipient of a number of U.S. programs and funds, most of which have been funneled into infrastructure such as a desalinization plant and a sewage treatment facility.

Caribbean

Naval forces in Puerto Rico have been extremely helpful to local authorities during and after major storms and flooding by providing transport, medical assistance, and earth-moving equipment. Naval forces at Roosevelt Roads also conduct a number of civic action projects locally. DOD also increased defense contracting in Puerto Rico from $187 million in fiscal year 1983 to $417 million for the first 11 months of 1985.

Under a memorandum of understanding between the U.S. Navy (USN) and the Government of Puerto Rico, DOD has undertaken a number of measures to improve the welfare of the people of Vieques, through the provision of medical equipment, supplies for local hospitals, assistance in public works construction, and a concerted effort to attract American industries to the island resulting thus far in 366 new jobs. In addition, it contracted with the Smithsonian Institution to provide a major study of the mariculture potential of that island. This has led to the creation of some 400 jobs.

Most environmental problems resulting from U.S. military activities on U.S.-affiliated islands appear to have resulted from the lack of understanding or awareness of procedures, or from insensitivity on the part of individual military officers, rather than from the absence of relevant policies or directives. Military officers generally lack the time, staff, and training to handle resource protection responsibilities, and the military has been slow to comply with some local environmental regulations.

Procedures To Consider Environmental and Land-Use Issues in Extant Military Installations and Activities

The U.S. military has a variety of procedures to consider environmental and land-use issues in its island operations, including the National Environmental Policy Act of 1969 (NEPA) and three DOD directives. In general, the same directives, regulations, and instructions that apply to current military activities and extant installations also apply to any plan to expand land use, initiate new and expanded activities, or acquire new sites.

1. Directive 6050.1, "Environmental Effects in the U.S. of DOD Actions," covers all U.S.-affiliated islands, and is based on NEPA, Council on Environmental Quality implementing regulations, and several pertinent Executive Orders, It specifies several goals related to the protection, restoration, and enhancement of island environments; resource recycling; and preservation of important historical, cultural, and natural aspects of the island's national heritage. It requires assessment of the environmental consequences of proposed DOD actions that could affect the quality of the environment; the use of ecological and sociological information in planning and decisionmaking where there may be an impact on the environment; and consideration of presently unmeasured environmental amenities in decisionmaking, as well as of reasonable alternatives to recommended actions that would involve conflicts concerning resource use.
2. Directive 4700.1 covers natural resource conservation and management, prescribes DOD policies and establishes a program for multiple use management of renewable natural resources on DOD lands, consistent with military missions.
3. Directive 4710.1 calls for integrating the legal requirements regarding archeological and historic preservation with the planning and management of DOD activities. It requires each DOD installation to scientifically evaluate the likelihood that significant archeological or historic properties are present. If so, these must be inventoried and evaluated.

All three military departments (Army, Navy, and Air Force) have issued their own directives or instructions reflecting the contents of these directives. The USN, for example, has issued a detailed instruction to its components which provides for a navywide program of compatible management, protection, and nondamaging recreational use of renewable land and water resources. Engineering Field Divisions (EFDs) administer the program in the U.S.-affiliated islands and, with staff biologists, soil scientists, and agronomists, review plans that might have an impact on local renewable resources, They may direct the preparation of environmental impact statements or contract necessary studies.[2] The EFD on Tinian is now reviewing the island's flora and fauna. A companion study covering Guam is scheduled for 1987.

Likewise, Department of Army regulation AR200-2 covers Army policy, procedures, and responsibilities for the conservation, management and restoration of land and renewable resources consistent with military mission and national policies. Chapter 2 of this regulation calls on local commanders to actively cooperate with local, State, and Federal organizations to carry out national land-use and conservation policies for all management operations. Each major command and installation with jurisdiction over substantial acreage must provide technically qualified personnel to oversee all natural resource management activities, Land management plans must be reviewed every 5 years. USAF instructions are virtually identical to the Army's and Navy's, but also address such problems as noise abatement and the protection of birds from aircraft.

Potential Mechanisms To Increase the Role of the Military in Sustainable, Environmentally Sound Island Economic Development

The U.S. military could do more to promote environmentally sound economic development on the islands, including greater information sharing with local authorities, procurement of local foods and other resource-related products, and support of the local tourism industry (military transients can be considered long-term "visitors").

The U.S. Military as a Market for Local Food and Other Renewable Resource-Related Products

DOD is reassessing its overseas food procurement policy and recently sent a team to Guam to evaluate prospects for greater reliance on local markets. The USN now relies primarily on the Defense Procurement Supply Center in Philadelphia, a guaranteed source of warranted products with instant credit and refunds for substandard products. Only if this center does not carry a particular item, or fails to meet minimum standards, are local commanders encouraged to procure locally. The base

[2]Recently a proposal from the Utah National Guard to hold maneuvers on Tinian was rejected because the Guard has failed to produce an acceptable preliminary environmental impact statement.

commander at Andersen AFB is permitted to procure some fresh, indigenous produce, but there is no consistent or substantial reliance on local food, in part because local sources are not completely reliable.

Without cogent incentives, greater reliance on local markets by the U.S. military is unlikely. Factors that could increase local procurement include improved relations between the military and local governments and citizens groups, more competitive local prices, and more reliable local sources. None are likely to materialize substantially soon.

U.S. Military Contributions to the Tourist Industry

The USN of Guam puts much time and effort into "beautification" work in and near the Naval Air Station at Agana, as part of the "COMNAVMARIANAS" civic action program, and conducts a "sister village" program with some local communities involving small public works and beautification projects. The Navy also conducts civic action work on Tinian and, less frequently, at the Memorial Park area of Tanapeg Harbor, Saipan. In the Caribbean it has reportedly done a superb job in maintaining the natural beauty of Vieques Island, although this is not a major tourist attraction. Navy Seabees from Roosevelt Roads engage in various civic action projects, mainly at the request of local village leaders, and distribute brochures from Puerto Rico's Tourism Company to its personnel. The naval command there is considering a request to transport spent rockets from the mainland to the city park of Bayamon, and has already transported cannons from the El Morro fortress for needed repairs and restoration at no cost.

However, the military is committed to its primary military missions, and few tactical units are equipped and inclined to assist civilian authorities with development programs. Exceptions include CATS and various construction and engineering units in the islands. DOD might be persuaded to press Congress for the authority and measures to increase these units' current levels of effort on behalf of island populations. Military commanders on the islands could be directed to provide more assistance to local authorities and/or give higher priority to the improvement of on-base ecological systems. Military groups would be unlikely to comply, however, without being given more resources for such a purpose.

Appendix D
Integration of Traditional and Modern Law[1]

As emerging Pacific nations enter the world order as independent sovereigns, they turn increasingly to the Anglo-American concept of the role of law to maintain social order, resolve disputes, and distribute resources. There is, however, a danger that western law will undermine traditional practices and culture, as occurred in Hawaii. A genuine attempt was made during westernization of the Hawaiian Islands in the mid-19th century to recognize and preserve important cultural prerogatives and customary privileges associated with the native way of life. These attempts failed.

After the division of the King's lands in the 1850s, less than 1 percent of land remained in the hands of commoners. Many did not understand the foreign concept of private ownership, or were never aware of the law giving them the right to own land that they had cultivated. Even those who did exercise their rights, through claims and exercise of resource access, found that the rapid evolution of the islands' social and economic structure left lifestyles associated with the land almost without viability.

The ground rules for the interpretation of claims of native rights were established the first time the newly formulated western-style courts of Hawaii were confronted with the issue. In 1959, when a tenant claimed the traditional right to pasturage on the undeveloped lands of the landlord, the claim of custom was rejected as unreasonable, uncertain, and repugnant to the spirit of the present laws (Oni v. Meek, 2 Hawaii 87, 90 (1898)). It was made clear that in the absence of explicit instructions to the contrary, the system of private ownership would be treated as preeminent. Traditional prerogatives simply ceased to exist except to the degree they were explicitly preserved, and rights became applicable only when they did not effectively interfere with western concepts of law and property.

Today, despite recent efforts to give new vitality to native rights and custom, the law of Hawaii is virtually devoid of meaningful retention of native Hawaiian culture, and Hawaii's native people occupy nearly the lowest rung of the socioeconomic ladder. Their rights and privileges have not been permitted to evolve in relation to contemporary privileges in a way that ensured their continued vitality, nor was the genuine value of these rights ever demonstrated or insisted upon. No comprehensive scheme emerged to satisfy a long-term vision of how the culture was to evolve.

Custom is a valued asset of U.S.-affiliated island communities. Anglo-American law can, but need not, follow the Hawaiian example and be destructive of that asset. Movement toward self-government in Micronesia presents an opportunity to merge the best of traditional practices with the democratic system of law.

Advantages From Adoption of the Rule of Law

The traditional practices of a community (i.e., custom) are often so engrained in belief and behavior, and so well-known to the populace that they require no legislative decree, no police, no judge, and no law library to exist and to shape social life. This raises the question of why anyone would want to import western law to displace or supplement an existing regime of customary law. Historically there are several reasons why human beings move to law.

For emerging nations, the primary impetus for adoption of western legal systems is to establish sovereignty and achieve legitimacy in the West-dominated world order. The emerging Micronesia nations have adopted wholesale various comprehensive American codes, such as the Federal Rules of Evidence and the Federal Rules of Civil Procedure, The appropriateness of these codes for use in Micronesia may not be as important as their legitimizing function. A nation with American rules of procedure "looks" more like a democracy whose sovereignty deserves respect. The use of codification and adoption of western law to achieve sovereignty is familiar to Pacific legal historians.

Law also serves to promote economic development, The rise of legalism throughout history is correlated with economic growth, industrialization, and the emergence of a class-differentiated society. U.S. legal historians, for example, study the use of legal doctrine and legal systems to promote railroads and other large industries. While critics charge that

[1]This section is summarized from W. Chang, "The Integration of Customary and Traditional Renewable Resource Practices in a Modern Legal Framework," OTA commissioned paper, 1986.

the rule of law can be a tool to increase production while concentrating wealth in a few hands, the instrumental value of law as a promoter is obvious to government leaders, particularly where economic self-sufficiency is seen as a key to political autonomy.

The rule of law provides a stable, predictable environment for economic growth. The adoption of the uniform commercial code in Guam, for example, assures business investors that familiar rules apply to transactions there. Law can actively promote certain business activities by subsidy, tax advantages, and limited grants of privilege. If a Pacific island decides, for example, to promote development of ocean thermal energy conversion (OTEC), it can offer these advantages to OTEC developers.

A corollary to the power to promote is the power to deter through the power of criminal law to punish, or regulatory law to prohibit and of eminent domain to take. Obvious uses of coercive legal rules in the realm of natural resource use include zoning laws, endangered species laws, pollution control laws, and building code laws. All are used by governments to shape development.

Advantages of Rule of Custom

As the Hawaiian example reveals, however, law has a tremendous power to dislocate and eventually destroy culture. This is particularly true when western systems of law are imported into a community in which citizens are unfamiliar with legal rules and unaware of the need to assert their rights. Given this danger, it is important to recall the reasons for preserving custom. Custom is typically the ordering mechanism used in communal cultures such as those found in the islands of the Pacific. Custom has maintained order, provided for the general welfare, created unity, and preserved a way of life. Custom also is the ordering mode of choice: citizens are proud of their culture and traditions and express genuine sorrow at the passing of custom and dismay at the incursions of westernization. A sudden displacement of custom by law is likely to cause anxiety, cultural dislocation, and disorder.

Customary rules of resource management often have an ecological basis. Fishing taboos help preserve fish populations, use restrictions preserve delicate reef systems, and clan rights allocate scarce water resources. These restraints are accepted and observed while restraints by law are often ignored. As one islander commented on an endangered species law: "How does some man in Washington know how many turtles there are in Yap?"

Integration of Custom and the Rule of Law

Pacific island lawmakers have been careful to state explicitly their intent to preserve custom within the context of the rule of law (e.g., see Constitution of the Federated States of Micronesia). This will require explicit recognition of the value and fragility of custom, coupled with a formalized system for incorporation of custom into a new system of law appropriate for use in societies rich with custom.

Explicit recognition in constitutions, statutes, and case law of the value and primacy of custom can result in the preservation of custom and traditional values, Custom can be recognized and acknowledged whenever a new law is adopted, providing a legislative reminder to courts interpreting statutes. Given the constitutional and legislative mandate for preservation of custom, the role of the courts would be to develop rules of interpretation that follow the mandate. Judges would look first at the system of customary rules and derive underlying values and principles of custom, then use those principles to create legal rules within the system of the rule of law,

For example, there may be a rule on one island that strangers approaching a village at night must carry a lighted torch. The underlying principles represented here is that strangers must respect the peace of the village and make their presence known. The judge may have to decide whether a flashlight can be used in lieu of a torch; whether an unfamiliar light is potentially disruptive of community peace; or whether the light from the flashlight was conformable with the underlying principle of the customary rule. The point here is that the judge, using his knowledge of the village and taking testimony from traditional leaders and community members, strives to find and preserve the essence of custom.

The reason for this process of the distillation of the underlying principles behind customary rules is that, while custom is fluid and adaptable to changing circumstances, certain underlying values remain unchanged, Values such as respect for traditional leaders, consensus-based dispute resolution, and significance of clan membership have survived the impact of colonialism and modernization, and form a significant part of the identity of island peoples.

To the western-trained lawyer, such a judicial system seems to invite imprecision into a system of law that values precision. The western insistence on precision, however, tends to denigrate custom which, by definition, is unrecorded, internalized, and integrated with culture. If precision is valued, the written statute or case will always defeat custom. If preservation of custom is the goal, judges must reach beyond the demand for precision, and experience the cultural milieu of custom.

The search for analogies between island customs and Anglo-American experience may prove fruitless. As one judge noted in a Marshallese property dispute:

> ... there is no analogy between the common American idea of an absolute owner and the Marshallese idea of the holder of any one of the levels of rights in the Marshalls.

The concept of property and natural resource ownership is dramatically different in emerging Pacific nations. Ownership is frequently communal, and characterized by layers of use rights rather than fee-simple ownership. Access to reefs, landing areas, surface waters, and fishing grounds may each follow different sets of customary rules,

Judges must recognize that in island communities where access to resources is a part of the livelihood of the people, complex systems of ownership and use have evolved that are very different from western concepts of ownership, In resolving disputes over resource use, access, and ownership, the courts may wish to delay intervention until traditional leaders are consulted and customary methods of dispute resolution are exhausted. In western law, this idea is incorporated in the doctrines of abstention and exhaustion. Encouraging citizens to rush to court with disputes will be destructive of consensus-based systems that have effectively maintained peace and allocated resources in the past.

Appellate courts could defer to findings of custom made by trial judges who are familiar with a community and not lightly overturn a local judge's finding of custom unless it is clearly erroneous. If courts use custom as a guiding principle, they may be able to avoid the destruction of traditional values.

Appendix E

Organizations Dealing With Renewable Resource Management in the U.S.-Affiliated Caribbean and Pacific Islands

A growing number of organizations are concerned with the development and management of renewable resources and with environmental quality in the U.S.-affiliated islands. These organizations represent a multiplicity of efforts to maintain, restore, and enhance the resources both to their benefit and to the benefit of the populations that depend on them. Organizations cover a spectrum from private voluntary organizations to Federal regulatory agencies to international development assistance institutions. Tables listing the organizations, their area of operation, field of interest, and type of activity are divided between the two regions:

This list of organizations (derived from a commissioned paper), reviewers additions, and a survey conducted by OTA, is by no means all-inclusive, but only suggestive of the types and variety of organizations dealing with renewable resources in the U.S.-affiliated islands.

