TROPICAL ISLAND ECOSYSTEMS AND PROTECTION TECHNOLOGIES TO SUSTAIN RENEWABLE RESOURCES IN U.S.-AFFILIATED ISLANDS

by

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ABSTRACT

Islands are essentially different from continental areas because of their small size and isolation. Their biological populations depend on the rates of immigration and extinction of species, and often include unique endemic species that have evolved to suit island conditions. There are also socio-economic constraints on island human populations, including the high cost of communications, the lack of economies of scale, and the difficulties in supporting the infrastructure and specialization necessary for modern technologies.

The ecosystems present in the U.S.-affiliated islands include lowland rain forest, moist forest and dry forest; submontane and cloud forest on mountains; riverine and swamp forest; mangrove forest; atoll/beach forest; scrub, savanna and grasslands, often in disturbed areas; wetlands and fresh water environments; coral reefs; and lagoons and shallow bottoms. The interrelationships between ecosystems link them together into a single island system. The islands can also be classified into continental islands, volcanic islands, atolls or raised coral limestone islands, or some combination of these structures.

The ecosystems and species contribute in many ways to the maintenance of island life-support systems and the sustainable use of island resources. Different types of protected areas can be used to protect these essential contributions. Other measures may also be necessary to ensure the survival of island species that are a significant genetic resource. Traditional island cultures developed many sustainable resource management and conservation technologies that can be used as models for modern approaches appropriate to islands. Protected area programs must take into account island cultural and ecological factors.

The establishment and management of protected areas will require adequate scientific information, including quantitative information on the sustainability of resources. Protected areas must be planned for multiple benefits, with due regard to the difficulties created for islanders deprived of their land or customary resources. The participation of local people in the planning and management of protected areas is imperative on islands. Regular monitoring of resource use and protected areas is essential to their management, and should feed information into the planning process. Protected areas can contribute to public education, and should be integrated with other protection mechanisms.

To overcome the constraints and take advantage of the opportunities of the island situation, there are several objectives for congressional action, including simplified and appropriate legislation, special programs of technical and research assistance, and support to species protection and educational programs. Actions are proposed for institutions at the international, regional, national (Congress and Federal agencies), and insular government levels, and for private industry, academic institutions, non-profit institutions and traditional organizations. Implementing the proposed actions should lead to the creation of protected areas, a reduction in extinctions, and eventually the more sustainable use of island resources; failure to act will lead to a continuing decline in the ability of the islands to support a human population.

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INTRODUCTION

Islands are by definition small areas of land isolated by water, and it is their small size and isolation that make them different from continental land areas.

If anything is reduced enough in size, it undergoes an essential change in nature. For example, a herd of cattle can be reduced down to one bull and one cow and still be capable of reproducing the herd. Any further reduction eliminates the capacity for reproduction, and reduction beyond a single animal means slaughtering it and cutting it up. The herd has become something different (meat), and has lost some essential characteristics. The same principle applies to any population or ecosystem. When they are reduced in size (as they are on a small island), they become increasingly fragile, an may eventually collapse if too small.

Small objects have a much greater surface to volume ratio than large objects. In the same way, small islands have a higher ratio of coastline to land than larger land areas. As islands get smaller, they increasingly become coastal zone, but with much less land area to support coastal demands than on a continental coast. Since coastal regions are also more exposed to natural disasters, the increased coastline means the land is less protected and more at risk.

The U.S.-affiliated islands are all quite small. Puerto Rico, by far the largest, is 3435 square miles in area and about a hundred miles across in its longest dimension. Guam is next in size at 206 square miles. All the Northern Mariana Islands together total 184 square miles, as do the islands of Palau. The U. S. Virgin Islands total 133 square miles, and this is still larger than any of the states in the Federated States of Micronesia. American Samoa is 76 square miles, and all the Marshall Islands 70. Since most of the above

figures are for island groups, the individual islands are much less; Majuro, the capital of the Marshall Islands, is 3½ square miles in total area. For comparison, the District of Columbia is 69 square miles.

Work in island biogeography (MacArthur and Wilson, 1967, and many subsequent studies) has defined the basic principles for the establishment and maintenance of plant and animal populations on islands (Dahl, 1984). The number of species that can live on an island depends on its size, with a bigger island able to hold more species. This is because on smaller islands with smaller population sizes, it is easier for some to be driven to extinction. The number of species also depends on the distance of the island from sources of colonizers like continents or other islands. It is hard for most land plants and animals to travel over the sea, so the arrival of a newcomer is a rare event after being carried by storm winds, a drifting log or stuck to a seabird's feet. In addition, it is usually necessary for both a male and female to arrive at the same time, and then to overcome the risks of getting established in a new place. The equilibrium island population thus depends on the rates of immigration and extinction, which in turn depend on distance and size.