Table [illegible]: Selected U.S. Government Agencies in the U.S.-Affiliated Caribbean

Name	Address	Region Covered	Field of Interest	Type of Activity/Service
DEPARTMENT OF AGRICULTURE				
Agricultural Research Service (ARS)				
Area Office	PO Box 5677 Athens, GA 30613	PR, USVI and southern States	Agricultural research	Management of research programs
Puerto Rico Agricultura Experiment Station	Venezuela Contract Station Rio Piedras, PR 00928	Puerto Rico only	Agronomy, soils, productivity	Research
Tropical Agriculture Research Station	PO Box 70 Mayaguez, PR 00709	Caribbean region	Plant research	Research, pe ams
Agricultural Stabilization & Conservation Service	PO Box 11188 Santurce, PR 00910	Puerto Rico & USVI	Conservation, commodity support	Matching grants, projects technical assistance
Animal & Plant Health Inspection Service (APHIS)				
Plant Protection and Quarantine Program	Rm. 206, Fed. Bldg. Hato Rey, PR 00918	Puerto Rico & USVI	Prevention of plant diseases	Technical assistance, in-kind services
Veterinary Services	GPO Box 71355 San Juan, PR 00936	Puerto Rico & USVI	Prevention of animal diseases	Technical assistance, in-kind services
Farmers Home Administration	GPO Box 6106 San Juan, PR 00936	Puerto Rico only	Rural development	Grants, loans, loan guarantees
Food and Nutrition Service -- Caribbean Area Office	Rm. 220, Fed. Bldg. Hato Rey, PR 00918	Puerto Rico & USVI	Promote food production	Research, grants
Forest Service (FS)				
Caribbean National Forest	PO Box 21390 Rio Piedras, PR 00928	Puerto Rico only	Management of national forest	Agency operations, technical assistance
Institute of Tropical Forestry	Southern Forest Exp. Stat PO Box 25000 Rio Piedras, PR 00928	Western Hemisphere	Forestry research	International forestry, collaborative projects
Meat and Poultry Inspection Service	Rm. 206, Fed. Bldg. Hato Rey, PR 00918	Puerto Rico & USVI	Meat and poultry inspection	Agency operations, technical assistance
Soil Conservation Service	GPO Box 4868 San Juan, PR 00936	Puerto Rico & USVI	Soil and water conservation, environmental education	Technical assistance, consultation

Table E-1 continued: Selected U.S. Government Agencies in the U.S.-Affiliated Caribbean

Name	Address	Region Covered	Field of Interest	Type of Activity/Service
DEPARTMENT OF COMMERCE				
Economic Development Administration				
Puerto Rico Office	Room 620, Federal Building Calle Carlos Chardon Hato Rey, PR 00918	Puerto Rico	Growth of economically distressed areas	Public works, planning, community grants; loan guarantees; feasibility studies; technical assistance
Caribbean Regional Office	Liberty Square Building 105 South 7th Street Philadelphia, PA 19106	Puerto Rico & USV	Growth of economically distressed areas	Loans, loan guarantees, technical assistance, agency operations
National Oceanic and Atmospheric Administration (NOAA)				
Office of Ocean and Coastal Resources Management -- Caribbean Region	2001 Wisconsin Ave., N.W. Washington, DC 20235	Puerto Rico & USVI	Coastal resource management	Research, grants, technical assistance
National Marine Fisheries Service -- Caribbean Fishery Management Council	PO Box 1001 Hato Rey, PR 00919	Puerto Rico & USVI	Manage regional fisheries, habitat conservation	Research, grants, technical assistance
DEPARTMENT OF DEFENSE				
Army Corps of Engineers -- San Juan Area Office	Fdz Juncos Ave. 400 San Juan, PR 00901	Puerto Rico & USVI	Civil works related to water resources	Agency operations, advice, permits
DEPARTMENT OF INTERIOR				
Fish and Wildlife Service (FWS)				
Caribbean Area Office	PO Box 510 Boqueron, PR 00622	Puerto Rico & USVI	Protect endangered species	Research, grants, in-kind services
Caribbean Islands National Wildlife Refuge	PO Box 510 Boqueron, PR 00622	Puerto Rico & USV	Wildlife and habitat management	Agency operations, in-kind services
Law Enforcement Office	Mayaguez, PR 00708	Puerto Rico only	Regulation of exotic species (import & export)	Agency operations
Office of Territorial and International Affairs	18th and C Streets, NW Washington, DC 20240	All U.S. Territories (USVI)	Promote economic, social, and political development	Federal Government representation, grants, technical assistance

Table E-1 continued: Selected U.S. Government Agencies in the U.S.-Affiliated Caribbean

Name	Address	Region Covered	Field of Interest	Type of Activity/Service
U.S. Geological Survey (USGS)				
Caribbean District Office & Water Resources Division	GPO Box 4424 San Juan, PR 00936	PR and USVI	Water resources investigation	Agency operations, technical assistance
Geology Division	PO Box 5917 San Juan, PR 00906	Caribbean region	Explore and map PR insular shelf	Research, scholarships
National Park Service (NPS)				
San Juan Nat'l Historic Site	PO Box 712 San Juan, PR 00902	Puerto Rico only	Operate historic site for public education	Agency operations, in-kind services
Virgin Islands National Park	PO Box 7789 Charlotte Amalie St. Thomas, USVI 00801	USVI only	Operation of national parks in USVI	Research, habitat and species protection, park management
DEPARTMENT STATE				
Man & the Biosphere Program -- Caribbean Islands Directorate	OES/ENR/MAB, SA-9, Suite 5[illegible]6 Department of State Washington, DC 20520	Caribbean basin	Island resource management and development	Conferences, research funding, information dissemination
ENVIRONMENTAL PROTECTION AGENCY				
Caribbean Area Office	Fdz Juncos Ave 1413 Santurce, PR 00910	Puerto Rico & USV	Environmental protection	Research, grants, technical assistance
FEDERAL EMERGENCY MANAGEMENT AGENCY				
Disaster Field Office (FEMA 746-DR-PR)	Stop 27.5, Ponce de Leon Avenue Hato Rey, PR 00919	Puerto Rico only	Disaster relief assistance	Technical assistance, matching grants

SOURCE: H. Diaz-Soltero and B. Oxman, "Organizations Dealing with Renewable Resource Development and Management in Puerto Rico and the U.S. Virgin Islands," OTA commissioned paper, 1986.

Table E-2: Se ected U.S.-Affiliated Caribbean Island Government Agencies

Name	Address	Region Covered	Field of Interest	Type of Activity/Service
COMMONWEALTH OF PUERTO RICO				
Cooperat ve Development Company	PO Box 21364 Rio Piedras, PR 00928	Puerto Rico only	Financial aid to cooperatives	Loans, loan guarantees
Eɑv ronmental Qual ty Board	PO Box 11488 Santurce, PR 00910	Puerto Rico only	Establish environmental policy and monitor compliance	Research, technical assistance
Department of Agriculture				
Central Off ce	PO Box 10163 Santurce, PR 0908	Puerto Rico only	Agricultural development and employment	Grants, loan guarantees, materials, research
Soil Conservation omm ttee of Puerto Rico	PO Box 10163 Santurce, PR 00908	Puerto Rico only	So l conservat on	Technica ass stance, grants
Agricultural Development Administration	PO Box 9200 Santurce, PR 00908	Puerto Rico only	Economic incentives for agricultural development	Projects, economic support
Sugar Board o Puerto Rico	PO Box 8727 Santurce, PR 009 0	Puerto Rico only	Sugar ndustry	Technical assistance, in-kind services
pa men ou				
Central Office (including areas of Flood Control, Planning, Resource Administration, Research, Ranger Corps)	PO Box 5887 San Juan, PR 0906	Puerto Rico only	Balanced management and development of natural resources	Agency operations, in-kind services
Coasta Zone Management Off ce	PO Box 5887 San Juan, PR 00906	Puerto Rico only	Conservation and management of coastal resources	Grants, research, technical assistance
Corp. for the Development of the Marine, Lacustrine and Fluvial Resources	PO Box 2629 San Juan, PR	Puerto Rico only	Promote fisheries and aquaculture	Grants, materials, technical assistance
Corporation for Development of Marine Resources (CODREMAR)	PO Box 3556 Mayaguez, PR 00709	Puerto Rico only	Assess fisheries resources	Research, projects, technical assistance
Culebra Conservation and Development Authority	PO Box 217 Culebra, PR 00645	Puerto Rico only	Conservation of natural resources of Culebra Is and	Projects, in-kind services
Farm Credit Corp of PR	PO Box 424 Hato Rey, PR 00919	Puerto R co only	Agr cultura	Loans, loan

Table E 2 continued: Se ected U.S.-Affi iated Caribbean Island Government Agenc es

Name	Address	Region Covered	Field of Interest	Type of Activity/Service
Government Development Bank for Puerto Rico				
Central Of ice	PO Box 42001 Santurce, PR 00940	Puerto Rico only	Finances projects in the publ c interest	Project development, loans, loan guarantees
Puerto Rico Development Fund	PO Box 42001 Santurce, PR 00940	Puerto Rico only	Economic development loans	Loans, loan guarantees, limited equity investment
PR Industrial, Medical and Environmental Pollution Contro Facilities Financing Authority	PO Box 42001 Santurce, PR 00940	Puerto R co only	Special financing for pollution control	Not stated
Land Authority of Puerto Rico	PO Box 9745 Santurce, PR 00908	Puerto Rico only	Agricultural programs and real estate	Agency operations, materials
Puerto Rico Aqueduct and Sewer Authority	PO Box 7066 Santurce, PR 00916	Puerto Rico only	Provide potable water and sewer services	Agency operat ons
PR E ectr c Power Authority rrigation Services Division	GPO Box 4267 San Juan, PR 00936	Puerto Rico only	Provide water for irrigat on	Agency operations
Puerto Rico Land Administration	GPO Box 3767 San Juan, PR 00936	Puerto Rico only	Create land reserve for public development and urban expansion	Special projects, in-kind services
Puerto Rico Planning Board	PO Box 41119 Santurce, PR	Puerto Rico only	Development policy, public investment	Research, technica assistance
Regulation and Perm ts Administration	PO Box 41179 Santurce, PR 00940	Puerto Rico only	Implement planning and monitor development	Technical assistance
Rural Development Corporation of Puerto Rico	PO Box 9100 Santurce, PR	Puerto Rico only	Administer Title VI family farms	Agency operations, projects
So id Waste Management Author ty	PO Box 40285 Santurce, PR 00940	Puerto Rico only	Solid waste process ng facilities	Agency operat ons
Sugar Corporat on of Puerto co	PO Box 9477 Santurce, PR	Puerto Rico only	Operate sugar mi and refinery	Agency operations, projects, loans
Tourism Company of Puerto R co	PO Box 4435 San Juan, PR 00901	Puerto Rico only	Tourism development policies and programs	Research, technical assistance, projects

able = z continued: Selected U.S.-Affiliated Car bbean s and Government Agencies

Name	Address	Region Covered	Field of Interest	Type of Activity/Service
TERRITORY OF THE VIRGIN ISLANDS OF THE UNITED STATES				
Coastal Zone Commission	Chalotte Amalie St. Thomas, USVI 00801	USVI only	Coastal zone use	Coastal zone regulations, issue major coastal zone permits
Department of Agriculture	PO Box U, Kingshi St. Croix, USVI 00850	USVI only	Agricultural services	Technical assistance, grants
Department of Conservation and Cultural Affairs				
Divison of Coastal Zone Management	PO Box 4399 Charlotte Amalie St. Thomas, USVI	USVI only	Protection and management of coastal zone	Research, technical assistance
Division of Natura Resource Management	Charlotte Amalie St. Thomas, USVI	USVI only	Development and management of natural resources	Agency operations, in-kind services
Bureau of F sh & W dlife	Estate Nazareth 11 Red Hook St. Thomas, USVI 00802	USVI only	Research and surveys of fish and wildlife	Research, technical assistance
D vision of Parks nd Recreation	Charlotte Amalie St. Thomas, USVI 0080	USVI only	Management of protected areas	Development and management of parks and recreational facilit es
VI Planning Office	PO Box 2606 Charlotte Amalie St. Thomas, USVI 00801	USVI only	Economic de pme planning	Mapping, information dissemination

SOURCE: H. Diaz-Soltero and B. Oxman, "Organizations Dealing with Renewable Resource Development and Management in Puerto Rico and the U.S. Virgin Islands," OTA commissioned paper, 1986.

Table E-3: Selected Academic Institutions in the U.S.-Aff ated Caribbean

Name	Address	Area Covered	Field of Interest	Type of Activity/Service
UNIVERSITY OF PUERTO RICO				
Agricultural Experiment Stat on	GPO Box 21360 San Juan, PR 00936	Puerto Rico only	Research on soils, crops, livestock, fisheries	Agency operations, technical advice
Botanical Garden	GPO Box 4984 San Juan, PR 00936	Puerto Rico only	Passive recreation, education	Agency operations, research, technical assistance
Center for Energy and Environmental Research (CEER)	GPO Box 3682 San Juan, PR 00936	Caribbean reg on, world-wide	Research into energy and environmental matters	Research, technical assistance
Marine Sciences and Advisory Service	University Station Mayaguez, PR 00708	Puerto R co	Marine sciences, oceanography	Research, scholarships, grants, technical advice
COLLEGE OF THE VIRGIN ISLANDS				
Caribbean Research Institute	CVI, St. Thomas USVI 00802	Car bbean region	Applied research in physical & socia sciences	Research, technical assistance
Water Resources Research Center	CVI, St. Thomas USVI 00802	Car bbean region	Appl ed research	Research
Cooperative Extension Service	CVI, PO Box L, Kingshill, St. Croix USVI 00850	Virgin Is ands only	Education and outreach on flora, fauna, environment	echnical ass stance
Marine Advisory Service	CVI, St. Thomas USVI 00802	[illegible] s ands only	resources	Research, technical assistance
Virgin Islands Ecological Research Station (VIERS)	PO Box 429, Cruz Bay St. John USVI 00830	Wor d-wide	Ecology of tropical systems	Research, technical assistance
WEST INDIES LABORATORY	Fairleigh Dickinson Univers ty PO Box 4010, Teague Bay Christiansted, St Croix USVI 00820	Caribbean reg on	Marine resources	Research, education, technical assistance

SOURCE: H. Diaz-Soltero and B. Oxman, "Organizations Dealing with Renewable Resource Development and Management in Puerto Rico and the U.S. Virgin Islands," OTA commissioned paper, 1986.

Table E-4: Selected Local Non-Governmental Organizations in the U.S.-Affiliated Caribbean

Name	Address	Region Covered	Field of Interest	Type of Activity/Service
PUERTO RICO				
Agricultural Developme Federation of PR	Rural Box 81', Carite Guayama, PR 00654	Puerto Rico only	Promote alternative agricultural development and employment	Research, loans, in-kind services, technical advice
Agro-Commercial Cooperative of PR	PO Box 331 San Juan, PR 00902	Puerto Rico only	Aid former tobacco farmers to find alternative jobs	Technical advice, loans, materials
Borinquen Audubon Society	306 Darlington Bldg. Rio Piedras, PR 00925	Puerto Rico only	Protect flora and fauna	Technical assistance
Chamber of Commerce of Puerto Rico	PO Box 3789 San Juan, PR 00904	Puerto Rico only	Promote economic development	Technical assistance, in-kind services
Conservation Trust of Puerto Rico	PO Box 4747 San Juan, PR 00905	Puerto Rico only	Land acquisition for preservation	Public education, projects
Cooperative League of Puerto Rico	GPO Box 707 San Juan, PR 00936	Puerto Rico only	Education	Technical assistance
Dairy Industry Development Fund	GPO Box 454 San Juan, PR 00936	Puerto Rico only	Promote sale of dairy products	Technical assistance, in-kind services
Farm Credit Banks of Baltimore	GPO Box 2856 San Juan, PR 00936	Puerto Rico only	Credit for farmers	Development projects, direct loans
Federal Land Bank Association of San	GPO Box 3649 San Juan, PR 00936	Puerto Rico only	Credit for farmers	Loans, project implementation
Future Farmers of America -- Puerto Rico Association	PO Box 759 Hato Rey, PR 00919	Puerto Rico only	Promote youth interest in agriculture	Projects, technical assistance, loans
Garden Club of Puerto Rico	GPO Box 88 San Juan, PR 00936	Puerto Rico only	Urban beautification, protection of trees, plants	Projects, scholarships
Horticultural Society of Puerto Rico	GPO Box 4104 San Juan, PR 00936	Puerto Rico only	Promote horticulture	Projects, technical assistance
Humane Society of Puerto Rico	PO Box 7242 Ponce, PR 00732	Puerto Rico only	Humane education, animal protection	Projects, technical assistance
Industrias Avicolas de Puerto Rico	PO Box 229 Coamo, PR 00640	Puerto Rico only	Commercial poultry processing	Projects

Table E-4 continued: Se ected Loca Non-Governmenta Organizations in the U.S.-Af i iated Caribbean

Name	Address	Region Covered	Field of Interest	Type of Activity/Service
Natural History Society of Puerto Rico	GPO Box 1036 San Juan, PR 00936	Puerto Rico only	Explorat on, natura history, education	Research, projects, technical assistance
Puerto R co Farm Bureau	Ponce de Leon 1605 Santurce, PR 00909	Puerto R co only	Promote agriculture	Technical assistance
Puerto R co Green Thumb	PO Box 41231 Santurce, PR 09	Puerto R co only	Training elderly persons in employable skills	Projects
Puerto Rico Improvement Fund -- "Fondo de Mejoramiento"	GPO Box 4740 San Juan, PR 00936	Puerto R co only	Promote human and environmental betterment	Research, technical assistance, projects
Puerto Rico Manufacturers Association	PO Box 2410 Hato Rey, PR 00919	Puerto Rico only	Promote trade and services	Projects, technical assistance
Puerto Rico Product on Credit Association	GPO Box 3649 San Juan, PR 00936	Puerto Rico only	Credit for farmers	Projects, loans
Puerto Rico Products Association	GPO Box 3631 San Juan, PR 00936	Puerto Rico only	Management service for minority entrepreneurs	Technical ass stance, consulting
To-Ricos, Inc.	PO Box 646 Aibonito, PR 00609	Puerto Rico only	Poultry raising and process ng	Research, techn cal assistance
Tropic Ventures	PO Box 231 San Juan, PR 090	Puerto Rico only	Beneficial use of tropical forests without ecological damage	Research, grants, joint ventures, technical assistance
U.S. VIRGIN ISLANDS				
Virgin Islands Conservation Society	PO Box 12379 St. Thomas, USV 080	Virgin slands only	Educational programs, direct legal action to promote conservation	In-kind serv ces
Virgin Islands Resource Management Cooperative	Red Hook Box 33 St. Thomas, USV 080	Virgin Islands	Resource management strategies, research, and education	Resource inventories, ecosystem monitoring, technical assistance

SOURCE: H. Diaz-Soltero and B. Oxman, "Organizations Dealing with Renewable Resource Development and Management in Puerto Rico and the U.S. Virgin Islands," OTA commissioned paper, 1986.

Table E-5—Selected International and Regional Organizations Operating in the U.S.-Affiliated Caribbean

Name	Address	Region Covered	Field of Interest	Type of Activity/Service
Association of Island Marine Labs of the Caribbean	University of Puerto Rico Mayaguez, PR 00708	Caribbean basin	Marine research and resource management	Research coordination, technical assistance, info. dissemination
American Assoc. for the Advancement of Science -- Caribbean Division	University of Puerto Rico Rio Piedras, PR 00709	Caribbean region	Science and technology	Professional group
Caribbean Conservation Association	Savannah Lodge The Garrison St. Michael, Barbados	Caribbean region	Conservation and development of natural resources. Preservation of cultural heritage	Information dissemination, advisory services, field projects, research, technical assistance, education and training, quarterly journal
Caribbean Food Crops Society•	Address variable, may be contacted through PR or USVI Departments of Agriculture	Caribbean region	Food crop research	Annual meetings, information dissemination, research coordination
Caribbean Institute for Resources Management (CIRM)	GPO Box 3682 San Juan, PR 00936	Caribbean region	Facilitate training and research, develop information base	Research, technical assistance
Eastern Caribbean Natural Areas Management Program (ECNAMP)	West Indies Laboratory, St. Croix, USVI 00820	Caribbean region	Conservation of natural resources and protected areas	Research, technical assistance
Gulf & Caribbean Fisheries Institute	University of Miami 4600 Rickenbacker Causeway Miami, FL 33149	Caribbean region	Research on tropical fisheries	Research, technical assistance
Island Resources Foundation (IRF)	Red Hook Box 33 St. Thomas, USVI	World-wide	Planning, development, and management of island resources	Research, technical assistance

SOURCE: H. Diaz-Soltero and B. Oxman, "Organizations Dealing with Renewable Resource Development and eme in Puerto Rico and the U.S. Virgin Islands," OTA commissioned paper, 1986.