These principles of island biogeography underlie one of the major problems for the preservation of natural systems on islands. Where the size of the island is already limiting, any reduction in the size of the natural areas or habitats, such as by development, will probably lead eventually to some species extinctions.

Islands have another biological characteristic, they tend to develop new varieties and species (called endemic species) that are found nowhere else. This comes again from their isolation. If there is less mixing with other populations, there is more chance for the rare colonizing organism to develop differences suited to his new environment, or simply to change in some

random way over time (genetic drift). The lack of competition may mean that there are several available niches, so a new arrival may evolve into different forms to fit the spaces available (adaptive radiation), as in the classic case of Darwin's finches in the Galapagos Islands. Thus the more isolated islands have a genetic richness and unique ecosystems quite unlike comparable areas on continents. They are also more liable to species extinctions, which represent an irreversible loss of part of the world's genetic heritage.

The best word to characterize the island situation might well be vulnerability. Because of the small size of islands, it is easier for a natural event like a storm or epidemic, or human stress from pollution or development, to affect an entire habitat or ecosystem, and recovery may be slow because the base from which to build is so small. Their isolation means that they may have unique endemic forms, and if something is lost it will be difficult or impossible to replace. Their species and ecosystems have adapted to their isolation through the loss of their defenses and competitive ability, so that they are easily preyed on or out-competed by the many species that man tends to introduce intentionally or accidentally wherever he goes.

The above facts show why islands cannot just be considered scaled-down versions of continents (Towle, 1984). While the island microcosm may be a small simple system providing an instructive example for larger systems such as nations or our whole planet that must learn to live within their limits, it is hard to use the analogy in the opposite sense. The difference in scale is too great.

Socio-economic aspects of insularity

Similar principles to those for biological communities also apply to human societies on islands. Insularity has its own socio-economic peculiarities. Isolation greatly increases the expense of transportation and communications,

which may also be much slower and less reliable (especially when you urgently need a spare part). Small size prevents the economies of scale that underlie most modern development, and it reduces the population base over which essential services can be spread. Small communities cannot have the same levels of specialization as large ones, and the amount of infrastructure and bureaucracy they can support is limited. It is thus harder for them to develop or use modern technologies requiring specialized care and maintenance. The more they modernize, the more they become dependent on the outside without necessarily being able to cope. The elaborate requirements of a modern technological society can no more be scaled down to a small island than can a continental ecosystem. Island societies need to evolve their own simple and appropriate ways of doing things, just as islands evolved their own species.

ISLAND ECOSYSTEMS: DESCRIPTION, STATUS AND RESPONSE TO STRESS

The U. S.-affiliated islands share with many other tropical islands a certain number of ecosystem types. These are usually quite similar in structure and function, even if the species which make them up differ greatly from one region to another. The following are the major biomes and habitats that correspond to the island ecosystems (based on Dahl, 1980, with additions from Bryan, 1971; Dahl, 1973; Dahl et al., 1974; Island Resources Foundation, 1977; IUCN, 1985; Newell, 1985; OTA, 1984; and Saenger et al., 1983).

Lowland rain forest

Forest composed of numerous species of fast-growing trees, many exceeding 80 to 120 feet in height, with a closed uneven canopy and sparse undergrowth; often growing on and helping to build the best island soils; complex dynamics in growth and reproduction maintain species diversity.

Puerto Rico: rain forest formerly covered one quarter of the island, mostly on volcanic soils on the lower mountain slopes with more rainfall; a special type occurred on serpentine soils; little of this or any lowland forest type remains today.

Virgin Islands: none.

American Samoa: several types with different dominant species occur on different volcanic soil types; two thirds are now destroyed with the remainder on steep slopes.

Guam: there are both a low limestone forest type and a rich forest with many endemic tree and bird species; only scattered and inaccessible remnants remain.

Northern Marianas: similar to Guam, plus a lowland lava forest in the northern islands.

Marshall Islands: none.

Pohnpei: lowland forest on weathered basalt soil; many endemics; now mostly disturbed.

Kosrae: present with many endemics; nearly undisturbed.

Truk: no undisturbed forest remaining.

Yap: a dense species-rich forest growing on metamorphic and volcanic soils; most is now disturbed or replaced.

Palau: a dense very rich forest with epiphytes and tree ferns grows on old volcanic soils; there is also a species-rich limestone forest growing with very little soil; considerable areas are disturbed.

Lowland rain forests are important for water catchment and for building soil nutrients and humus. They have the highest forestry potential of any island forest, but the land is often required for competing uses like agriculture and human settlements. The ecosystem is naturally resilient; the greatest risk is logging or forest conversion to other uses, often with the loss of significant genetic resources and wildlife. Continuing human disturbance, a lack of seed sources, and competition from introduced plants prevent recovery, which might take decades under good conditions. Reforestation is sometimes attempted, but usually with exotic species as most native species are considered too slow growing to be economic. Planting and weeding in the early years are labor-intensive and expensive. Coverage of forest areas can be monitored by remote sensing to determine if areas drop below minimum sustainable size. With the continuing pressure for land development, information on forest cover should be updated regularly. Floristic composition may also need to be monitored in areas of forest regeneration.