Table E-6: Selected u.S. Government Agencies in the U.S.-Affiliated Pacific

Name	Address	Region Covered	Field of Interest	Type of Activity/Service
ACT1(M				
Micronesia Desk	806 Connecticut Ave., N.W. Washington, DC 20525	Micronesia	Community development	Volunteer technical assistance, demonstration grants and programs
DEPARTMENT OF AGRICULTURE				
Agricultural Research Service (ARS)				
District Office	800 Buchanan Street Albany CA 94710	CA, Hawaii	Agricultural research	Management of research programs
Tropical Fruit and Vegetable Research Laboratory	PO BOX 2280 Honolulu, HI 96804	Tropics	Fruit and vegetable research	Research, cooperative programs
Forest Service				
Institute of Pacific Islands Forestry	Southwest Forest and Range Eperiment Station 1151 Punchbowl St., ROOM 323 Honolulu, HI 96813	Pacific region	Forestry research	International forestry, collaborative projects
Soil Conservation Service				
District Office	4316 Kuhio Federal Building Honolulu, HI 96850	Hawaii and Guam	Resource conservation and development, environmental education	Management of regional programs
Guam Office	UOG Station Mangilao, Guam 96913	Guam and CNMI	Soil and water conservation, resource management	Technical assistance, soil survey consultation, support soil and water conservation districts
DEPARTMENT OF COMMERCE				
Economic Development Admin. -- Regional Office	1700 Westlake Avenue North Seattle, WA 98109	American Samoa, Guam, and Western States	Growth of economically distressed areas	Public works, planning and community grants; Loan guarantees, feasibility studies, technical assistance
National Oceanic and Atmospheric Administration (NOAA)				
National Marine Fisheries Service -- Western Pacific Fisheries Management Council	PO BOX 3830 Honolulu, HI 96812	Western Pacific	Manage regional fisheries; habitat conservation	Research, grants, technical assistance

Table E-6 (continued): Selected U.S. Government Agencies in the U.S.-Affiliated Pacific

Name	Address	Region Covered	Field of Interest	Type of Activity/Service
National Oceanic and Atmospheric Administration (continued)				
Office of Ocean and Coastal Resources Management -- Pacific Region	2001 Wisconsin Ave., N.W. Washington, DC 20235	Pacific islands	Coastal resource management	Research, grants, technical assistance
DEPARTMENT OF DEFENSE				
Army Corps of Engineers -- Pacific Ocean Division	Building T-1 Fort Shafter, HI 96855-5440	U.S. Pacific islands	Civil works related to water resources	Agency operations, permits, advice, marine surveys
DEPARTMENT OF THE INTERIOR				
Fish and Wildlife Service -- Pacific Area Office	PO 60X 50167 300 Ala Moana Boulevard Honolulu, HI 96850	Hawaii and Pacific islands	Protect endangered species habitat management	Research, surveys, grants, in-kind services
Office of Territorial and International Affairs	18th and C Streets, NW Washington, DC 20240	All U.S. territories	Promote economic, social, and political development	Representation to Federal Government, grants, technical assistance
Technical Assistance Program -- American Samoa Office	c/o Office of the Governor Territory of American Samoa Pago Pago, American Samoa 96799	American Samoa	Economic development	Technical assistance
Technical Assistance Program -- Guam Office	PDN Building Agana, Guam 96910	Guam	Economic development	Technical assistance
U.S. Geological Survey -- Pacific District Office	PO Box 50166 300 Ala Moans Boulevard Honolulu, HI 96850	Hawaii and Pacific islands	Water resource and minerals management, cartography, planning systems	Research, mapping, technical assistance, information dissemination
DEPARTMENT OF STATE				
Man and the Biosphere Program -- Pacific Directorate	OES/ENR/MAB, SA-9, Suite 506 U.S. Department of State Washington, DC 20520	Pacific region	Resource management and development; habitat and species conservation	Inactive
Office of Pacific Island Affairs	2201 C St., NW, Room 5210 Washington, DC 20520	Pacific basin	Foreign policy development and management	Guide diplomatic establishments; direct, coordinate and supervise interagency matters in the region

Table E-6 (continued): Selected U.S. Government Agencies in the U.S.-Affiliated Pacific

Name	Address	Region Covered	Field of Interest	Type of Activity/Service
ENVIRONMENTAL PROTECTION AGENCY				
Office of Territorial Programs Region 9	215 Fremont Street San Francisco, CA 94105	U.S. affiliated Pacific	Managing EPA programs	Consolidated program grant management; wastewater facility construction grants; direct regulatory activities; technical assistance
SMALL BUSINESS ADMINISTRATION				
Honolulu District Office	PO Box 50207 Honolulu, HI 68	Hawaii, Pacific territories	Small business development	Business development and disaster assistance loans, technical and program assistance
Guam Office	Room 508 238 O'Hara Street Agana, Guam 96910	Guam	Small business development	Loans to businesses, loans and assistance to programs assisting small businesses

SOURCE: Compiled from responses to an OTA questionnaire, interviews and correspondence.

able ≤ 7: Selected U.S. Affi ated Pac fic Island Government Agencies

Name	Address	Area Covered	Field of Interest	Type of Activity/Service
Pacific Basin Development Counc	567 S. King Street Honolulu, HI 98613	American Samoa, Guam, Hawaii, CNMI	Regional economic development	Applied research, education, materials, in-kind services
AMER CAN SAMOA				
Department of Agr culture	Pago Pago American Samoa 96799	me Samoa	Agr cultura pme	(see note)
Office of Wildlife and Marine Resources	Pago Pago American Samoa 96799	American Samoa	Habitat and spec es management	(see note)
COMMONWEALTH OF THE NORTHERN MARIANA ISLANDS				
Department of Natural Resources				
Division of Agriculture	Saipan CNMI 96950	CNMI	Agricultural development	(see note)
Division of Fish & Wildlife	Saipan CNMI 96950	CNMI	Habitat and species management	(see note)
Division of Marine Resources	Saipan CNMI 96950	CNMI	Marine resources development and management	(see note)
Soil and Water Conservation Districts	c/o Office of the Governor Dept. of Natural Resources Saipan, CM 96950	(1) Saipan & North Is. (2) Tinian and Agu gan (3) Luta	Soil and water conservation and resource management	Assistance to land users in conservation planning and practical application
Coastal Resources Management Program	Office of the Governor Saipan, CMNI 96950	CNMI	Coastal resource management, environmental education	(see note)
FEDERATED STATES OF MICRONESIA[1]				
Department of Agr culture	PO Box Kolonia, Pohnpei FSM 96941	FSM	Development of agricultural food crops	Research, extension, quarantine enforcement, advice to State Depts of Agriculture
Department of Planning and Statistics	PO Box Kolonia, Pohnpei FSM 96941	FSM	Social, economic and resource planning and analysis, informat on dissemination	(see note)
Department of Resources and Development	PO Box 490 Kolonia, Pohnpe FSM 96941	FSM	Economic deve opment, management of natural resources	Information dissemination, grants, enforcement, materials, advice to and coordination of State Depts of Natural Resources

Table E-7 continued: Selected U.S.-Affi iated Pac f c Island Government Agenc es

Name	Address	Area Covered	Field of Interest	Type of Activity/Service
Federated States of Micronesia (continued)				
Marine Resources Division	PO Box B Kolonia, Pohnpei FSM 96941	SM	Fisheries management, economic development, conservation law enforcement	Applied research, educat on grants, extension, in-kind services
Micronesian Mar time Authority	PO Box D Kolonia, Pohnpei FSM 96941	Pacific basin	Marine resource development and management	see note)
GUAM				
Department of Agriculture	PO Box 2950 Agana, Guam 96910	Guam	Resource development and management and conservation of	
Division of Aquatic nd Wildlife Resources	PO Box 23367 GMF, Guam 96921	Guam	Habitat and spec es conservation	Applied research, information dissemination, enforcement
Agriculture Experiment Station	Mangilao, Guam 96923	Pacific basin	Agriculture and aquaculture	Applied research, education extension
Soil and Water Conservation D stricts	c/o Governor of Guam Department of Agriculture Agana, Guam 96910	Guam	Soi and water conservation and resource ma eme	Assistance to land users in conservation planning and implementation
pa men omme	590 South Marine Drive Tamuning, Guam 96911	Guam	Economic development	
Coastal Zone eme Program	Agana, 96910	Guam	Coastal resource development and management	see note)
Economic Development Authority	Agana, 96910	Guam	Public works and private sector development	see note)
Environmenta Protect on Agency	PO Box 2999 Agana, Guam 96910	Guam	Monitoring and conservation of natural resources	Program development, regulation, resource monitoring, enforcement
REPUBLIC OF THE MA HA L ISLANDS				
Ministry of Resources and Development	Majuro RMI 96960	Marshal Islands	Resource conservat on and development	(see note
Office of Planning and Statistics	Majuro, RMI 96960	Marshal Islands	Development planning	(see note)

Table E-7 continued: Selected U.S.-Affiliated Pacific Island Government Agencies

Name	Address	Area Covered	Field of Interest	Type of Activity/Service
REPUBLIC OF PALAU				
Ministry of National Resources				
Bureau of Commerce	PO Box 100 Koror, Palau 96940	Palau	Economic development, labor and employment	Coordination, enforcement
Division of Agriculture	PO Box 100 Koror, Palau 96940	Palau	Agricultural development	Research, extension, technical assistance
Division of Marine Resources	PO Box 100 Koror, Palau 96940	Palau	Development, management, and conservation of natural resources	Applied research, extension, in-kind services
Micronesian Mariculture Demonstration Center	PO Box 359 Koror, Palau 96940	Micronesia	Aquaculture and species restocking	Research, demonstration, and supply of breeding stock

NOTE: At the time of printing, information on the activities of these offices was not available to OTA. Readers interested in these organizations should contact them directly.

[1]In addition to central FSM Offices, the States of Kosrae, Pohnpei, Truk and Yap have individual departments or divisions of agriculture, marine resources, natural resources, planning, economic development, etc. that conduct planning and research and provide technical assistance.

SOURCE: Compiled from responses to an OTA questionnaire, interviews and correspondence.

Table E-8: Selected Academic Institutions in the U.S.-Affiliated Pacific

Name	Address	Area Covered	Field of Interest	Type of Activity/Service
American Samoa Community College	Pago Pago, American Samoa 96799	American Samoa	General and vocational education	Research, education, extension grants
College of Micronesia	Kolonia, Pohnpei FSM 96941	Micronesia	General and vocational education	Research, education, extension grants
Guam Community College	PO Box 2950 Agana, Guam 96910	Guam	General and vocational education	Education, extension, grants
Micronesian Seminar	PO Box 250 Moen, Truk FSM 96942	a	Social and historical sciences	Education, in-kind services, materials
Northern Marianas Community College	PO Box 1250 Saipan, CNMI 96950	Northern Marianas	General and agricultural education	Research, extension, technical assistance
Ponape Agriculture and Trade School (PATS)	PO Box 39 Pohnpei, FSM 9694	Micronesia	Agricultural and vocational education	Education, applied research extension
University of Guam				
College of Agriculture & Life Sciences	UOG Station Mangilao, Guam 96913	Guam	Education in ecology, biology, geography, agriculture	Education
Cooperative Extension Service	UOG Station Mangilao, Guam	Guam	Agricultural development, environmental education	Extension, technical assistance
Micronesian Area Research Center	UOG Station Mangilao, Guam 96913	Micronesia	Social and historical sciences of Micronesia	Research, education, in-kind services, materials
Micronesian Area Tropical Agriculture Database Center	UOG Station Mangilao, Guam 96913	Micronesia	Agriculture, aquaculture, forestry, community dev.	Bibliographic information storage and dissemination
Marine Laboratory	UOG Station Mangilao, Guam 96913	Tropical Pacific	Coral reef biology, marine resource development	Education, research, extension, training
University of Hawaii				
Hawaii Institute of Marine Biology	PO Box 1346, Coconut Island Kaneohe, HI 96744-1346	World wide	Nearshore tropical marine biology, fisheries, aquaculture	Research, education, in-kind services, materials, facilities, vessels
Hawaii Institute of Tropical Agriculture and Human Resources	3050 Maile Way Honolulu, HI 96822	Pacific basin	Agricultural technology	Applied research, grants, extension

Table E-8 (continued)—Selected Academic Institutions in the U.S.-Affiliated Pacific

Name	Address	Area Covered	Field of Interest	Type of Activity/Service
Hawaii Natural Energy Institute	2540 Dole Street Honolulu, HI 96822	Pacific basin	Renewable energy technologies	Research
Pacific Island Studies Program	Moore Hall, Room 216 1801 University Avenue Honolulu, HI 96822	Pacific basin	Island culture, history and development	Education
Sea Grant Extension Service	Marine Science Bldg., Rm 213 1000 Pope Road Honolulu, HI 96822	HI and Pacific islands	Marine resource management, environmental education	technical
University of the South Pacific	PO Box 1168 Suva, Fiji	Pacific Basin	Island culture, history and development	Education, research, extension
Vocational Rehabilitation Center	PO Box 3492 Pago Pago, AS 96799	American Samoa	Vocational training of disabled locals	Education, training, materials, grants

SOURCE: Compiled from responses to an OTA questionnaire, interviews and correspondence.

Table E-9: Selected Local Non-Governmental Organizations in the U.S.-Affiliated Pacific

Name	Address	Area Covered	Field of Interest	Type of Activity/Service
Consortium for Pacific Arts and Cultures	2141C Atherton Road Honolulu, HI 96822	American Samoa, Guam Northern Marianas	Art, handicrafts, cultural heritage	Research, training technical assistance
East/West Center				
Environment and Policy Institute	1777 East-West Road Honolulu, HI 96848	Global	Development of resource planning & assessment techniques	Research, training, technical assistance
Pacific Islands Development Program	1707 East West Road Honolulu, HI 96822	Pacific basin	Island development	Research, training, technical assistance
Guam Fisherman's Cooperative	PO Box 23394 GMF, Guam 9692[illegible]		Fishery development	(see note)
Marianas Audubon Society	PO Box 4425 Agana, Guam 969[illegible]	Guam and Northern Marianas Islands	Conservation of natural resources	Information dissemination
Marshall Islands Community Action Program	Majuro, RMI 96960	Marshall Islands	Community development	(see note)
Palau Community Action Program	Koror, Palau 96940	Palau	Community development	(see note)
Pan-Pacific Community Association	100 Thomas Jefferson St., N.W., Suite 605 Washington DC 20007	Pacific basin	Rural and community development	(see note)
Yap Institute of Natural Science	PO Box 215 Yap, FSM 96943	Micronesia	Biology, natural history, resource management	Research, extension, education, projects

NOTE: At the time of printing information on the activities of these organizations was not available to OTA. Interested readers are suggested to contact them directly.

SOURCE: Compiled from responses to an OTA questionnaire, interviews and correspondence.

Table E-10: Selected nternationa Organizations Operating in the U.S. ^≡f· iated Pacific Is ands

Name	Address	Area Covered	Field of Interest	Type of Activity/Service
Committee for Coordination of Joint Prospecting for Mineral Resources in South Pacific Offshore Areas (CCOP/SOPAC)	Pvt. Mail Bag Suva, Fij	Pacif c basin	Mineral exploration, economic development, environmental protection	Research, education, co-ordination, materials, in-kind services
Commonwealth Science Council	Marlborough House London SW1 5HX	World-wide	Scientific & technological cooperation for development	Applied research, grants, education, extension
International Center for Living Aquatic Resources Management (ICLARM)	MCC PO Box 150' Makati, Manila Philippines	World-wide	Aquaculture, fisheries assessment & management	Research, education, training, projects
ou Pacific Office	PO Box 1531 Townsville QU 4810 Australia	Pacific basin	Aquaculture, fisheries assessment & management	Research, education, training, projects
Foundation for the Peoples of the South Pacific, Inc.	Suite 808 200 West 57th Street New York, NY 10019	Pacific basin	Small business development	Grants, projects, in-kind services
Foundation to Promote Economic, Agricultural and Community Endeavors (PEACE)	40 East 49th Street New York, NY 10017	Paci c basin	Resource and community development	Technical assistance, information dissemination
Oceanic Institute	Makapuu Point Waimanalo, HI 79	Global	Aquaculture	Research
Pacific Fisheries Development Foundation	PO Box 2359 Honolulu, HI 96804	Pacific basin	Fisheries development, economic development	Applied research, grants in-kind services
South Pacific Bureau for Economic Cooperation (SPEC)	GPO Box 856 Suva, Fiji	Pacific basin	Economic and trade development	Education, projects, trade activities
South Pacific Coconut Industry Federation	c/o GPO Box 856 Suva, Fiji	Pacific basin	Coconut palm products	Coordination of research, production, processing anc marketing
South Pacific Commission (SPC)	Post Box D5 Noumea Cedex, New Caledonia	Pacific basin	Economic pme	Education, technical assistance
South Pacific Regional Environmental Programme SPR≤=)	Post Box D5 Noumea Cedex, New Caledonia	Pac f c basin	Environmental protect on, education	Research, grants, materials, education
South Pacific Regional Fisheries Development Programme	UNDP Pvt. Ma l Bag Suva, Fiji	Pacif c basin	F shery deve pme	Applied research, education, extension

Table E-10 continued: Se ected nternat onal Organizations Operating in the U.S.-Affilia ed Pacific Islands

Name	Address	Area Covered	Field of Interest	Type of Activity/Service
UNITED NATIONS				
Economic and Social Commission for Asia and the Pacific (ESCAP)	PO Box 503 Port Vila, Vanuatu	Pac f c basin	Economic and socia development	Technica assistance, training
UNESCO Regional Office for Science and Technology for Southeast Asia (ROSTSEA)	Jl. Thamrin 14 Jakarta, Indonesia	Southeast Asia and Western Pacific	Science nd technology	Research, education, extension, grants, fellowships
Pacific Energy Development Program (UNPEDP)	15 Goodenough St. Private Mail Bag Suva, Fiji	Pacific basin	Energy policy	Education, advisory services, materials, grants
U.N. Development Programme, Integrated Atoll Development Project	UNDP Private Mai Bag Suva, Fiji	Pacific basin	Atoll resource development	Research, technical assistance

SOURCE: Compiled from responses to an OTA questionnaire, interviews and correspondence.

Appendix F
Summary of Regional Workshops

Introduction

Three regional workshops were conducted to collect information from local island resource managers, planners, and educators. A total of 55 persons representing various aspects of terrestrial and marine resources participated in the workshops and are listed at the end of this summary. Interests in sustainable resource use ranged from scientific research, to food and fiber production for enhancement of self-reliance, to developing and sustaining tourism based economies,

Within each workshop participants were divided into three working groups covering agriculture, marine resources, and education and planning. The individual workgroups addressed a list of issues identified by the Assessment Advisory Panel at its initial meeting. Work group participants were charged with identifying the applicability of these issues to the various islands, the extent of resulting problems, efforts attempted to ameliorate problems, and the potential transferability of these efforts to other islands. Participants also identified Federal programs extended to the islands that mitigate or aggravate the situation. Options suggested by workshop participants were not restricted to those pertaining to Congress or U.S. Federal agencies; but include some suitable for local governments, regional or international institutions.

Despite varying degrees of development among island areas, many problems, issues, and opportunities are shared. The workshops provided an opportunity for participants to discuss local issues and share possible solutions. The following is a summary of the major points discussed at the three workshops,

Agriculture and Forestry

Information Availability and Sharing

An effective and readily accessible baseline data/information system is integral to planning, management, and development of island resources. However, baseline data on island resources, and information on potentially suitable agricultural technologies are inadequate or unavailable to many island governments, Baseline data on island resources and information on technologies are well-developed in the U.S.-affiliated Caribbean islands, but systems for delivering technical and marketing information to practitioners and planners need improvement. Effective mechanisms and systems for sharing data/information among international, regional, inter- and intra-island agencies and practitioners are needed in most of the U.S.-affiliated islands,

Factors that hinder development of organized data/information systems in the U.S.-affiliated Pacific islands include: 1) inadequate island infrastructure to support a computerized storage/retrieval system; 2) inability to fund and maintain such a system, 3) a scarcity of on-island experts to interpret technical data, and 4) lack of or inadequate systems for easy access of available baseline data.

Substantial improvement is needed in some information areas (e.g., timely updating of marketing information, increased computerization of information for easy access and manipulation). Increased technology transfer may be accomplished through improving extension services, public education programs, and providing demonstration and pilot projects.

Except for some Freely Associated States (FAS) archives, essentially all baseline resource data for FAS islands are furnished by U.S. Federal agencies, off-island educational institutions, or private organizations. The University of Guam's Micronesia Area Research Center Information System and the Micronesia Area Tropical Agriculture Database Center have effective information storage and retrieval systems, however, development of complementary centers is needed.

suggested Options:

- Establish regional information clearinghouse(s) for acquisition, storage and dissemination of information,
- Increase federal funding and/or technical assistance in data interpretation, dissemination and technology extension.
- Strengthen and broaden the scope and services of the existing local and regional research centers' information systems.
- Develop or improve on-island expertise for data interpretation.

Current Agriculture Technology

Traditional agricultural technologies remain suitable for certain FAS polities, however, these technologies generally are undervalued or ignored by decisionmakers, developers, planners, and donor agencies. Few government agencies are involved in the planning and marketing of traditional crops or in extension of traditional agriculture practices. Hence, little effort is directed toward assessment or improvement of traditional agriculture technologies. Increased consideration of low input, small-scale technology development and implementation is needed. Extension, public education, and demonstration projects may increase public awareness of available alternative technologies.

Semi-commercial, small-scale agriculture is widely practiced in the U.S. Pacific Flag territories, except in American Samoa where subsistence farming predominates. The strong traditional agricultural practices in American Samoa hinder successful introduction and application of commercial agriculture production technologies. Small-scale farming requires sophisticated management and marketing techniques to be competitive.

A strategy of improving traditional agriculture technologies and encouraging transformation of traditional agricultural practices to semi-commercial practices and (ultimately) into commercial farming may hold promise. Reliable markets must be created concurrently to absorb farm produce.

Most introduced commercial agriculture technologies have proven unsuccessful due to various factors. Major constraints to successful application of commercial agriculture technologies include sociocultural (e.g., techniques incompatible with local custom/culture), ecological (e.g., technology unsuitable for island ecology or size), and economic factors (e.g., small intra-island and inter-island markets, fluctuating world markets). Factors such as efficient technology, good management, minimal adverse environmental impacts, and selection of high-value crops are important considerations in agriculture development. Suitable agricultural production technologies that overcome the various ecological, social, and economic constraints of small islands are needed.

Full-time commercial farming employing currently available technologies is considered a high risk activity and uneconomical due to high agricultural production costs. Many enterprises have failed despite government subsidies and support. In the U.S. Caribbean islands, some farmers have either stopped farming or now engage in part-time family farming because of low returns. Consequently, large areas of agricultural lands are left idle, or are used for non-agricultural purposes. A number of farmers in Puerto Rico and the U.S. Virgin Islands (USVI) now are practicing semi-commercial family farming.

High wages, compared to regional averages, and low productivity are the major constraints to agriculture development in US. Caribbean islands. Productivity might be increased by selecting improved technologies and high yield crops. Currently, mechanization and/or intensification of agricultural practices is a preferred method to increase agricultural productivity while low-input technologies commonly are ignored. Although this approach might increase productivity, it may not solve unemployment problems in rural areas.

Viable commercial agriculture is restricted to small-scale operation in the USVI because of the small land area and limited freshwater resources. Some small-scale farming of selected crops (e.g., sun-coffee, herbs and spices, passionfruit, ornamental plants) is profitable in the U.S.-affiliated Caribbean islands. Precise identification of high value markets may improve the profitability of this type of farming.

Selected large-scale commercial agriculture using suitable technologies and management may be economically viable in Puerto Rico under certain conditions. A large-scale drip irrigation farming system designed by Israelis and developed on the semiarid lands of southern Puerto Rico seems potentially economically viable, despite a large initial capital investment and management problems. However, some intensive large-scale farming technologies are not profitable, as evidenced by the failure of the rice project on the northern Puerto Rico coast.

Post-harvest technologies (processing, storage, and transportation) of agriculture products are poorly developed in many of the Pacific islands. Although a number of post-harvest technologies could be applied, they are generally not cost effective. Island institutional capacity to develop and implement suitable technologies is limited.

Application of available processing technologies is constrained by a variety of factors, including the high cost of processing; irregular availability and relatively small quantity of local raw materials; small-sized local markets; distance between processing centers and potential export markets; and poor island infrastructure that make transportation and storage costs prohibitive.

Although simple post-harvest technologies such as sun-drying are practiced, local markets for such products are limited, These products could not com-

[1]U.S. Pacific Flag territories include Guam, the Commonwealth of the Northern Mariana islands and American Samoa.

pete with lower priced items in export markets, and commonly do not meet stringent Federal quality or labeling standards.

In Puerto Rico, post-harvest processing technologies are available and many have been researched and tested. However, as yet, few have been applied commercially. This is due primarily to high labor costs, small markets, and the limited quantity and irregular supply of local raw materials. These factors increase production costs, hence products of the U.S.-affiliated Caribbean islands are not competitive with those produced in countries having either cheap labor costs or more efficient production technologies. In Puerto Rico, products using simple processing technologies, such as plantain chips, supply local markets and have entered some export markets.

Success of commercial export crop development depends not only on appropriate production and post-harvest technologies, but also on accurate market identification and forecasting. Organized marketing information generally is inadequate in the U, S.-affiliated Pacific islands and this problem is exacerbated by lack of island experts to interpret available information. Although marketing information is available from Federal agencies and through the Hawaiian Marketing Information Center, high cost and lack of on-island experts to interpret the information effectively prohibit its use. Further, island government institutions largely are unable to identify and create off-island markets, Mechanisms for effectively obtaining, interpreting, and transferring marketing information to planners are needed.

Suggested Options:

- Local governments should formally recognize the merits of those traditional agricultural technologies which sustain island renewable resources.
- Assess current and potential roles of traditional agriculture in overall economic development, and support research for improving suitable traditional island agriculture technologies.
- Assess small-scale commercial agriculture development for applicability to the U.S.-affiliated islands considering the technological, management, economic, environmental, and social factors,
- Identify island commodities with good market value that can be profitably produced, processed, and transported.
- Market economists should participate in island agricultural development planning.
- Establish a new regional marketing information clearinghouse for U.S. Pacific islands or strengthen and broaden the scope and service of the existing Marketing Information Center in Hawaii,
- Federal agencies could make appropriate marketing information available to island institutions or to a regional depository, and assist in information interpretation.
- Develop on-island expertise in data interpretation.

Education, Training, and Skills

Education, research, training, and extension programs related to island resource bases generally are inadequate and not well coordinated on many islands. Curricula on island resource development and environmental impacts need strengthening at all educational levels on many of the U.S.-affiliated Pacific islands. Consequently, labor skilled in renewable resource management is scarce on many U. S.-affiliated Pacific islands. A lack of public awareness of the importance of resource development issues and concomitant lack of government support for education and training on resource related subjects hinder the development of a cadre of skilled resource managers. Although current programs in the U.S.-affiliated Caribbean islands generally are adequate, further improvement and emphasis is needed to enhance education in environmental issues.

Research on island resource development in the U.S.-affiliated Pacific islands is inadequate and needs coordination. Few research and training opportunities are available and many island governments only can afford to finance research on particular development needs, Research activities are further hindered by lack of experts, funds, and baseline information, Moreover, many research activities are beyond the capacity of some island polities. Results of research projects conducted by island organizations commonly are presented in a format unusable by planners or practitioners,

Suggested Options:

- Provide practical training opportunities in collaboration with other institutions in the Pacific region or with established institutions in Hawaii,
- Support focused and coordinated research projects designed to fulfill island development goals, Encourage and make available experts from Federal agencies and other institutions to assist in research project formulation and execution.

- Develop and provide curricula and educational materials that emphasize island resource related topics at all educational levels.
- Strengthen and improve existing educational programs on the environmental consequences of resource development.

Resource Development Planning

Island institutions have limited capacity to develop integrated resource-use plans. Planners knowledgeable on island developmental issues and resource capability and qualified to develop integrated development plans or to forecast the likely impacts of development are needed in the U.S. Pacific islands. Planning processes are hindered further by fragmentation of governmental jurisdiction over island resources, political interference in planning and implementation of resource use and management, inadequate baseline information, lack of mechanisms to coordinate resource management on islands, and lack of mechanisms to identify appropriate sustainable resource development technologies.

Socio-cultural and political aspects of islands rarely are considered by decisionmakers and off-island planners in resource planning and development, Commercial resource use practices may conflict with customary lifestyles particularly in areas where traditional exchange and sharing obligations and tenure systems are strong. Agriculture development planning for U.S. Caribbean islands similarly is hindered by social, technological and economic characteristics unique to these islands.

Much research undertaken on the islands is not designed to fulfill the information needs of local planners or practitioners, and commonly is not presented in a format suitable for local needs. Development is complicated by Federal regulatory compliance requirements, and by the inability of most U, S.-educated planners and decisionmakers to adapt their skills to local conditions.

Private sector involvement in commercial development of island resources is rare. An increased number of private entrepreneurs (on or off-island) are needed in the commercial agriculture sector. Private (especially off-island) participation in commercial agriculture development on these islands is constrained by factors such as complex land-tenure systems, inability to acquire ownership of lands, islanders' attitudes toward commercialization, relatively high wages compared with labor productivity, limited markets, and great distances between islands and large markets.

Even though large-scale farming may be attractive to those off-island investors who are willing to bear higher risks, constraints for such undertakings are severe on small islands. Smallholder farming systems, on the other hand, may be more likely to succeed, thus yielding increased socio-cultural, ecological, and economic benefits.

Although financial incentives for private sector involvement in commercial resource base development exist in the U.S.-affiliated Pacific Flag territories, many island social and cultural practices, and decisions driven solely by political considerations can negate the effectiveness of these incentives.

Government agencies in the U.S. Caribbean islands have the capacity to formulate integrated resource-use plans. However, political goals commonly overshadow island resource-use management and development plans. Politically motivated decisionmaking results in uncoordinated resource planning and development and, consequently, in resource-use conflicts and mismanagement. Proponents of resource development plans generally have little influence or political clout in the decisionmaking process.

While incentive schemes may have beneficial effects, indiscrimate cash subsidies may lead to uneven local development. Incentive schemes that have immediate cash benefits are attractive for private investors, yet certain management programs that have no immediate and visible cash benefits (e.g. erosion control) may have long term benefits which may not be readily appreciated by practitioners or decisionmakers. Complex formulae and application procedures for obtaining subsidies may constrain the average farmer from applying.

Tax incentives or land leases for overseas investors may be an effective way to stimulate development of the private sector. Development financed by foreign investors also may transmit considerable indirect benefits to the island economies.

Suggested Options:

- Local governments should hire qualified consultants to assist in resource development planning, and increase coordination of agencies now overseeing island resource management and development.
- Coordinate integrated development planning and improve island resource information management capabilities.
- Develop on-island expertise in integrated development planning.
- Provide regular training and education to development planners, resource managers, and

practitioners on island resource use and management technologies.

- Develop public awareness programs and supply training programs on integrated resource management for decisionmakers.
- Include social scientists in development planning and decisionmaking processes to assure that views of traditional island leaders are incorporated.
- Encourage the U.S. private sector to develop and implement technologies that not only sustain island renewable resources, but also are compatible with the islanders' social setting.
- Institute incentives that are conducive to off-island investors.
- Encourage private sector involvement in commercial development of resources through attractive incentives.
- Institute a flexible and simple incentive scheme designed to meet the needs of local practitioners and incorporate tight control and management of these programs.
- Simplify assistance program application procedures and provide assistance to farmers in form completion.

Marine Resources

Information Availability and Sharing

Knowledge of tropical marine ecosystems and current baseline information on marine species is inadequate for sustainable island marine resource development and management in the FAS polities; biological inventories, evaluation, and monitoring of marine resources are needed. Absence of baseline data makes identification of suitable resource management technologies difficult. Local universities address mostly basic biological questions and local marine divisions conduct little applied research on production-oriented issues. Immediate demands on limited personnel and funds hinder investigation of new and/or more appropriate technologies for specific island areas and resources.

Competition and isolation hinder access to information in the FAS, Local fishermen are hesitant to share catch data, sites, and methods with expatriates and local island resource managers for fear of increased fishing competition at preferred fishing sites. Many also have a general distrust of governments, Local markets could serve as information collecting points but owners also are uncooperative, Much U.S. government information is inappropriate for tropical islands, and existing information is difficult to obtain. Information from regional organizations is useful but takes months to receive. Outside consultants commonly do not share their findings with local resource users.

Considerable resource information exists in the Pacific Flag territories, but it is not readily accessible and is not presented in a way useful to local governments or resource managers. Data commonly are collected only on selected aspects of marine resources and resource uses (e.g., data from Hawaii is collected primarily to determine maximum sustainable yields and U.S. National Marine Fisheries Service information is primarily focused on offshore fisheries), and data collection is not designed for management purposes. Catch data (species, sizes, and numbers) and nearshore ecosystem carrying capacity information are particularly inadequate for sustainable resource management.

National fishery databases exist in the Pacific Flag Territories, but no system integrates the information into a regional database. National and international fisheries management is hindered by lack of a regional information system. Examples include the WESTPACFIN database developed by the Western Pacific Fishery Management Council at the University of Hawaii and the database Resource Assessment Marianas Archipelago database, which contains primarily maximum sustained yield information.

Overall, information on the nearshore marine resources of the U.S.-affiliated Caribbean islands is adequate, but knowledge of pelagic fisheries is insufficient for sustainable management. Management plans often are based on short-term goals and in some instances rely on data from temperate regions. (e.g., maximum sustained yield estimates for pelagic fishery management plans are based on temperate fisheries data). Current government efforts focus on developing artisanal fisheries, but local interest exists in developing pelagic fisheries,

Data on weights and size are available, but life history data on economically-important species is needed for development of appropriate resource management plans. Puerto Rico's Corporation for the Development of Marine Resources (CODREMAR) collects fisheries statistics but they are not used in management plans and programs. Fisheries management research, although primarily focused on groupers, has initiated new mesh-size standards which have been applied to all species and islands.

Although local information systems exist (Sea Grant, CODREMAR, Caribbean Fisheries Management Council, and the USVI Fish and Wildlife Service), lack of inter- and intra-agency coordination inhibits dissemination and thus affects local decision-making capabilities. Commonly, data are research oriented instead of application oriented.

Local governments in all of the U.S.-affiliated islands need improved methods for identifying and disseminating information to practitioners. CODREMAR currently is developing programs to extend information directly to the fishermen but implementation is hindered by lack of funds.

Suggested Options:

- Increase funding and personnel for fish-tagging and statistics-gathering programs to include local fish markets, boats and docks, and island governments as well as commercial United States and Japanese sources.
- Collect catch information from American Samoan tuna canneries to improve monitoring of pelagic fish harvest. Legislation or incentives may be needed to overcome their reluctance to share such information,
- Study effects of closed seasons on fish populations.
- Create incentives for village representatives to monitor marine species.
- Increased research on life history data and recommendations on appropriate mesh size restrictions specific to Caribbean fisheries could be carried out by such agencies as the Caribbean Fisheries Management Council,
- Increase the monitoring components of the environmental impact assessment process,
- Local resource organizations could organize informal interviews and workshops for resource managers and local practitioners to promote communication and to collect and disseminate information on local resources and resource uses.
- Designate a person or create a program within marine divisions to screen potential fisheries technologies developed or used in other island areas.
- Develop computerized information management systems to facilitate data collection, monitoring and information dissemination.
- Create information exchanges mechanisms among the Pacific Fisheries Development Foundation, the Pacific Islands Development Program, the Pacific Basin Development Council, and the Aquiculture Development Program, all of which are based in Hawaii.
- Develop inter- and intra-agency information systems coordination with greater emphasis on dissemination of information and exchange with the public sector.
- Develop a network of information sources to include universities, government agencies, and private organizations.
- Develop an information management system accessible to both islanders and outside experts incorporating both written and computer-oriented information.
- Standardize existing databases to facilitate exchange of information and allow regional fisheries management.
- Develop a centralized regional database and disseminate information and analyses to contributors.