Since most of these forests have already been destroyed, conservation of the remnants is a high priority. Areas abandoned after other uses could be replanted in native species to buffer or expand natural areas, or could be

developed for agroforestry to restore some forest values. Once sufficient lowland forest areas have been restored, light selective logging might be possible if accompanied by replanting of logged species.

Submontane rain forest

These are mountainside forests of shorter broad-leaved trees with an even canopy, many epiphytes, and abundant undergrowth including tree ferns and small palms. The dynamics are similar to lowland rain forest.

Puerto Rico: probably occurred formerly on higher mountain slopes.

Virgin Islands: none.

American Samoa: different types grow on ridges and as secondary forest at middle elevations; some disturbed.

Guam: none.

Northern Marianas: none.

Marshall Islands: none.

Pohnpei: found at middle elevations with dense mixed broadleaf and palm forest types; some disturbed.

Kosrae: at middle elevations.

Truk: only 2 acres now remaining on top of one volcanic island.

Yap: none.

Palau: none.

The forests at higher elevations in the islands are essential to control erosion and landslides on the steeper slopes. The topography usually precludes commercial forestry, but a few areas may have agroforestry potential. Such forests are often best preserved for their ecological and scenic values, as wildlife habitat, and as sources of forest products such as medicinal plants.

The principal threat to these forests is unwise land clearing for agriculture, which is generally followed by abandonment after a short period.

Once cleared, introduced weeds may prevent or slow forest regeneration, leading to chronic erosion and frequent landslides. Reforestation is often not practical because of the steep terrain and difficult access. The area covered by intact forest is the best indicator of the state of the ecosystem.

A few submontane forest areas may have potential for tree crops that maintain forest cover. Otherwise their value for water catchment and erosion control outweighs any development potential.

Cloud forest

This is a forest of mountain and ridge tops kept wet by clouds, composed of gnarled trees burdened with mosses and lichens, and with the ground covered with club mosses and ferns. It is often high in endemic species. Little information exists on its dynamics.

Puerto Rico: present on mountaintops.

Virgin Islands: may have been present on mountaintops.

American Samoa: occurs only on the top of Ta'u, undisturbed.

Guam: may grow in a limited area on top of Mt. Lamlam.

Northern Marianas: found on Mt. Tapachau, Saipan; the cloud-covered summits of some other island calderas are unexplored.

Marshall Islands: none.

Pohnpei: occurs at highest elevations, with endemic plants and orchids.

Kosrae: present on mountain top.

Truk: none.

Yap: none.

Palau: none.

The inaccessibility and extreme conditions of the mountain top habitat preclude significant human use of the ecosystem. The area of cloud forests is often extremely limited and they may be threatened by competing uses for

their sites such as the construction of antennas and communications relays. Recovery after disturbance is probably extremely slow, as erosion would set in quickly after any damage to the ecosystem. Conservation would seem to be the only appropriate human use, and the area of any essential construction should be kept to an absolute minimum. Studies of cloud forest dynamics and of the possibilities of restoration are needed.

Riverine and swamp forests

These dense forest of water-loving species occur along rivers and in low swampy areas, sometimes inland of mangroves.

Puerto Rico: probably still present, at least in some areas.

Virgin Islands: none.

American Samoa: small amounts occur along streams.

Guam: found along rivers and in moist ravines, now mostly gone except in the south.

Northern Marianas: in ravines of smaller islands, little explored but known to contain rare and endemic plants.

Marshall Islands: none.

Pohnpei: dense forest along rivers and inland of mangroves.

Kosrae: along rivers and inland of mangroves.

Truk: inland of mangroves.

Yap: inland of mangroves.

Palau: along rivers and inland of mangroves.

Riverine forests are very important in erosion and flood control along stream banks and in preventing pollution of water supplies, and they are best preserved for this purpose, although they are frequently cleared for agriculture or land development, as are swamp forests. Replanting of these forests should be possible, since the areas involved are limited and the

environmental benefits would be substantial. Human uses are possible as long as the vegetation cover is maintained. Some areas have recreation potential.

Subtropical moist or seasonal forest

The drier Caribbean climate produces lowland forest types not found in the U. S. Pacific islands. The tree species of moist forest are more resistant to drought and may lose some leaves in the dry season.

Puerto Rico: 60% of the island was originally covered by this forest type in the lowlands on the wetter north side of the island; different types occupied alluvial and limestone areas; little of this forest remains today.

Virgin Islands: moist forest formerly covered ¼ of the islands; the fraction that remains is mostly in mountainous or inaccessible areas.

These desirable lowland areas were long since converted to agriculture, industry and urban development, and such uses will continue to be given priority over the natural ecosystem on these lands. If any fragments of original forest remain, they should be protected for their conservation interest.