Current Marine Resource Development and Management Technologies

Current fishery technologies in the FAS are designed for short-term harvesting goals and not as sustainable systems. Fish aggregating devices are being instituted widely to increase fish catch per unit of effort and island organizations are testing different designs through pilot projects. Concerns have increased, however, over potential adverse impacts of increased fishing activity.

Exploitation of pelagic and of reef fishes require different technologies. Significant differences in scale and in fishing ability exist among certain island groups. For example, small boats may be suitable in Truk because most fishing is within a large, protected lagoon. Pohnpei, Kosrae and Yap, however, are isolated high islands without large lagoonal fishing areas, and the Marshalls are dispersed widely and require fishing boats that are suitable for long-distance travel.

In the U.S. Caribbean islands, there is concern that nearshore fish populations are declining because currently available exploitation technologies restrict harvesting to the continental shelf, Current technologies have promoted harvesting at or above maximum yield within the narrow continental shelf where potentials are limited.

Management schemes have been employed in St. Johns Park, VI which demonstrate the positive effects of protected nearshore areas on fish populations, Similarly, fish populations increased with the closing of Vieques, Puerto Rico waters to fishermen,

Suggested Options:

- Develop new projects and technology based on the comparative advantages of different island environments. Expand feasibility analysis of potential projects (e.g., vertical mariculture in Truk Lagoon, giant clam culture in Kosrae).
- Increase training and technology transfer from

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mariculture institutions such as the Micronesia Mariculture Demonstration Center in Palau and the International Center for Living Aquatic Resources Management in the Philippines.
- Devote more land grant funding to development of aquiculture programs.
- Redirect fishermen to exploitation of pelagic stocks to relieve pressure on nearshore stocks.
- Zone areas for fishing, recreation, and protected areas.

Storage, processing, and transport systems are inadequate in the FAS, largely restricting resource development to subsistence and small commercial scales. Poor storage and transport facilities and variable catches currently inhibit full-time fishing efforts and, thus, the development of local and outside markets. Expansion of the fisheries industry into new markets cannot be considered until extension programs develop local expertise in marine product processing, storage facilities are made available, and transportation is assured.

Similarly, storage and transport technologies are poorly developed in the Pacific Flag territories. Export of marine products between islands and to off-island markets is constrained by high airline cargo costs and shipping times. Lack of funds hinders development of processing and storage facilities, although some progress has been made. Increased frequency and improved reliability of cargo transportation services could significantly expand markets.

In the U.S.-affiliated Caribbean islands, lack of infrastructure creates storage and transfer problems; refrigeration, processing, and transport technologies need improvement. Because the whole fish is demanded in local markets,[2] processing does not pose a problem, however, what is not sold commonly cannot be stored or refrigerated. Facilities are not available for processing or storing excess catch which constrains development of pelagic fisheries. Potential mechanisms to overcome these constraints are being considered by CODREMAR, including establishment of a fishmeal processing plant to make use of fish by-products, and a public education program on fish processing, home storage, and use.

Suggested Options:
- Encourage training and technology transfer from private sector entrepreneurs operating enterprises in the island areas to those interested people lacking such skills.
- Investigate on-board freezing technologies suitable for container ships for islands able to undertake large-scale fishing.
- Investigate joint-venture opportunities to facilitate development of post-harvest facilities.
- Develop storage facilities and increase frequency of pick-up from outer islands,
- Investigate the potential for reducing cargo charges for marine products on local airlines.
- Encourage development of small frozen-product processing enterprises.
- Increase processing technology transfer from Hawaii,
- Increase storage capacity on outer islands to allow larger harvests.

Education, Labor and Skills

Traditional resource use methods may be the most appropriate for fostering development of certain resources in the FAS polities. A need exists to identify special local knowledge and to incorporate this with further development of local technical skills, Local knowledge also plays a role in maintaining island traditions and cultural identity. Sea Grant and the Historic Preservation Program, for example, are Federal programs which have been active in recognizing traditional skills.

Assistance to the islands should be redirected from increasing island government bureaucracies to developing technical expertise for island practitioners. Sea Grant can be an effective education organization, but it commonly focuses on recreational and environmental education and not on development of exploitation or management skills, Outside assistance is needed to develop island management skills.

Little traditional knowledge remains in some of the Pacific Flag territories, but it should be considered in conservation technology implementation activities. Local technical training is needed for all aspects of marine resources development including: project planning, start-up, operation, and maintenance. Business management skills need further development. Development and implementation of new technologies is hindered by lack of education in needed fields.

In the U.S. Caribbean islands, traditional knowledge and cultural characteristics need to be given higher priority in recruiting resource managers and practitioners. Little credit is given to local people possessing traditional knowledge of resource exploitation and management technologies. In St. Thomas, for example, resource skills are disappearing as most employment is found in tourism. This

[2] Fear of ciguatera poisoning has initiated a trust between customers and individual fishermen.

is due, in part, to an economic development emphasis on capital-intensive technologies in all sectors. The importance of personalities and cultural differences between groups are underestimated in project feasibility considerations.

A better understanding of island ecology by the public, and improved exchange of knowledge between groups is needed in the U.S.-affiliated Caribbean islands. The major goals of public education should be to expand and influence consumer markets and to develop an appreciation of local ecology and resources. Emphasis should be placed on informal education techniques, such as is provided by the park naturalist/guides that are being trained in the USVI.

Pressure to meet U.S. mainland standards in formal education programs hinders creativity and discourages activities focusing on island ecosystems and cultures, Text books currently in use are developed for mainland classes. Some teachers are initiating field activities but they are receiving little support. The Sea Grant program has programs to train teachers in the field, but these have suffered under recent budget cuts.

Suggested Options:

- Recognize value of traditional methods of resource use and management.
- Develop island ecology curricula and materials for primary and secondary schools.
- Encourage school systems to support innovative island-oriented economic development and ecology education activities.
- Use community college programs to enhance local skills.
- Offer classes in higher learning institutions that are directed to management of resource-related enterprises.
- Develop education programs in local schools that encourage information exchange with government resource managers and incorporate traditional values and practices with new technology development.
- Use volunteers and students for short-term assistance rather than consultants.
- Sponsor "fish festivals" oriented towards creating markets for resources and teaching understanding of local ecology.

Extension, Marketing, and Incentives

Changing social values and island economic structures make extension difficult in the U. S.-affiliated Pacific islands. Conflicts between communal and individual interests hinder extension services effectiveness, especially in American Samoa. The Pacific Fisheries Development Foundation is fostering the development of fishery cooperatives in part to increase transfer of information and technology to practitioners. However, cooperative management systems in the U.S. Pacific have historically failed due to mismanagement and irregular cash flows.

Extension programs in the U.S. Caribbean islands are helping planners to identify resource opportunities through increasing contact between fishermen and representatives of government agencies. However, these programs need to consider both formal and informal information channels, and variability of technologies needed for different ecosystems, as well as increase their emphasis on the technological aspects of small-scale fisheries.

Organizational structures for development of small-scale fisheries exist, but they are underused. Only one of the 17 government-subsidized fishing cooperatives in Puerto Rico is self-managing, and it alone is considered successful. Key people in managerial roles are important. Formal organizations may interfere with marketing links between fishermen and customers.

There are informal marine extension agents and training programs for island managers, but more technical assistance is needed to extend fisheries and aquiculture technologies. The U.S. Soil Conservation Service (USSCS) gives advice on pond irrigation technologies, yet this does not incorporate opportunities for aquiculture in irrigation ponds. CODREMAR is trying to create Fisheries Centers with facilities to store gear and clean and sell fish. It also is providing grants for equipment and giving seminars on small-scale fisheries management.

Suggested Options:

- Develop legislation authorizing the use of local foods in federally funded programs (e.g., school lunch and aid for the aging), to increase markets and to develop local capability to supply nutritional needs in the event of a decline in income subsidies and free food programs.
- Analyze successes and failures of existing joint venture projects to guide development of future agreements, and develop legislation to ensure that an appropriate part of the profits remains within the island areas.
- Expand and improve community college capabilities to teach technical skills.
- Increase media outreach efforts by Sea Grant extension services.
- Encourage appropriate nonprofit organizations to contribute to extension of information and transfer of technologies.

- Increase cooperation between U.S. mainland universities researching warm water aquiculture (e.g., the University of Mississippi) and U.S. Caribbean academic institutions, CODREMAR and Sea Grant services.
- CODREMAR could undertake demonstration aquiculture projects.
- Establish community foundation funds for pilot aquiculture projects and direct extension activities at coastal farmers.

Marketing Information

Current marketing information does not effectively address fisheries catch and consumer demands in the U.S. Pacific Flag territories where demand for fishery products exceeds supply. Because so few fishermen supply local markets, they easily can influence retail prices; surplus catch flooding local markets causes significant price fluctuations. Alternative markets are needed to absorb surplus fresh catch and to stabilize prices, The large military populations on some islands may provide untapped markets for local fresh catch, but they have not been developed because of variability in the quality and quantity of local catch. Market potential also could increase with better air transport services.

Marketing overall needs improvement in the U.S. Caribbean islands. Marketing information is oriented toward commercial and trade associations rather than the fishermen or public. Government marketing strategies need to incorporate new resources and consider both fishermen and consumers as clientele. Government marketing assistance is provided mainly for the manufacturing and service sectors—aimed at promotion of island products in the U.S. market—and little assistance is given to small-scale fishermen in marketing their products locally. Local government agencies are looking for new resources and markets. Tourism development provides a significant opportunity for creation of new markets. Hotel markets currently purchase only certain species of fish; creating tourist demand for native fish could be part of tourism promotion.

Suggested Options:

- Continue to investigate development of cooperatives to coordinate and regulate fish catch to stabilize local markets.
- Develop hotel and military markets to absorb excess products and, thus, to prevent price fluctuations in local markets. This may require special programs and support from upper levels of the military hierarchy.
- Investigate reduction or subsidization of cargo fees for transport of fish products on local airlines.

Incentives

Development of cash economies in the FAS has altered perceptions of acceptable employment and expectations of goods and services. Subsidies and remittances from off-island relatives have created a false sense of security and further disincentive for local conservation. Increased market demand for fresh fish has encouraged small-scale fishing and local marketing efforts, yet full-time fishing is not considered economical or secure compared to government jobs.

Local governments have increased efforts to develop joint venture arrangements. Such projects provide a profit motive and a guaranteed market. Most tuna processing and on-board fish-freezing are examples of joint Micronesian/Japanese ventures.

Politics, limited profits, and government subsidies are major disincentives to fisheries and aquaculture development in the Pacific Flag territories. There are no economic incentives to devise or employ sustainable resource development technologies. Interest in reef fishing is declining because of low and uncertain returns and availability of alternative employment or income (e.g., U.S. social support programs). Minimum wage standards in the Pacific Flag territories translate into high product prices that are not competitive in export markets.

Disincentives for expansion of local fishing opportunities in the U.S. Caribbean islands include: limited funds, monopolistic families, former project failure, and government politics. Individual families have acquired dominance over some fishing areas by virtue of owning larger equipment and discouraging other individuals from expanding their enterprises. Local incentive programs are nonexistent. The U.S. Department of Agriculture (USDA) provides production and conservation incentives for farmers; there is no similar agency for fishermen.

Outside entrepreneurs have eliminated local incentives for aquiculture development. Project viability must be proven before any local entrepreneur will attempt aquiculture. Currently, the perceived risks outweigh economic incentives. Further, most outside investments have been extremely capital- and skill-intensive and, thus, have not demonstrated technologies suitable for local enterprises.

Suggested Options:

- Provide financial help for initial investments, perhaps through Community Development

Block Grants from the Department on Housing and Urban Development (HUD).
- Inland sport fisheries could be developed on St. Croix.
- Encourage hotels to promote local resources through "catch of the day" offerings on menus or weekly local food festivals.
- Provide incentive programs for small-scale fishermen similar to those of USDA directed at farmers.
- Provide low interest loans for aquiculture pond construction (corresponding to the USSCS funds for irrigation ponds).

Planning and Enforcement

Integrated ecosystem management and marine resource development generally are given insufficient priority in island planning and are ignored in long-term management plans in the FAS. Currently, few island people fish full-time. Governments are increasing efforts to change this because of a recogized need to reduce imports and increase employment. Priority ranking in planning and project funding is given to marine resources only during identified crises (e. g., the recent *Acanthaster plancii* "Crown of Thorns" outbreak). Marine resources receive less attention in planning than other development sectors such as tourism or agriculture. No mechanisms to facilitate integrated management exist in the Freely Associated States.

Incompatibility of local tenure systems in the FAS with western development principles and technologies hinders identification of potential resource management techniques. Local marine resource tenure systems are incompatible with western ideas and technology based on free access to marine resources. Leasing does not seem to be an effective alternative to ownership.

Mechanisms to increase local participation and flexibility are needed in the planning process in the FAS, Appropriate planning can help direct effective information acquisition and appropriate use of outside assistance, Individual projects must be specified in development plans in order for them to gain support in budgetary determinations. Federal programs commonly are not flexible enough for application to the islands, therefore, funding for marine resource development will be limited if sources beyond the United States are not considered,

The importance of marine resources to economic development needs wider recognition in planning in the Pacific Flag territories. The potential of marine resource development to create employment and generate income is not recognized and subsistence fisheries are ignored in overall plans. Fisheries managers have little input in the planning process, although plans are becoming more comprehensive (e.g. the plans for Guam included local, Federal, academic, and private interests). There is a need to reconcile short-term activities with long-term goals.

Economic development planning is fragmented among economic sectors, and resource agency plans rarely consider impacts on or from other agency activities. Tourism, in particular, is considered to be overemphasized in planning. Coastal Zone Management programs are trying to to integrate tourism and fishery development. The Western Pacific Fisheries Management Council has developed integrated planning methods. A new data base has been developed to aid in fisheries planning (Western Pacific Fisheries Information Network—WESTPACFIN), but it has not yet been used in the U.S.-affiliated islands.

Politics and limited funds inhibit planning and enforcement capabilities in the Pacific Flag territories. Regulations are rarely appropriate management mechanisms for island areas. Despite regulations to the contrary, many nearshore areas are overfished and subjected to bleaching and dynamiting (primarily by Tongans), The few well-accepted regulations include the laws on harvest of sea turtles and black corals: occasional harvest is acceptable for traditional purposes but not for commercial sale. However, enforcement of these regulations is weak, and both turtles and black corals are being harvested commercially.

Recognizing marine resource ownership as a management mechanism is extremely difficult when traditional boundaries are no longer recognized, and marine resource tenure is often incompatible with western style development. Permitting and zoning programs can help to sustain resources in the long run.

Marine enforcement capability is increasing in the flag territories; some areas are now able to confiscate boats. However, local enforcement authorities generally cannot handle unlicensed fleets. Because of reduction in Coast Guard presence in the islands, there is no enforcement capability over Korean boats poaching along island shorelines and no longer any monitoring of the 20()-mile zone. Village level conservation pressure exists, but commonly enforcement of resource conservation laws is hindered because of extended family relationships between judicial agents and resource users.

Marine resources similarly receive low priority in development planning in the U.S. Caribbean islands due to politics, lack of planning funds, and

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planning focused solely on generating maximum income. Existing fisheries are considered to be developed to capacity in the Virgin Islands. However, Puerto Rico probably could meet the domestic fishery market from their marine resource base. There is a need for more long-term planning which commonly conflicts with short-term goals.

Enforcement of fisheries regulations generally is weak in the U.S. Caribbean islands. One positive example is enforcement of laws prohibiting setting of unmarked (and therefore unlicensed) fishing pots. Informal tenure—perceptions of territories—already exists and makes government enforcement of restricted access difficult. Informal tenure also complicates coastal planning. Formal recognition of marine area ownership would be virtually impossible to implement and might not improve the sustainability of resource exploitation.

Politics and lack of funds hinder effective resource planning and enforcement. Limited funding has further effects on the development of a cadre of skilled resource planners in resource agencies or planning offices. Political changes make implementation of long-term planning difficult: each admininstration has to be re-educated and lobbied for program support. Fishermen provide virtually no input for planning.

Although food self-sufficiency must be derived from a combination of terrestrial and aquatic resources, planning in Puerto Rico is primarily concerned with terrestrial development. Adverse impacts on marine ecosystems from terrestrial sources, except those affecting mangrove areas, often are not considered. Consequently, terrestrial influences on marine resources are underestimated.

The primary interest of Virgin Island developers and planners is generating income and employment, and tourism is given high priority. The USVI Department of Conservation and Cultural Affairs gives equal treatment to terrestrial and aquatic interests. Coastal zone management appears to be ineffective in St. Thomas. Federal coastal zoning laws and management plans are poorly accepted by local inhabitants. Local input is needed at all levels of planning to increase local understanding and acceptance.

Suggested Options:

- Develop a local coastal resource management program (perhaps based on the U.S. Coastal Zone Management model) or initiate more coordination between regional and Federal programs.
- Managers of Federal assistance programs should deal directly with the agencies.
- Develop formal mechanisms for inter-agency coordination.
- Collect employment, income, and revenue data generated by fishery and tourism sectors on a comparative basis to illustrate the importance of fisheries management and development.
- Evaluate and compare the potentials of marine resources development and agricultural opportunities, by island groups, in order to improve planning and implementation of both marine and agricultural programs.
- Increase communication between resource managers and resource users.
- Establish links between conservation services and enforcement agencies.
- Initiate monitoring and ecosystem recovery programs that are buffered from political changes and are consistent with enforcement capacities.
- Educate local judicial agents in renewable resource problems and conservation.

Planning, Education, and Commerce

Information Availability and Sharing

Some information is available on biophysical resources in each of the FAS island areas, however, more is required in order to manage and develop resources sustainably. Collection of baseline biophysical information is extremely costly on the islands. Although U.S. agencies have provided useful biophysical information, it commonly is not timely and, often may not be presented in a format useful for local implementation.

Few people within either resource or planning agencies know how to interpret or use biophysical information. Although training opportunities are available from outside organizations (U.S. agencies, regional organizations, etc.), some changes are needed to increase participation.

The information that is now available to the local FAS governments commonly is not centralized. A system to identify what type of information exists within resource agencies and to increase sharing within and among sectoral areas in governments is needed. Further, little of this information is available to planning offices.

Information sharing among governments could be increased. A major hindrance to information sharing among governments is the possibility of creating competitors and of freely sharing information which may have been purchased by just a few organizations, Regional cooperation depends on the perception that each government wins by sharing.

Despite the efforts of the U.S. Department of Interior's Technical Assistance Program in the Office of Territorial and International Affairs (OTIA), there is considerable difficulty locating and acquiring appropriate technical expertise in the FAS. Further, governments may not know what outside assistance (financial, technical assistance, etc.) programs are available to them, or specific eligibility criteria for those of which they are aware.

While resource data and information are available to the Pacific Flag territories, commonly it is not centralized, organized, or readily accessible. Baseline resource information in Guam and the Commonwealth of the Northern Mariana Islands is good; American Samoa needs a basic lands survey. However, in general, inadequate or discontinuous funding hinders resource census and monitoring activities by local resource agencies. Further, in American Samoa, information traditionally is considered proprietary and sharing can be difficult.

Each government has access to regional information-sharing mechanisms such as Pacific Basin Coastal Zone Management Conferences and South Pacific Commission conferences. Government operations on the Flag islands are beginning to be computerized; this needs to be extended to resource information. Assistance is needed with archive management and mechanisms to integrate and analyze information.

Information relevant to island resource management developed by international and bilateral assistance agencies is not directly available to the Pacific Flag territories and can be difficult to acquire. Local government agencies in the Pacific Flag territories have little capability for data interpretation and impact monitoring or integration of information which hinder planning. Some areas may have experts to interpret data but few who can translate it to the public.

Impact monitoring is performed when mandated by Federal regulations, although both Federal and local environmental impact statements are especially obtuse. Data interpretation provided by Federal agencies commonly is too technical for local use or fails to consider local development concerns or issues. Guam is developing a monitoring capability, but it is hindered by unstable funding. The CNMI Coastal Zone Management program also monitors projects.

Data collection, integration and presentation to decisionmakers pose no apparent problem in Puerto Rico, however, basic data are not readily available in the U.S. Virgin Islands (USVI). The University of Puerto Rico (UPR), Puerto Rico Department of Natural Resources and Puerto Rico Department of Agriculture maintain major resource-related databases. Information produced by these organizations is used in development planning and other decisions.

Government data collection is directed towards special goals and tends to be aggregated and presented for the entire territory and not by specific island or island subregion, which may hinder effective use of information.

Limited funding hinders the USVI planning office in data collection and analyses, and makes it difficult to maintain a cadre of skilled people. A facility is needed in the USVI where data could be centralized, aggregated, made accessible, and analyses could be provided that extend beyond line agency immediate needs. Such a facility could house a mechanism to screen outside information for applicability to the island.

Some mechanisms to identify technologies that have the potential to sustain island resources are available in the U.S. Caribbean islands, but these probably do not screen the full extent of information available outside the islands. In part, this is due to problems in identifying appropriate people in Federal agencies with whom to maintain contact. "Shared" employees, such as USDA Agricultural Experiment Station and Cooperative Extension Service staff bridge this gap to a considerable extent in some areas. There is some sharing with non-U.S. Caribbean organizations (e.g., Puerto Rico with the Caribbean Development Bank; USVI with the Economic Commission on Latin America), but this probably should be increased.

Suggested Options:

- U.S. agencies could give high priority to establishing baseline information for island use by providing assistance (financial, personnel, equipment, etc.) in data collection and training in data interpretation, manipulation and management. Local governments could contract out for information needed to supplement this information and local education institutions could encourage students to collect such information in the course of their education.
- Each government should develop an archival system to centralize, manage, and control hard-copy information on resources and resource systems. This system should have copy distribution capacity, storage and retrieval capacity, and mapping and statistical systems.
- A computerized system needs to be developed

to assist with data management and to assist in data manipulation for planning. This system should be centralized for each government.

- Federal data of relevance to resource management in the islands should be made available both to the hard-copy archival systems and to the statistical computerized systems.
- A curriculum could be added to the College of the Virgin Islands directed towards producing graduates skilled in data collection, data manipulation and analysis and resource development planning.
- The United States could duplicate international assistance programs applied in neighboring areas to equalize the benefits; or it could provide a mechanism to channel internationally-derived information to the islands. This could be done through domestic programs or through a special fund to the U.N. to provide such services.
- The United States could permit direct representation of islanders to U.N. conferences so that information can be collected first-hand.
- Provide local people the opportunity to work with Federal data collectors to provide some on-the-job training and better understanding of data for eventual interpretation. Most Federal agencies touch base with local experts.
- The University of Guam could provide training in critique and performance of environmental impact statements, and other data interpretation and planning methods.
- One or more "Regional Clearinghouses" could be maintained to share relevant information between governments. These clearinghouses could scan literature produced outside the local governments (U.S. agencies and international) and share relevant information with the governments, and could maintain a "Directory of International Programs" that contains information on assistance programs, contact people, regulations, and procedures.

Current Planning Technologies

The FAS largely are unable to develop technologies for resource management. Island organizations can provide basic research to determine which technologies are potentially suitable, and conduct applied research to adapt technologies developed outside of the areas and to upgrade those traditionally used in the islands. An organization or organizations are needed to identify potentially suitable technologies from the "outside pool" of technologies.

Deficiencies exist in the capacity of island institutions in the Pacific Flag territories to develop and implement needed technologies and programs. This largely is due to a lack of skilled employees. Some efforts are underway to ameliorate this. The CNMI is opening a 2-year agricultural program in their new land-grant college. Guam and American Samoa have had Land Grant programs for some years. However, Guam reports a need to develop expertise outside of the biological sciences in areas such as physical sciences, engineering, business administration, marketing, finance, and accounting.

While small-scale fisheries may be reported as important in development plans, this does not translate into importance in terms of budget. Government officials may think that fishing requires little support; or they may not wish to encourage fishing as a commercial enterprise. Small-scale fisheries tend to be overwhelmed by large, outside fisheries issues. Competition among U.S.-affiliated islands hinders commercial development of small-scale fisheries. Development of small-scale deep-sea fishing enterprises would support tourism and thus may be a type of small-scale fishing on which to focus. American Samoa's economy and food consumption largely are based on its marine resources; CNMI's falls somewhere in the middle, and Guam's are least based on marine resources.

In the U.S. Caribbean islands, local interest exists in ethnobotany and other areas related to development of "new" renewable resources with potential commercial applications, but present activities are small. These activities depend strongly on university staff and programs, and have been hindered by Federal budget cuts. The CVI Agriculture Experiment Station and Cooperative Extension Service, along with the Island Resources Foundation, are studying local versions of commercial crops and ethnobotany. The Puerto Rico Medical School is researching ethnopharmacology.

Suggested Options:

- Regional Information Clearinghouse(s) might collect and provide information on potentially suitable technologies to the islands in addition to such services provided by OTIA and the South Pacific Commission (SPC).
- Federal agency "loaners" through the Intergovernmental Personnel Act from the Environmental Protection Agency and other agencies would help with immediate problems. Military liaisons with local agencies and access to Naval Ocean Command Center expertise would also provide needed skills and information.
- Perform economic impact statements of small-scale fisheries to provide good estimates of their current importance to local economies.

- Research small-scale fisheries technologies to determine which may be appropriate for local enterprises.
- Marine resource conservation laws would assist with managing inshore areas to support pelagic fisheries. Also, definition of traditional fishing areas would prevent pelagic fishermen from hindering local catches,

Education, Labor, and Skills

FAS need curricula development on resources and development for primary, secondary, and college-level programs. Efforts are being undertaken by a variety of organizations to provide needed materials. The public should be made aware of the value of education, and programs should be developed to promote early student interest in fields most integral to the islands.

All island areas need to develop a cadre of skilled resource managers and planners. Students educated off-island in resource-related fields frequently return to jobs which do not allow them to use their skills. In fact, some students decide not to return at all. The Trust Territory of the Pacific Islands (TTPI) Manpower Council identified island development skills priorities and gave scholarships based on those analyses. Similar attempts have been made by local governments by contracting with students to pursue certain fields in return for financial support, There is no enforcement of "contracts" with students because it is too difficult and costly to monitor their course choices and undesirable to withdraw support for education altogether for non-compliance (changing course plans) when educated people are needed in so many fields.

Mechanisms to identify suitable technologies will require development of skilled islanders, which in turn will depend on development of educational institutions. The University of Guam priorities currently are determined not by island needs but by the availability of U.S. matching funds. Students seeking skills from U.S. mainland universities frequently do not return to the islands. Further, mainland expatriates have greater freedom to operate as professionals within the political/cultural island systems,

Development of educational programs, particularly in science, is problematic, Much locally relevant, resource-related information may be traditional proprietary knowledge and, therefore, may be largely inaccessible to formal educational programs. There also is a distinct lack of continuity in school programs.

Primary and secondary school level programs and materials designed to show the links between development and its ecological consequences need substantial improvement for applicability to the Pacific Flag territories. The Government of Guam, in association with the U.S. Department of Education is developing a curriculum and textbook on environment and development, and the American Samoa Coastal Zone Management program is providing environmental education materials and training in field research techniques. However, these programs are seen as piecemeal efforts.

Immigration is causing stress on existing infrastructure, distorting labor markets and adversely affecting some resources in the Pacific Flag territories. Foreign nationals may displace local labor and their paychecks are often remitted to families at home. (For example, 70 percent of the labor in American Samoa tuna canneries are foreign nationals.) However, reducing the availability of foreign labor would result in economic dislocations.

Related to resources, foreign nationals may take resources beyond acceptable or legislated amounts (e.g, land crabs in the CNMI) and may use inappropriate methods of resource capture. Foreign fleets are a significant cause of harbor pollution, largely by crashing on reefs and discharging bilges in harbors.

Colleges in the U.S. Caribbean have resource-related programs, however, primary and secondary school level programs and materials (e. g., textbooks), designed to show the links between development and its ecological consequences need substantial improvement. Some materials are being developed by the Coastal Zone Commission on St. Thomas and at the CVI as well as at the Puerto Rico Department of Education. In addition, there is a distinct lack of vocational education curricula to provide basic agriculture and fisheries (and small business management) skills. Puerto Rico has ample 2-year vocational education programs, but the proposed Hess Oil program focusing on mechanics and agriculture has not materialized in the USVI.

Both island areas have difficulty attracting and retaining skilled personnel. In the USVI, the problem lies primarily in locating and attracting skilled staff for government agencies. Mid-level managers are scarce and local businesses do not train them, In addition, outside companies investing in the islands rarely hire local islanders. Local talent probably already is captured by the government because extra-government jobs generally are not higher paying.

In Puerto Rico, the problem is not in keeping people in the government specifically, but in keeping people on-island. Skilled personnel commonly are attracted to higher-paying jobs in the mainland, although they frequently return. Despite UPR's poor salary system, its retirement system encourages long tenure. Managerial training opportunities—both on-island and off-island—are considered more than adequate for island resource managers. In the USVI, however, methods to upgrade skills are strongly needed to replace costly outside experts.

Suggested Options:

- A Human Resource Development study is needed to help island governments identify skills needed in the future; this information should be used to direct current educational and curricula development programs.
- Local governments should ensure continuity of local government personnel in order to promote environmental education, and continuity of educational programs despite changes in personnel.
- A program encouraging the elderly to teach young people in formal school systems to transfer resource-related information and skills should be instituted on each island.
- Village "monitoring" of resource status should be instituted to supplement college / university monitoring of resources in their research programs.
- Local governments could invest in scholarship funds to encourage college education in target areas.
- The University of Guam could provide increased substantive courses for secondary school teachers, mostly in the areas of math and science. To do this, they need to develop appropriate curriculum materials.
- Support and assistance should be provided to include planning curricula in university-level education in the islands.
- Provide increased training opportunities in the USVI and provide incentives to increase longevity of tenure in the government agencies (probably security incentives rather than financial incentives).
- Directories of local resource management expertise might be a first step to identify which skills are available, which can be shared, and which are needed.
- Coast Guard surveillance of navigable waterways should be returned to former levels or increased.

Extension, Marketing, and Incentives

Lack of marketing information is a serious problem in each of the FAS island areas. While systems to deliver marketing information are available, the delivery of such information is inadequate.

Incentives systems and programs are a problem in the FAS. Payment incentives are seen as disincentives to manage and follow-through on projects. Participants felt that independent initiative was the best incentive to manage and follow-through on any project. Wage disparities are perceived as the major disincentive in investment in resource management and development. Favorable government salaries affect education choices, increasing selection of fields such as political science and law, and leaving fields such as agriculture and fisheries, lacking.

Lack of needed marketing information hinders planning and resource development in the Pacific Flag territories. Although some marketing studies are being performed, these are not as yet adequate to take advantage of expected appropriate markets. The local tourist market, in particular, needs to be assessed and developed to support local production. Cooperatives as a mechanism to guarantee required quality and quantity to fit into modern markets have not been very successful.

Marketing information is not perceived as a problem in American Samoa, but educated marketers are needed to work in the government and to monitor market trends. Needs exist to reduce competition in exported products among neighboring islands. And surplus goods must be marketed to fulfill plant capacity and achieve economies of scale. American Samoa hopes to develop as a major transshipment port with some on-island processing.

Few incentives exist in the islands for resource conservation. All governments have resource management incentive systems but these tend to be oriented to development. These also focus on management of government-owned, leased land much more heavily than for management of private lands.

Technology identification and transfer mechanisms are needed at all levels: international / bilateral / Federal to local organizations, and local organizations to practitioners.

While technical information is available in the U.S. Caribbean islands, marketing is a major problem to development. In the USVI, four Small Business Administration (SBA)-type organizations help practitioners with marketing, but this is not available to planners. In Puerto Rico, the current focus is on selling Puerto Rico to big business; these efforts probably have not been extended to small producers.

Although traditional fisheries and landholding systems are aggregations of small-scale activities, the small entrepreneur often is overlooked in favor of large, mainland subsidiaries. Scale is perceived as the major source of divergence between traditional systems and contemporary systems.

Several organizations provide information and assistance to the small entrepreneur, The Cooperative Extension Services is one source of information applicable to varying scales of enterprise. In addition, the SBA has programs designed to help entrepreneurs/innovators/inventors go to market with new products, Other, similar groups exist to help small businesses. However, little of the training is directed towards small agricultural and fisheries businesses.

Resource management incentive programs at a local government level are weak in both island areas. In Puerto Rico, priorities vary among departments and fluctuate widely over time. In the USVI, economic development is given almost consistent priority over resource management, which is reflected in low budgets for resource programs.

Suggested Options:

- The Regional Information Clearinghouse could provide marketing information collection and dissemination services.
- Old TTPI "2-pagers" on research projects relevant to potential island development projects, including marketing information, should be located, updated, and redistributed,
- Governments could swap developable lands (determined by land suitability analysis) for "resource-valued" land as a means of preserving certain resources or resource uses (e.g., protection of critical habitat or creating agricultural districts),
- Land Grant and Sea Grant organizations may provide some of these services, and should receive continued support.
- Under Internal Revenue Code 936, large banks in Puerto Rico are holding up to $6.5 billion for investment in development of private firms in Puerto Rico. Although this has been used for renewable resource-related development in the past, it has been used conservatively. Creation of a "Caribbean Research Institute" could support renewable resource development as well as other technology development making use of these 936 funds.

Planning for Resource Management and Development

Resource development and land use planning in the FAS is extremely problematic largely due to land tenure systems and local perceptions of land as a family heritage rather than a commercial resource. Land tenure is fragmented, hindering development of economies of scale in most undertakings. The implementation of land use guidelines or restrictions will be the task of local governments. However, U.S. government agencies could assist with information collection, landowner education, and transfer of information on suitable development projects.

Local governments have not had enough experience with the impacts of development to reliably forecast the likely impacts of future projects. Guidelines for analysis and training of people to perform analyses are required. Some suggested analyses are: (1) benefit/cost analysis or other appropriate decisionmaking aids; (2) tourism impact assessment or carrying capacity analyses.

Currently, resource management and development (and other) programs are not directly chosen by local islanders in the FAS. The U.S. Department of the Interior (USDOI), OTIA sends a list of programs "chosen" in Washington, DC and asks governments if they wish to sign up for any of them. Although some of these programs have been very good, this system is perceived as inappropriate:

1. Federal agencies rarely respond to further island communications about programs,
2. island governments may never hear again about programs in which they have interest, and
3. island governments are given no more choice by the USDOI than "yes" or "no."[3]

Long-term planning of resource development is rarely accomplished in the Pacific Flag territories. Although the information base is strong, it is rarely used in long-term planning of land uses. Further, contemporary use and management principles sometimes are not compatible with existing island land- and sea-tenure systems.

The Pacific Flag territories do not have the history of experience with the development impacts to adequately consider them in development studies and planning. Planners commonly focus on immediate economic concerns, sometimes to the detriment of the sustainability of resource uses. A major problem is presented by the nature of development and its impacts; economic development occurs in tangible indivisibilities while resource impacts tend to be gradual and diffuse, making it less easy to identify the causes.

Historically, resource management and development planning in the U.S. Caribbean has not adequately considered maintenance of natural resources that underlie economic development activities, but

[3][Statement potentially made obsolete by the Compact of Free Association]

this has changed during the past decade. The regulatory power of the governments is capable of dealing with adverse impacts under leasing, zoning, permitting, and other systems. Still, monitoring capabilities need strengthening.