Subtropical dry forest

A drought-resistant forest with many species and often an understorey of shrubs; slower growing than wet forest.

Puerto Rico: this lowland dry forest once covered 16% of the island on the South side; different communities were distinguished in coastal areas and on limestone. As with other Puerto Rican forests, little of the original ecosystem remains.

Virgin Islands: this was the predominant original vegetation, covering ¾ of the land; today it is considerably reduced.

These dry areas have little potential for forestry production and tend to be converted to grazing land. The forests along the immediate coastal strip may be important in filtering runoff from the land and thus in preventing coastal pollution by sediment and agricultural chemicals. Their rich species composition would require relatively large areas to maintain reproduction and regeneration in the ecosystem, and this makes conservation of such forests more difficult.

Mangrove forest

Salt-resistant trees with stilt roots or pneumatophores growing in the intertidal range along ocean shores or estuaries. The leaves falling from the trees provide food for marine life sheltering among the roots or exported to the lagoon and coastal waters.

Puerto Rico: there are about 25 square miles of mangroves scattered around the coast, representing a significant and productive resource.

Virgin Islands: while scattered mangrove plants occur along the coast, mangrove forests only survive at Salt River, St. Croix and Jersey Bay, St. Thomas; the largest areas have already been filled in for development.

American Samoa: mangroves only grow in Pala Lagoon (under stress from development) and at Aunu'u.

Guam: some small mangrove areas, particularly in Apra Harbor, where there has been much dredging, filling and development.

Northern Marianas: limited areas in the southern islands.

Marshall Islands: in small depressions on a few atolls.

Pohnpei: 13,690 acres of mangrove forest along the coast and in estuaries of Pohnpei, and a small amount on Pingelap Atoll.

Kosrae: 4,030 acres around the island.

Truk: 3,315 acres around the main islands.

Yap: 906 acres on Yap and small amounts on Elato and Woleai Atolls.

Palau: 9,344 acres in estuaries and along the coasts of the archipelago.

Mangroves support major coastal fisheries producing fish, oysters, crabs and other delicacies, and they supply wood and other forestry products on some islands. They also trap and stabilize sediment, thus building land and protecting reefs and lagoons from pollution. They are an important factor in coastal protection from storm damage. In urban areas they may purify the organic wastes and pathogens in urban runoff. Several commercially important fish species use mangroves for breeding or nursery grounds, and food produced in mangrove forests may contribute to the productivity of lagoons and coral reefs.

Storms may damage mangroves, although they tend to regenerate quickly after storm damage. On the other hand, human-induced stress can be disastrous; mangroves are often killed by changes in land runoff or water circulation which alter delicate salinity balances, and oil pollution can wipe out mangrove areas for years. Stressed mangroves will drop their leaves, and may die if the stress remains too long. If conditions permit seedling reestablishment, then the forest can regenerate in 10 to 50 years. Replanting mangroves has become a current practice in Florida at costs equivalent to reforestation on land.

If mangrove forests are carefully managed they can sustain a high fisheries output and some limited forestry production. However their undeserved reputation as nasty swamps, reinforced by the pressure to create land, has led to their destruction in many areas.

Atoll/beach forest and scrub

This forest and scrub type composed of a few widely-distributed species of trees and shrubs occupies sand and rubble on islets and along the coastal beach strand close to sea level.

Puerto Rico: present in some areas.

Virgin Islands: present.

American Samoa: widespread; special types occur on Swain's Island and Rose Atoll.

Guam: common, including some endemic species.

Northern Marianas: occurs on some of the southern islands.

Marshall Islands: this was the major forest cover on atolls, with a variety of types; today the natural forest has largely been replaced by coconuts and breadfruit except on some northern atolls such as Wotho.

Pohnpei: occurred on atolls and behind the beaches of high islands; now often replaced by planted trees.

Kosrae: behind beaches.

Truk: on atolls and islets, and in some coastal areas.

Yap: on atolls and behind beaches, usually replaced by coconuts.

Palau: in a few areas behind beaches and on Kayangel Atoll.

The coastal fringe of vegetation helps to stabilize the coastline and protects the land behind it from storm damage. Some of the plants also provide traditional materials. The plants in this ecosystem are quite resistant to all except destruction by man. Land is so limited on atolls that it is hard to justify leaving large areas in natural forest except in nature reserves and seabird breeding areas; however on high islands, tourism, recreation and residential developments are often more destructive of these forests than

necessary, and their preservation as a storm defence and for their scenic value is in the public interest. As early colonizing species they can recover quite readily, but they could be replanted where rapid stabilization was needed.

Scrub

Scrublands or thickets with woody shrubs to 15 feet high often occur where water or soil are too limiting for forest development.

Puerto Rico: present, often as secondary regrowth on drier abandoned lands.

Virgin Islands: present.