While fragmentation of jurisdiction over island resource management and development is irrelevant to Puerto Rico, where agencies are well-coordinated, it is a major problem in the USVI. This is particularly acute due to the division in jurisdiction between the Coastal Zone Commission (which regulates only the 200 foot contour) and the rest of the islands covered by the planning office and other agencies. Permitting and other activities need to be centralized.

Coastal Zone Management (CZM) and other Federal programs supporting local government activities require consideration of environmental, social, and political consequences of activities. However, private undertakings may not consider these or even respond to mandates that they consider the consequences of their proposed actions. Environmental Impact Statements (EISs) and economic development impact analyses are common and well-understood, but social impact analyses are not. Developers commonly are "outsiders" investing in the islands and so do not have a feeling for public hearing issues.

Despite considerable public scrutiny of both public and private developers in the islands, there is no format or standardized measures for social impact analysis available to either public or private groups. One participant suggested that the Oak Ridge National Laboratory has a methodology/model for conducting a social impact analysis. This methodology is reported to be simple, requiring some adaptation to the islands but otherwise readily applicable. Still, the model does not include cultural considerations. It was suggested that formal mechanisms had not been applied because they were not perceived as necessary to derive adequate analyses.

Carrying capacity is theoretically understood, but there is not enough experience or political clout to oppose private developers on this basis. Skilled people hired by the local government are commonly "captured" by the private sector. Further, political criteria overshadows the use of scientific information in decisionmaking.

Suggested Options:

- Planning offices need to review proposals from corporations interested in investing in island activities to ensure that local environmental, social, economic, and political considerations are incorporated in island development.
- Further assistance with planning through the HUD A-76 Comprehensive planning program would be beneficial to all planning efforts.
- Encourage students with planning expertise to take employment with government agencies. To promote this, government agencies could provide such perquisites as guaranteed jobs, homes, and program continuity.
- Environmental impact studies and monitoring should be regularly performed and systematically conducted to determine which development projects may be reducing future productivity in immediate or nearby ecosystems.
- Encourage all Federal and local studies to incorporate social impact analysis, as well as environmental impact analysis.
- CZM programs provide the basis for integration of resource management and development information, and their development should be encouraged. However, there is an occasional need to redirect funds going into local **CZM** programs to respond to local needs; a mechanism to do this should be determined.
- The Federal government should assist with ecosystem simulation models for the islands to allow greater certainty in review of environmental impact statements, and to provide planners with a simple mechanism to educate the public and decisionmakers,

Enforcement

Federal programs, designed for mainland ecologies and communities, sometimes are not appropriate for the islands and may not be adaptable to island needs. Local regulations in the U.S. Caribbean tend to be more flexible than Federal programs; policies are becoming stricter, but methods to waive them are available if it is clearly beneficial. However, waivers from Federal regulations are much more difficult to achieve.

A dilemma exists: stricter regulations are needed, but this tends to increase regulatory rigidity, A public resource constituency is needed to force issues to political attention to help determine when waivers are appropriate.

Although aid to the islands already is evaluated for its impacts to some extent, review panels of Federally-funded programs rarely include a local islander, perhaps reducing their adequacy in pointing out applicability to the islands.

The Pacific Flag territories lack a strong conservation ethic and enforcement of conservation laws is hindered by extended family structures. A conservation ethic was not really needed until recently, however, the development of a conservation ethic may be hindered by a long-running perception of "plenty." In some cases, police will overlook infractions of environmental regulations and focus arrests or fines on criminal laws.

Regulation is perceived as useful only until education catches up. Thus, environmental education should be a high priority for local educational institutions.

Suggested Options:

- Local representation could be required for review of federally funded projects in the islands, perhaps by law. Local governments could also create project proposal evaluation teams with which Federal agencies must cooperate.
- Because environmental education priorities are designated by Federal agencies, a program should be developed to fund and assist local environmental education.
- Guam courts directed a public awareness program of the potential prison sentences and fines given to law-breakers. This might be useful in other islands.
- Having circuit court judges (judges not part of local extended family structures) impose sentences may reduce the perceived need to ignore laws in order to "maintain good feelings."

Resource Development Focii

In all three Pacific Flag territories, "new" resources are the resource-related planning focus. Guam is looking into eucheuma and rabbitfish culture; CNMI is studying tangan-tangan charcoal; and American Samoa is researching traditional pest control methods such as coleus intercropping, Medicinal plants are an area overlooked in this thrust. Although "new" resources are important to future development, they are not as important as keeping up with major current developments such as tourism.

For example, tourism is perceived as creating a mixture of beneficial and adverse resource impacts, It can be beneficial insofar as it increases public awareness of resource values. On the other hand, foreign labor commonly is brought in to fill higher positions due to a lack of local skilled labor; local labor commonly fills lower-wage positions, reducing potential local economic gains, Unfortunately, tourism development in Guam and the CNMI occurred too rapidly for effective control. A better system would have been to have locals trained to support development, thus slowing the "brain drain. "

Tourism is not seen as a distorting force in the U.S. Caribbean islands, but certainly as the driving force behind many activities and issues. Tourism is seen as a primary method of deriving gross domestic product and employment, although jobs often are filled by mainlanders and there is a public drive in St. Thomas (USVI) to restrict tourism development such that land remains privately owned/used. In addition, tourism is perceived as a mechanism to spread stress on resources from more developed areas (e.g., St, Thomas) to less developed areas (e.g., St. Croix).

Because of the determination to derive income from tourism, participants suggested that the real need of the islands was not to increase their self-sufficiency in terms of increased local food production, but to reduce the high cost of food. Methods of achieving this are to:

1. increase local processing of imported raw materials (taking advantage of the historical use of the islands as Caribbean-mainland transshipment points), and
2. restore barriers to importation of lower-cost down-island products reduced by the Caribbean Basin Initiative,

Suggested Options:

- First, governments need to rank the possibilities for economic development in order to: 1) rank research priorities, 2) direct Economic Development Administration-type promotion strategies, and 3) direct planning focii.
- Second, a study (or studies) should be performed for each area to uncover already known information about local resources; requiring a major literature search (including the Micronesian Area Research Council and PBDC). Then, governments should fund cooperative scientific/resident surveys of local practices to determine which resources may have potential for commercial development (e.g., raw materials for industrial use) and which resource management practices may be transferable to larger-scale use.
- Third, regional herbaria or germplasm storage centers need to be created to save opportunities offered by local plants. (The Waimea Botanical Gardens have a collection of Pacific island plants, but this may not cover the entire range of local species available,)
- Fourth, for those resources which appear to have the potential for commercialization, there needs to be university/college faculty research and publications to tap into international knowledge (e.g., the South Pacific Commission

may collect such information). Perhaps a regional information center could perform the archival search and extend into an international literature search.

- Finally, governments need to give continuing attention-to the most promising products so that the "boom-and-bust" syndrome does not occur.

Grassroots scrutiny of and participation in local government activities is growing, but remains rare in the Pacific Flag territories. Guam holds public hearings on zoning variances and on specific development projects, and provides a weekly "Land-Use" column for the local newspaper. Private organizations such as the Marianas Parks and Recreation Council, Guam Science Teachers Council and a local chapter of Audubon may respond to proposed government activities, but these groups have little continuity. In the CNMI, the public land planner presents projects to the public but there is commonly little response. American Samoa has not developed much in the way of public participation. Hearings are held in Pago Pago and they are often felt unnecessary. No environmental groups have chapters in American Samoa.

Suggested Option:

- The media probably is the best form of introducing the public to the planning process, to methods of public participation and to the potential impacts of proposed projects.

Summary of Meeting With Representatives of Paku[4]

Palau's development plans are directed toward: 1) development of a tourism industry, and 2) increasing export of island products. However, tourism impact or carrying capacity studies have not yet been performed. Although it is estimated that current fishery production can provide for approximately 16,000 tourists annually, current agricultural production is insufficient to support the additional demand.

A major constraint to development is the lack of essential air/surface transportation to the islands. Infrequent air carrier schedules inhibit tourism travel and the current airline service structure results in higher fares for the consumer. Lack of regular air cargo services inhibit the island's ability to become an effective exporter. Certain clauses of the Jones Act exacerbate this problem. For example, the aircraft noise restraint is applied equally to the island as to major airports in the continental United States, resulting in infrequent air schedules to the island. "Noise reducers" can curb engine noise to comply with the regulation, however, aircraft power also is reduced which prevents certain types of aircraft from using the short island runways. Currently, aircraft noise is not considered a problem in Palau compared to the economic benefits expanded air service would provide.

Foreign carriers that do service Palau are not permitted to carry local traffic between Palau and other U.S. ports (e.g., Guam, Hawaii). Clauses related to shipping contained in the Jones Act defines Micronesia as a "foreign" territory, thus, hindering the islands' export potential.

Suggested Option:

- Congress could grant an exemption or waiver of certain clauses (i.e., aircraft noise restraint, definition of Micronesia as "foreign") of the Jones Act for the islands.

Interest exists in encouraging foreign investments in agriculture. Currently, Palau imports approximately 75 percent of their agricultural products. An increase in the island's capacity for food production in conjunction with providing essential transportation would sustain tourism, The Palauans have made investigations into possible markets in Japan for island products. Discussions are planned between the President of Palau and the President of Japan regarding potential Palauan exports to Japan.

Suggested Option:

- Congress could influence Japan to be receptive to island exports.

No foreign vessels are permitted to fish in territorial waters without a permit, however, Palau lacks the capacity to enforce this law over their 12-mile zone. Coast Guard vessels could provide the needed protection although it was recognized that enforcement of harvest limits would be difficult. Some local enforcement exists on a limited basis in some marine areas, although several marine species are virtually unprotected (i.e., lobster, red snapper, mangrove crab). Poaching remains a serious problem from both the local population and foreign poachers. Restocking species in reef areas is futile unless these areas can be adequately protected and poaching laws can be enforced. The Japanese International Cooperative Agency has funded research and protection of the hawksbill turtle.

Conservation regulations are a recognized need not only for nearshore resources but also for species considered "highly migratory. " It was noticed

[4]Due to logistical problems, representatives of Palau were not able to attend the workshop sessions on September 26 and 27, as planned. OTA staff subsequently met with them on September 28.

that nearshore tuna population declined when the Japanese began fishing Palauan waters. A local tuna canning plant owned by Van Camp went out of business due to the decline of available tuna, However, approximately two years after the cessation of the Japanese harvest, the tuna reappeared in nearshore waters indicating that regulation of pelagic harvest could help assure a sustainable yield.

The local government needs the flexibility to allocate funds for conservation programs which agencies have the resources to enact. Strong and numerous family ties between local offenders, enforcement forces and the judiciary make enforcement of conservation regulations difficult.

Suggested Option:

- Circuit rider judges could conduct trials and impose fines and sentences for convictions in cases where there are family ties between the judiciary and the defendent.

Methods to integrate the resource development analyses provided to Palau by various multi-lateral and U.S. governmental agencies are needed. Resource analyses are necessary to allow local planners to make wise decisions on local development projects and maintain a sustainable resource base. A number of resource assessments have been made by various US. agencies and regional organizations. However, many of these analyses were not designed for the needs of the local resource management agencies and some of the information collected has not become available to the local government.

Suggested Option:

- Integration of this type of information and provision of baseline data on other resources would allow local planners to identify techniques to minimize environmental damage from development projects.

Analyses of marine resources are particularly deficient, although the SPC supports good fishery projects. Necessary baseline information on marine resources (e.g., red snapper, grouper) could be gathered by a U.S. ocean research vessel and assistance for a mariculture assessment has been requested. The International Union for the Conservation of Nature and Natural Resources could provide assistance in developing management plans for protected areas.

No mining legislation exists for Micronesia islands and waters. Legislation is needed on Palau to control seabed mining, extraction of manganese and gold, and their associated impacts on ecosystems.

Suggested Options:

- Make technical assistance grants available to the islands to integrate available information in resource management plans. Five years was the suggested length of the grant which would allow time for development of the on-island expertise.
- Lack of recognition for local science experts results in a disincentive for local people to become educated in science fields. Outside studies should incorporate the expertise of local scientists and give credit for their contributions.

Appendix G
Commissioned Papers[1]

Assessment of Energy-Integrated Farming Technologies for U.S. Insular Areas (NTIS PB87 142691/AS)
Alex G. Alexander
Energy Cane, Inc.
Everett, WA

Cultural Dimensions of Resource Definition and Use in Micronesia (NTIS PB87 142675/AS)
William H. Alkire
Department of Anthropology
University of Victoria, B.C.

Tourism Development and Sustainable Renewable Resource Management for U.S.-Affiliated Pacific Islands (NTIS PB87 142725/AS)
Janice Auyong
Raymond Tabata
Sea Grant Extension Service
University of Hawaii

The Development and Management of Nearshore Fisheries in the U.S.-Affiliated Pacific Islands (NTIS PB87 142691/AS)
Paul Callaghan
University of Guam

Assessment of Livestock Production Technologies in U.S.-Affiliated Caribbean Islands (NTIS *1%87 142691/AS]*
Ruben Caro-Costas
USDA Agricultural Research Service
Rio Piedras, Puerto Rico

Assessment of Agricultural Crop Production Technologies in Puerto Rico (NTIS PB87 142691/AS)
Fernando Castillo-Barahona
Plantas Tropicales de Puerto Rico

The Integration of Customary and Traditional Renewable Resource Practices in a Modern Legal Framework (NTIS PB87 142725/AS)
Williamson B.C. Chang
Mari J, Matsuda
Brian K. Nakamura
Wm. S. Richardson School of Law
University of Hawaii

Tropical Island Ecosystems and Protection Technologies to Sustain Renewable Resources in U. S.-Affiliated Islands (NTIS PB87 142675/AS)
Arthur L. Dahl
Ecological Advisor
Plomodiern, France
(formerly with South Pacific Commission]

Organizations Dealing With Renewable Resource Development and Management in Puerto Rico and the U.S. Virgin Islands (NTIS PB87 142675/AS)
Hilda Diaz-Soltero
Nature Conservancy, Washington DC
(formerly Secretary, Puerto Rico Department of Natural Resources)
Boris Oxman
Special Adviser, Coastal Zone Management Program
Puerto Rico Department of Natural Resources

Forestry in Puerto Rico: A Case Study in Successful Organizational Change (NTIS PB87 142700/AS)
Hilda Diaz-Soltero
Nature Conservancy, Washington DC
(formerly Secretary, Puerto Rico Department of Natural Resources)
Ralph Schmidt
United Nations Food and Agriculture Organization, Rome
(formerly Chief, Puerto Rico Forest Service

Agriculture Development Needs and Opportunities in the U.S. Virgin Islands (NTIS PB87 142691/AS)
Eric Dillingham
Farmer, U.S. Virgin Islands

Case Studies of the Impacts of Introduced Animal Species on Renewable Resources in the U. S.-Affiliated Pacific Islands (NTIS PB87 142675/AS)
Lucius Eldredge
University of Guam Marine Laboratory

Traditional Agriculture and Resource Management Systems in the High Islands of Micronesia (NTIS PB87 142683/AS)
Marjorie V.C. Falanruw
Yap Institute of Natural Science

An Analysis of Black Pepper Production in Ponape (NTIS PB87 142683/AS]
Meredith Glenn
Consultant, New York

[1]Microfiche or paper copies of collections of commissioned papers may be purchased from the U.S. Department of Commerce, National Technical Information Service (NTIS), Springfield, VA 22161. The NTIS order number following each title indicates in which part of Volume 11: Commissioned Papers the paper appears:

Part A: The Setting for Resource Development	NTIS PB87 142675/AS
Part B: Agriculture - Pacific	NTIS PB87 142683/AS
Part C: Agriculture - Caribbean	NTIS PB87 142691/AS
Part D: Agroforestry and Forestry	NTIS PB87 142700/AS
Part E: Aquatic Resources	NTIS PB87 142717/AS
Part F: Development Planning Considerations	NTIS PB87 142725/AS

(formerly with Pohnpei State Department of Resources & Development)

Aquiculture Development in the U.S.-Affiliated Islands (NTIS PB87 142717/AS)
John Glude
Glude Aquiculture Consultants, Inc., Seattle, WA

Aquiculture and Fisheries Development in Puerto Rico and the U.S. Virgin Islands (NTIS PB87 142717/AS)
Melvin Goodwin
Paul D. Sandifer
Environmental Research Projects, Rhode Island

Forestry and Agroforestry Technologies: Developmental Potentials in the U.S.-Affiliated Pacific Islands (NTIS PB87 142700/AS)
Craig C. Halbower
Consultant, Colorado
(formerly with Yap State Department of Resources & Development)

The Role of Marine Resource Tenure Systems (TURFS) in Sustainable Nearshore Marine Resource Development and Management in U. S.-Affiliated Pacific Islands (NTIS PB87 142717/AS)
Robert Johannes
CSIRO Marine Laboratories, Division of Fisheries Tasmania, Australia

Implications of History and Culture for Sustaining Development of Renewable Resources on U. S.-Affiliated Pacific Islands (NTIS PB87 142675/AS)
Robert C. Kiste
Pacific Island Studies Program
University of Hawaii

Impacts of U.S. Military Presence on U. S.-Affiliated Islands (NTIS PB87 142725/AS)
Stephen A. Loftus, Jr.
Consultant, McLean, VA

An Overview of Selected Natural Systems Planning and Management Techniques for U. S.-Affiliated Islands (NTIS PB87 142725/AS)
G. Kern Lowry
Department of Urban and Regional Planning
University of Hawaii

Assessment of Commercial Agriculture Technologies for U.S.-Affiliated Pacific Islands (NTIS PB87 142683/AS)
Robert Lucas
Robert L. Lucas and Associates
Honolulu, HI

Coastal Resource Development and Management in the U.S. Pacific Islands (NTIS PB87 142725/AS)
James E. Maragos
Pacific Ocean Division
U.S. Army Corps of Engineers
Honolulu, HI

Assessment of Semiarid Agricultural Production Technologies for the U.S.-Affiliated Caribbean Islands (NTIS PB87 142691/AS)
Gregory L. Morris
Consulting Hydrologist, Puerto Rico
Douglas J. Pool
Tropical Research and Development, Inc.
Puerto Rico