American Samoa: mountain scrub grows on Matafao and Piao mountains, Tutuila.

Guam: found on the rocky limestone coast, and also on areas of southern Guam with some endemics.

Northern Marianas: grows on coastal volcanic rock in the northern islands and on the limestone coasts of the southern islands.

Marshall Islands: some scrub forest remains on the northern islands.

Pohnpei: occurs on rocky coasts and in some ravines.

Kosrae: present.

Truk: present.

Yap: present in some degraded areas.

Palau: found on the outer edges of limestone forest, on rocky coasts and in strip-mined areas.

As vegetation cover on difficult terrain, scrub often has an important role in erosion control and in recolonizing degraded areas. While it seldom has productive human uses, neither does the poor soil in which it grows. The major threats are construction and fire.

Savanna and grasslands

Grasslands or grass with scattered trees or shrubs (savanna) are often created and maintained as grassland by frequent burning.

Puerto Rico: considerable areas of man-made grassland exist, maintained as pasture or covering degraded and abandoned agricultural land.

Virgin Islands: present in former agricultural areas.

American Samoa: only as early regeneration after disturbance.

Guam: extensive fire-adapted areas occur on the southern part of the island.

Northern Marianas: extensive areas of grassland and tree savanna on the northern volcanic islands; man-made grasslands on Saipan and other islands.

Marshall Islands: found on the smaller islets of some atolls.

Pohnpei: present, often from burning.

Kosrae: present.

Truk: present.

Yap: now predominant; grows on clay soils or where frequently burned.

Palau: there are savanna and woodland on clay soils, and fire-maintained grasslands.

Grasslands and savannas are an ecosystem resulting on tropical islands from human disturbance, usually burning. Regrowth is usually rapid after a fire. The grasses do help to prevent erosion, and may contribute to scenic beauty, but the repeated burning degrades the soil, and the fire often spreads into and destroys adjacent areas of valuable forest or vegetation. Grasslands can be used as pasture for livestock, but overgrazing can be a problem, particularly in erosion-prone areas subject to drought followed by heavy rains.

If fires are controlled, scrub or secondary forest will usually invade and replace the grasses eventually. Grasslands can also be reforested, but accidental burning can be a problem.

Wetlands and fresh water environments

These include fresh water marshes and reed swamps, lakes, rivers and streams with aquatic plants and fresh water fauna, as well as salt marshes with saline water fauna. On small islands these ecosystems may be very restricted, and their tiny populations may be particularly vulnerable to disturbance.

Puerto Rico: there are some rivers, marshes and other ecosystems; salt marshes may occur behind mangroves.

Virgin Islands: no permanent rivers or streams exist; salt ponds are common in bays behind mangroves.

American Samoa: streams and coastal marshes are common, but most of the latter are disturbed; there is a permanent lake in Aunu'u crater, an intermittent lake in Ta'u crater, and a unique mud lake on Aunu'u.

Guam: there are some streams and rivers, extensive reed swamps, some fresh-water and salt marshes, and a man-made lake, forming some very limited fresh-water habitats with rare native plants and an endemic water fern.

Northern Marianas: some small fresh-water and salt marshes, fresh-water lakes on Saipan and Pagan (with hot springs), brackish lake on Pagan, and an intermittent lake in Anatahan caldera.

Marshall Islands: fresh-water pond on Lib; some tidal salt marshes.

Pohnpei: streams and rivers with fresh-water fauna, lakes, ponds, swamps and marshes.

Kosrae: short streams and other fresh-water habitats.

Truk: low swamps and marshes.

Yap: fresh-water streams, ponds, swamps and marshes.

Palau: streams and rivers, lakes, ponds, swamps, fresh-water and salt marshes; unique marine lakes with unusual ecosystems occur in limestone islands.

In spite of heavy rainfall, fresh water can often be limiting for development on islands, so all ecosystems associated with water supplies are important. Marsh and stream vegetation may slow run-off and prevent erosion, flooding and dirtying of the water. Fresh-water shrimp, fish and eels may be important local foods. Fresh-water ecosystems may filter pollutants and thus protect reefs and lagoons.

The small size of many fresh-water environments makes them vulnerable to natural damage by storm and drought and to disturbance and destruction by man. Some ecosystems may be adapted to temporary disappearance, or to the wide salinity changes of salt marshes and ponds, reappearing quickly when conditions permit, or going through a series of successional stages. However, they may be very sensitive to heavy sedimentation from construction, and to pesticides, agricultural chemicals and other pollutants. If the whole environment is wiped out, recovery may be very slow even if the sources of stress are removed. Some islands have endemic species associated with these habitats.

Recovery of damaged fresh-water ecosystems usually requires restoring natural conditions and removing sources of pollution, which can be difficult and expensive as experience in the U.S. and elsewhere has demonstrated. Even

where the protection of the natural ecosystems may not justify this, the need for unpolluted water supplies usually does.