The Suitability of Cooperative Enterprises for the Production of Food on the Territorial Islands of the United States (NTIS PB87 142725/AS)
Neal Nathanson
National Rural Development and Finance Corporation
Washington, DC

Aquiculture and Mariculture Development in the U.S. Pacific Insular Areas (NTIS PB87 142717/AS)
Steven Nelson
University of Guam Marine Laboratory

The Marshall Islands Coconut Industry: Prospects for Expansion and Development (NTIS PB87 142700/AS)
Skip Poison
University of Hawaii

Forestry and Agroforestry Technologies: Development Potentials in U.S.-Affiliated Caribbean Islands (NTIS PB87 142700/AS)
Douglas J, Pool
Tropical Research and Development, Inc.
Puerto Rico

Effects of U.S. Macroeconomic Policy on Puerto Rico and U.S. Territories (NTIS PB87 142725/AS)
Ben Posner
College of the Virgin Islands

Commercial Crop Production Technologies and Development Potentials for U.S.-Affiliated Pacific Islands (NTIS PB87 142683/AS)
Bill Raynor
Department of Agriculture
Ponape Agriculture and Trade School

Assessment of Food Processing Technologies for U.S.-Affiliated Caribbean Islands (NTIS PB87 142691/AS)
Ferdinand Sanchez-Nieva
Chemical Engineer, Puerto Rico

The Critical Role of the U.S. Congress in Fostering Self-Reliance in the Freely Associated States of Micronesia (NTIS PB87 142675/AS)
Henry M. Schwalbenberg, S. J.
West Side Jesuit Community, New York

Traditional Crafts in the U.S.-Affiliated Caribbean Islands: An Addendum (NTIS PB87 142725/AS)
Daniel Sheehy
Folk Arts Program, National Endowment for the Arts
Washington, DC

Non-Food Marine Resources Development and

Management in the U.S.-Affiliated Pacific Islands (NTIS PB87 142717/AS)
Barry Smith
University of Guam Marine Laboratory

Food and Feed Processing Technologies in the United States Insular Areas of the Pacific (NTIS PB87 142683/AS)
Philip G. Stiles
Division of Agriculture
Arizona State University

Assessment of Livestock Production Technologies in Micronesia and Feasibility Study for Locally Produced Pig Feed on Ponape (NTIS PB87 142683/AS)
Miklos Szentkiralyi
Animal Husbandry Department
Ponape Agriculture and Trade School

Applicability of Zeolite Refrigeration Systems to Small Tropical Islands (NTIS PB87 142717/AS)
Dimiter Tchernev
The Zeopower Company
Natick, MA

Fiscal Incentive Social Support Programs, the Caribbean Basin Initiative and the Development of Renewable Resources in Puerto Rico and the U.S. Virgin Islands (NTIS PB87 142675/AS)
Alan T. Udall
Technical Resources of Puerto Rico, Inc.

Boris Oxman
Special Adviser, Coastal **Zone** Managment Program
Puerto Rico Department of Natural Resources

Economic Pests and Pest Management Technologies Suitable for U.S.-Affiliated Pacific Islands (NTIS PB87 142683/AS)
Agnes Vargo
Agricultural Experiment Station
American Samoa Community College

Assessment of Agricultural Production Technologies for U.S. Caribbean Islands (NTIS PB87 142691/AS)
Jose Vincente-Chandler
USDA Agricultural Research Service
Rio Piedras, Puerto Rico

Handicrafts Industry Development and Renewable Resource Management for U.S.-Affiliated Pacific Islands (NTIS PB87 142725/AS)
Margo Vitarelli
Consortium of Pacific Arts and Cultures
Honolulu, HI

Non-Food Marine Resources Development and Management in the U.S.-Affiliated Caribbean Islands (NTIS PB87 142717/AS)
Charles Wahle
Stone Harbor Marine Laboratory
Lehigh University, NJ

Appendix H
Glossary of Acronyms and Terms

Acronyms

ACIAR —Australian Centre for International Agriculture Research
ADP —Aquaculture Development Program
AID —U.S. Agency for International Development
AMS —Agricultural Marketing Service (USDA)
ARS —Agriculture Research Service (USDA)
CARDI —Caribbean Agriculture Research and Development Institute
CATS –Civic Action Teams (U.S. Army)
CCDC —Consumer Cooperative Development Corporation
CFMC —Caribbean Fishery Management Council
CNMI —Commonwealth of the Northern Mariana Islands
CODREMAR —Puerto Rico Corporation for the Development of Marine Resources
COE —Army Corps of Engineers
CRIS —Current Research Information System (USDA)
CRM —Coastal Resource Management
CVI —College of the Virgin Islands
CZMA –Coastal Zone Management Act
CZMP —Coastal Zone Management Program
DAWR –Guam Division of Aquatic and Wildlife Resources
DHHS –U.S. Department of Health and Human Services
DOD —U.S. Department of Defense
DWI —Danish West Indies
DWIC —Danish West India Company
EFD —Engineering Field Divisions (U.S. Army)
EIS —Environmental Impact Statement
EPA —Environmental Protection Agency
ERS —Economic Research Service (USDA)
FAD —Fish aggregation device
FAO —Food and Agriculture Organization (United Nations)
FAS –Freely Associated States (FSM, RMI, and the Republic of Palau)
FEDA —Federation Para El Desarrollo Agricola de Puerto Rico
FIP —Forestry Incentive Program (USDA)
FLSA —Fair Labor Standards Act
FSM —Federated States of Micronesia
GAO —U.S. Government Accounting Office
GDP —Gross domestic product
1PM —Integrated pest management
ITC —Island Trading Company
ITCZ —Intertropical Convergence Zone
ITF —Institute of Tropical Forestry
IUCN —International Union for the Conservation of Nature and Natural Resources
KMR —Kwajelein Missile Range
MARC —Micronesian Area Research Center—University of Guam
MATADC —Micronesian Area Tropical Agriculture Data Center—University of Guam
MMDC —Micronesian Mariculture Demonstration Center
MSL —Marine Systems Laboratory (Smithsonian Institution)
MSY –Maximum sustainable yield
NEA —National Endowment for the Arts
NELH —Natural Energy Laboratory of Hawaii
NEPA —National Environmental Policy Act
NOAA —National Oceanic and Atmospheric Administration (USDOC)
NPS –National Park Service (USDOI)
OTEC —Ocean thermal energy conversion
OTIA —Office of Territorial and International Affairs (USDOI)
PBDC —Pacific Basin Development Council
PFDF —Pacific Fisheries Development Foundation
PIDP —Pacific Islands Development Program

RAMA	—Resource Assessment Marianas Archipelago database
RMI	–Republic of the Marshall Islands
SAC	–Strategic Air Command
SCS	—U.S. Soil Conservation Service (USDA)
SFCA	—Saipan Farmer's Cooperative Association (CNMI)
SPC	—South Pacific Commission
SPREP	—South Pacific Regional Environmental Programme (SPC)
TURF	—Traditional use rights in fisheries
TTPI	—Trust Territory of the Pacific Islands
UGML	—University of Guam Marine Laboratory
USAF	—U.S. Air Force
USCC	—United States Commercial Company
USDA	—U.S. Department of Agriculture
USDOC	—U.S. Department of Commerce
USDOI	—U.S. Department of the Interior
USFS	–U.S. Forest Service (USDOI)
USFWS	—U.S. Fish and Wildlife Service (USDOI)
USGS	–U.S. Geological Survey (USDOI)
US-MAB	—U.S. Man and the Biosphere Program
USN	–U.S. Navy
USNMFS	—U.S. National Marine Fisheries Service (USDOC)
USVI	–U.S. Virgin Islands
VIBR	—Virgin Islands Biosphere Reserve
VICORP	—Virgin Islands Corporation
VIRMC	—Virgin Islands Resource Management Cooperative
WESTPACFIN	—Western Pacific Fisheries Information Network
YINS	—Yap Institute of Natural Science

Terms

Agouti: A rabbit-sized rodent indigenous to the U.S.-affiliated Caribbean islands; believed to have been extirpated during the colonial period.

Agredados: Puerto Rican sharecroppers on hacienda land.

Agroecosystem: An ecosystem manipulated for agricultural purposes.

Agroforestry: Collective term for a number of agricultural production systems that incorporate a mixture of annual, perennial, and woody perennial species, sometimes including animals, on the same land management unit.

Aiga: A social landholding unit in American Samoa.

Algal ridge: An algae-covered ridge that forms on the shallow surface of coral reefs.

Algal turf: A flatbed of densely growing algae; also used to describe macroalgae-covered screens used as part of crab mariculture in the Caribbean.

Alley cropping: A form of agroforestry involving planting tree species in rows, with annual crops planted in the alleys or avenues. Also called *Avenue cropping.*

Alluvium/ Alluvial soil: Clay, silt, sand, gravel, or similar detrital material deposited by running water.

Aquifer: A water-bearing stratum of permeable rock, sand, or gravel; often used to refer to the Ghyben-Herzberg lens common to islands.

Artificial reef: An artificial structure placed in nearshore waters to encourage the settlement and growth of reef community species such as hard corals, mollusks, crustaceans, echinoderms (e.g., sea urchins), fish, and marine plants.

Avenue cropping: A form of agroforestry involving planting tree species in rows, with annual crops planted in the avenues or alleys. Also called *Alley cropping.*

Back-reef: The nearshore side of the reef.

Bauxite: An impure soil mixture of aluminum compounds largely devoid of common plant nutrients.

Bedding planes: Flat surfaces in sedimentary rocks along which adjacent beds tend to separate

Benthic: Of, referring to, or related to, the bottom of a body of water, such as the ocean.

Biophysical: The natural (biological and physical) attributes of a site and their interrelationships; a biophysical assessment involves assessing these attributes for their suitability for various uses.

Biosphere reserve: A form of protected area designed to integrate conservation efforts with research, monitoring, and education activities, traditional landuse and local socioeconomic needs. The typical reserve is comprised of a highly protected core area, an experimental research area, a rehabilitation area, a traditional use area, and a cooperative development area.

Boom-and-bust syndrome: A cyclic process in which: 1) a new resource or market for a resource is discovered offering opportunities for profit, 2) numerous entrepreneurs begin to produce the desired product eventually flooding the market

and driving down the price, and 3) the subsequent loss of profit-making opportunities results in entrepreneurial flight and collapse of the industry.

Bund: An embankment used to control the flow of water.

Bycatch: Miscellaneous marine species caught in addition to the desired species at which primary fishing efforts are directed.

Caique: Caribbean Indian chieftain.

Capillary forces: Surface tension force that acts to draw water upward in small openings.

Ciguatoxins: Toxin found in nearshore tropical marine fish, currently believed to be linked to sediment discharge from nearby terrestrial areas.

Copra: Dried coconut meat yielding coconut oil.

Conuco: Traditional Caribbean cultivation system involving interplanting of root crops in mounds of soil.

Convective precipitation: Precipitation generated from condensation of moisture laden air that has risen due to surface heating,

Corm: A common name referring to the tuber of a number of root crops including yam (Dioscorea spp.) and taro (Colocasia spp.).

Cruzan: Inhabitant of the island of St. Croix, U.S. Virgin Islands.

Curio: Something considered novel, rare, or bizarre.

Cyclones/ cyclonic storms: A system of winds or storm that circles around a center of low atmospheric pressure clockwise in the southern hemisphere and counterclockwise in the northern hemisphere, advances at a speed of 20 or more miles per hour, and often brings abundant rain; also called a hurricane,

Desacomodados: Squatters on Crown land in 18th century Puerto Rico.

District Center: Administrative centers established for the government of the Trust Territory of the Pacific Islands, which now comprise the major urban centers of the Commonwealth of the Northern Mariana Islands, the Republic of the Marshall Islands, the Federated States of Micronesia, and the Republic of Palau.

Diurnal: Of, relating to, or occurring in the daytime; having a daily cycle.

Ecosystem: The sum of biotic and abiotic components of a specific environment.

Endemic: Having evolved in or restricted to a locality or region.

Epiphyte: A plant that derives its moisture and nutrients from the air and rain and usually grows on another plant.

Evapotranspiration: Removal of water from the soil through the combined processes of evaporation and transpiration.

Externalities: A direct, commonly adverse, effect of an action (e.g., pollution) that affects another's welfare but that is not reflected in market prices or is not taken into account by the individual, firm, or group causing the externality in deciding to undertake the action.

Extinct: No longer existing.

Extirpate: To remove completely from a particularly area or region, but not completely removed from the Earth.

Fa'a Samoa: Traditional lifestyle and social structure of American Samoa ("the Samoan Way").

Fiafia: Traditional Samoan Sunday feast.

Fissures: A narrow opening or crack in rocks.

Fono: Governing council of American Samoan village,

Fore-reef: The seaward side of the coral reef.

Free association: A form of legal association between the United States, the Republic of the Marshall Islands, the Federated States of Micronesia, and expected in the near future between the U.S. and the Republic of Palau, in which the Freely Associated States have full control over their internal and external affairs and will receive U.S. funding over a specified period while the United States retains security and defense responsibilities.

Fumaroles: A small opening in rock associated with recent volcanic activity from which hot gases and vapors issue.

Ghyben-Herzberg lens: The lens-shaped freshwater-saturated zone formed as freshwater percolates down through island soils. This freshwater zone is confined in a general lens shape by the surrounding denser seawater.

Green manure: Green plant material that is incorporated into the soil as a means to enhance soil fertility.

Groundwater: Water that occurs in pores and cracks of rocks and sediments in the wholly saturated zone below the Earth's surface.

Guano: A phosphate-rich substance composed chiefly of the excrement of bats or seafowl and used as a fertilizer.

Hacienda: A large estate, often devoted to such agricultural pursuits as cattle ranching.

Hermatypic coral: Reef-building corals able to grow to a maximum depth of approximately 150 feet below sea level.

Humus: A complex soil resulting from partial decomposition of plant or animal matter and forming the organic portion of soil.

Hydrophyte: A plant growing in water or in soil too waterlogged for most plants to survive.

Hydroponics: Culture of plants in nutrient solutions with or without an inert medium to provide mechanical support.

Intercropping: The planting of two or more crops together at the same time by row, strip, or in a seemingly random mixture.

Interplant: To plant a crop between plants of another kind.

Intertidal: Of, relating to, or being part of the littoral zone between the high- and low-tide marks.

Jibaros: Puerto Rican peasants in late 18th century colonial agricultural economy.

Lancho: A rural, generally wooded, farm that urban dwellers in the Mariana islands traditionally used to cultivate a number of food crops and maintain livestock such as chickens and pigs.

Lithology: The study of rocks, or the character of a rock formation.

Littoral: Of, relating to, or situated in or near a shore, especially the shore zone between low and high water marks.

Macroalgae: Large, chiefly aquatic, nonvascular plants, especially seaweeds.

Matai: Titled chiefs in American Samoa.

Meristematic tissue: Plant tissue capable of forming a replicate of the original plant given appropriate growth conditions.

Microhabitat: The environment immediately surrounding the organism of interest.

Midden: A refuse heap; commonly analyzed in archaeology to provide information on prehistoric lifestyles.

Mongoose: Predator introduced to the U.S. Virgin Islands in the early colonial period and presumed responsible for extermination of local fauna, particularly the agouti.

Monoculture: The cultivation of a single product to the exclusion of other uses of a unit of land.

Muck: Highly organic, wet soils; typical of taro pits and mangrove swamps.

Mwarmwar: Head ornaments similar to leis and typically made of fragrant flowers and leaves, such as ylang-ylang, worn in the Caroline islands.

Naborias: Caribbean Indian lower class, generally laborers,

Neo-tradition: An elaboration or adjustment of a traditional practice.

Nitainos: Caribbean Indian higher class.

Ordnance: Military supplies, including weapons, ammunition, combat vehicles, and maintenance tools and equipment.

Orographic precipitation: Rainfall generated as moisture laden air is forced to rise over a topographic feature, most commonly mountains.

Overexploitation: Exploitation of a resource at greater than sustainable levels.

Pelagic: Of, related, to or living in the open sea; oceanic.

Pneumatophores: A root often functioning as a respiratory organ in marsh or swamp plants such as mangroves.

Polyculture: Agricultural production system incorporating a diversity of plant species and varieties concurrently on a unit of land.

Reef flat: The shallow reef area between the coral reef and shoreline.

Relay cropping: Planting a second crop prior to the harvest of the initial crop on a unit of land.

Savanna: A tropical or subtropical grassland containing scattered trees and drought-resistant undergrowth.

Sawei: A historical socioeconomic exchange system between Yap and nearby outer islands.

Scuba [self-contained underwater breathing apparatus]: Apparatus used for breathing while swimming under water.

Sedimentation: The process of deposition of usually fine-grained sediment; settling. Excessive sedimentation in nearshore waters can smother nearshore marine bottom communities and kill corals.

Slumps: Small landslides in sloping areas of highly weathered soils, common to degraded insular lands.

Snorkeling: To swim partly submerged and breathing through a tube.

Solution cavities: Various sized openings in rock formed through the dissolving action of water.

Subsistence farming: A system of farming that provides all or almost all the goods required by the farm family usually without any significant surplus for sale.

Swidden: A form of land clearing involving slashing standing vegetation and, commonly, burning it onsite to provide soil nutrients (also called slash-and-burn clearing).

Terrane: The area or surface over which a particular rock or group of rocks is prevalent.

Thalli: The fleshy portions of a plant, especially marine macroalgae.

Theca: The solid structure formed by reef-building coral polyps.

Traditional: Relating to indigenous, pre-western contact systems.

Trusteeship: Supervisory control by one or more countries over a trust territory.

Tsunami: Seismic sea wave; a great sea wave produced by submarine earth movement or volcanic eruption.

TURF [traditional use rights in fisheries]: Systems of limited access to marine resources practiced traditionally in the U.S.-affiliated Pacific islands.

Underutilized/underused: To utilize less than fully or below the sustainable maximum yield.

Water table: The top surface of the groundwater zone.

Watershed: A region or area draining into a particular watercourse or body of water; a fundamental ecological unit for resource development planning,

Weir: A fence or enclosure set in a waterway for taking fish,

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