Monitoring of water quality or sensitive species may permit early detection of problems. However, most island aquatic ecosystems are still very poorly known scientifically, and more work is needed to describe ecosystem functioning and tolerances.

While extraction of too much water may endanger some of these ecosystems, the sustainable use of water and fishing is not too difficult to regulate. The greatest threats come not from such direct uses but from the destruction of water catchments, pollution, or conversion of the land to other uses. Development controls and careful land management are necessary to protect fresh-water ecosystems and their resources.

Coral reefs

These are rich and complex ecosystems which build massive limestone reef structures with their skeletons. Their high productivity is maintained by efficient retention and recycling of nutrients within the ecosystem. Some reefs are built primarily by corals, others by coralline algae. Reefs may be subdivided into the following structural types:

Atoll reefs form a lagoon unassociated with any major landmass.

Barrier reefs are separated from the land by a large lagoon.

Fringing reefs grow directly out from the coastline and are not separated from it by more than a shallow depression.

Lagoon or patch reefs develop in the sheltered waters of a lagoon.

Submerged reefs have subsided below depths at which reef growth has been sufficient to regain the surface.

The different types of reef and different parts of reef structures may have quite different communities and functions, but these are too complex to distinguish here.

Puerto Rico: barrier, fringing and patch reef complexes occur at many places around the coast, but only a few further offshore or far from river mouths are still in good condition; most reefs are dead or dying as a result of pollution and sedimentation from land run-off and dredging.

Virgin Islands: there is a major bank barrier reef including an algal ridge (rare for the Caribbean) off the east end of St. Croix, and many other reef complexes with barrier, fringing and patch reefs elsewhere; some reefs have been damaged by pollution.

American Samoa: the main volcanic islands are in large part bordered by fringing reefs, and there are two atolls; dredging, pollution and dynamiting for fish have damaged some reefs and the inner reefs of Pago Pago Harbor have been destroyed by development.

Guam: there is a barrier reef and lagoon near Cocos Island and a variety of fringing and patch reef types elsewhere; some reefs have been affected by pollution and heavy human use, and probably by the heavy fighting during World War II.

Northern Marianas: fringing reefs are common and often broad in the southern islands, and some have been damaged by fishing with explosives (and earlier by warfare); little is known about the northern active volcanoes, but they probably have little more than a veneer of living corals.

Marshall Islands: all the islands are atolls built by coral reef ecosystems; there has been reef damage on some atolls from the pressures of the human population and from earlier nuclear weapons testing and associated military activity.

Pohnpei: an extensive barrier reef encloses a lagoon with fringing and patch reefs on Pohnpei; the outer islands in the state are all atolls.

Kosrae: the island is largely surrounded by fringing reef.

Truk: a major barrier reef with islets encloses the Truk lagoon which contains complex reef structures; there is considerable damage from fishing with explosives, and earlier from the sinking of a whole Japanese fleet in the lagoon; the outer islands are all atolls.

Yap: wide fringing reefs surround the main islands of Yap; the outer islands are all atolls.

Palau: the very rich and diverse coral reef areas include barrier, fringing and patch reefs; some damage is caused by destructive fishing, and earlier from W.W. II; there are also some atolls.

Coral reef ecosystems are productive both biologically and geologically. An active reef can build islands such as the atolls of Micronesia, make sand for beaches, and repair itself after storm damage, but if the reef-building processes are disturbed, erosion will take over and the reef will deteriorate. Reef fisheries can be extremely productive, averaging up to 25 tons per square kilometer per year in American Samoa (Wass, 1982) where they are a major protein supply for the local population. They are an important tourism resource, protect coastlines from erosion, and supply organisms of pharmacological interest.

Reefs are subject to occasional natural disasters, and may go through cycles of growth and destruction followed by consolidation and new growth. Hurricanes frequently smash coral reefs, but the broken fragments can usually regenerate within a decade. Abnormally low tides, temperature changes, torrential rains, epidemic diseases and plagues of predators like the Crown-of-thorns starfish may also kill off corals temporarily. Human destruction of reefs is most often by sedimentation from land erosion or dredging; the sediment smothers the corals and cuts off the light they need to live. Man also blasts and dredges reefs, smashes and poisons corals while trying to catch fish, and pollutes reefs with urban and agricultural runoff, oil and industrial wastes. Even when reef damage was originally caused naturally, man-caused stresses often interfere with the more sensitive processes of reproduction and settlement, preventing the coral reef ecosystem from recovering normally, and leaving it degraded and less productive. The cumulative effects of increasing human impacts are creating a crisis situation for reefs in many areas.

It should theoretically be possible to "replant" corals in the same way trees are replanted to make a forest, and some experiments along these lines are now being attempted, but restoring any complex ecosystem is extremely difficult and much more research will certainly be needed. There are monitoring techniques now available to detect changes or deterioration in coral reefs (Dahl, 1981; Gomez and Yap, 1984).

Some traditional cultures have sustained high fisheries yields from coral reefs, generally through some form of limited assess combined with other controls and an intimate knowledge of the resource, but modern legal systems for marine areas discourage this kind of management. 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 reef resources. The Australian Great Barrier Reef Marine Park Authority has been successfully pioneering effective approaches to coastal management in coral reef areas, balancing use and protection.

Lagoons and shallow bottoms

The enclosed waters inside atolls or behind reefs in coastal areas form ecosystems with special hydrographic conditions, including considerable variations in salinity in closed lagoons. Lagoon bottoms and other shallow coastal waters can support highly productive communities such as sea grass beds and algal beds, as well as sand and mud bottoms dominated by animals on and in the sediment.

Puerto Rico: present behind barrier reefs and other offshore features; frequently affected by heavy sedimentation from the land.

Virgin Islands: extensive in bays, inside the barrier reef and along the shelf; damaged in some places by dredging.

American Samoa: open atoll lagoon at Rose Atoll; closed freshwater lagoon at Swain's Island; Pala Lagoon on Tutuila has been damaged by dredging and pollution.

Guam: Cocos Lagoon.

Northern Marianas: shallow lagoon inside some reefs on Saipan and Tinian.

Marshall Islands: all the atolls have large open lagoons totalling 4,300 square miles except Namorik, which has a closed lagoon.

Pohnpei: 340 square miles including an extensive lagoon with sea grasses around Pohnpei, and within all atolls.

Kosrae: some shallow lagoons inside the reef.

Truk: over 2,000 square miles of lagoon including 820 square miles at Truk and the remainder within atolls; there is a closed lagoon at Namoluk.

Yap: some shallow lagoons with sea grasses within Yap reefs and about 400 square miles of atoll lagoons; Eauripik has a closed lagoon.

Palau: 525 square miles of lagoons within the barrier reef plus Kayangel Atoll and Helen Reef.

Algal and sea grass beds are very productive ecosystems that serve as pastures for fish and other animals of commercial importance. They also stabilize sedimentary bottoms and thus help to prevent coastal erosion. They have some capacity for absorbing organic wastes and sediment. However, heavy sedimentation can cut off the light to and smother bottom communities. Seagrasses are particularly vulnerable to dredging and to anchor and propellor damage, and holes cut in the bed may take years to regenerate; one dredge site in the Virgin Islands was still barren 40 years later (Island Resources Foundation, 1977). It might be possible to replant sea grasses, but it would be technically difficult to stabilize the bottom enough to prevent the loss of plantings. Monitoring the area and density of algal and sea grass beds is the best way to detect changes, and this can usually be done easily by remote sensing. The infauna of animal-dominated bottom communities must be sampled with a grab. The many non-destructive uses of lagoon areas can continue as long as care is taken to protect the bottom from damage.

Interrelationships between ecosystems

On small islands where many different ecosystems are in close proximity, the interrelationships between ecosystems are often critical to the functioning of the whole island system. The forest and other vegetation types build and hold island soil, creating fertile conditions and protecting the

coastal waters from erosion. The successional sequence of ecosystems from pioneer species to mature forest restores soil fertility in areas left fallow, but the cycle depends on the presence of nearby natural ecosystems to provide the seeds, and sometimes on animals and birds to transport them. The mangroves similarly filter land runoff. The forest is also essential to managing the island fresh-water regime, trapping and holding water so that ground-water supplies are recharged and streams flow year round, and reducing reef damage from fresh-water floods. Nutrient inputs from the land may be important in the fisheries and productivity of coastal waters, and in some cases the reverse is true, as seabirds may bring nutrients from the sea and deposit them on land. The production of coral limestone and sand by coral reefs and lagoon algae builds land areas which can then be colonized by terrestrial ecosystems. Reefs, lagoons and mangroves are all important in controlling coastal erosion.

Often organisms move between ecosystems and thus provide links between them. Some fish shelter on the reef, feed in the seagrasses and breed in the mangroves. Coconut crabs live on the land but breed in the sea, while turtles live in the sea but breed on the land. The breeding areas for such animals as turtles and seabirds are critical habitats, essential for their survival, where they are particularly vulnerable.

The close links between the major ecosystems mean that the island is in many ways a single system, and the degradation of any part of it will have effects on the productivity of the whole island. Even areas developed for human use depend on natural ecosystems for many of their essential renewable resources. The cycles of water and nutrients, the flows of materials and the movements of animal populations must therefore be managed for the island as a whole, with each ecosystem playing some significant part.

ISLAND CLASSIFICATION

Islands are generally classified into four principal types on the basis of their structure and geological origins (Dahl, 1980).

Continental islands are extensions of continents or fragments of continental crust. They have rocks of continental origin with a complex geological structure and composition producing many soil types.

Volcanic islands are the tips of volcanoes rising from the sea bed. Their underlying basaltic rock may be in the form of lava or volcanic ash. Young volcanic islands may be shaped like a cone or shield; older islands are eroded into very steep and rugged topography. Young volcanic soils can be quite rich, but as they age heavy rainfall may wash away essential soil nutrients.

Atolls are low coral islands formed when a volcanic island sinks beneath the sea while the coral reef surrounding it continues to grow up to the surface, forming a more-or-less ring-shaped reef. The land area on atolls is made from sand and rubble thrown up on top of the reef by waves and storms. Atolls generally have little or no soil.

Raised coral limestone islands result when tectonic processes lift an atoll or island coral reef above sea level, forming an exposed platform of coral limestone. Such limestone is very porous and water percolates through it quickly. The soil on raised limestone may be limited unless volcanic ash, alluvial deposits from adjacent mountains, or lagoon sediments have collected on top.

An island may be made up of more than one type of structure, such as a continental island with raised coral limestone areas, or a volcanic island surrounded by a barrier reef like an atoll.

These types of island structures have a strong influence on the ecosystems and natural communities that develop on them. They also affect the way these natural systems respond to human stress or disturbance, and they may show different kinds of environmental vulnerability. For example, volcanic islands may be more susceptible to erosion, while coral islands may be particularly sensitive to ground water pollution and the rapid loss of soil nutrients and organic matter. Such responses are common to all islands of that type, so that a knowledge of the structure may help to predict development possibilities and environmental impacts.

The U.S.-affiliated islands represent all of the major island types:

Puerto Rico is a continental island with areas of volcanic rock and of raised coral limestone.

The Virgin Islands are also basically continental in origin, with St. Thomas and St. John on the Puerto Rican Plateau, and St. Croix on a ridge of sedimentary rock.

American Samoa includes the volcanic islands of Tutuila, Aunu'u and the Manu'a group, as well as two atolls, Rose and Swain's.

Guam is basically a raised coral limestone island with some weathered volcanic soils on the southern hills and plains and a few low islets on the coral reef.

The Northern Mariana Islands include a southern chain of raised coral islands from Farallon de Medinilla through Saipan and Tinian to Rota, and a chain of volcanic islands in the north ranging from an almost barren active volcano to densely-colonized young volcanic islands.

The Marshall Islands are all atolls or low coral islands.

Pohnpei, Kosrae and Truk are volcanic islands, while Yap is a continental island with metamorphic and volcanic soil types. Each of these high islands is the center of a state including a number of surrounding atolls and one raised coral island, Fais.

Palau is a continental island with weathered basaltic soils and adjacent raised coral limestone islands, barrier reef and two atolls.

PROTECTED AREAS AND OTHER NATURAL ECOSYSTEM AND SPECIES PROTECTION TECHNOLOGIES

The value of the conservation of nature can be measured in several different ways. On a planetary scale, the genetic resources represented by the unique species and varieties of islands should be preserved for their possible contributions to human betterment and their scientific interest. Protecting viable samples of each of the ecosystems of the planet, including the unique island ecosystems in each geographic area, is important to the future well-being of mankind. More locally, natural communities maintain essential ecological processes and life-support systems on islands on which all living things including man depend; if they are not protected, islands become deserts not worth living on. Conservation can also contribute to the sustainable use of island resources like forests and fisheries.

Each island ecosystem has particular contributions to make to the sustainable development and management of island renewable resources. The following are some of the contributions which can only be ensured through the protection of these ecosystems and the species that compose them.

The **lowland forests**, including **rain forest, moist forest**, and dry forest, all occupy land that is frequently required for other uses. However, these forests contain useful predators that control mosquitos and insect pests in agriculture. They help to shield adjacent agricultural areas from storm damage. They are important in water catchment and maintaining ground water levels and soil moisture. They prevent erosion on slopes. They restore soil fertility in systems of shifting cultivation. They can provide wood and other forest products on a renewable basis. They are habitat for birds and fruit bats that may be local foods. Obviously it is in the general interest to preserve some proportion of the lowland forests for all of these values, particularly

where they are greater than the alternative agricultural value of the land as is the case in at least some local areas. The different (and not always compatible) uses of forests could be met through some combination of protected natural areas, forests managed for local wood production, and agroforestry, plus forest fallow where appropriate, depending on the island and population size, soil type, etc. It is particularly important that forest be re-established on degraded or abandoned agricultural land if island productivity is to be sustained. Eventually forest destruction must be balanced by forest regeneration if island needs are to be met on a continuing basis. Some tree production needs can even be met by the increased use of trees in urban areas and along roadsides which often occupy a significant proportion of an island's surface.

Submontane rain forest has similar values to lowland forest except that the steeper slopes and higher rainfall increase its importance for water catchment, flood prevention and erosion control. While some selective logging and agroforestry may be compatible with these values, agriculture is seldom sustainable, and the maintenance of water supplies and the sustained use of the most productive lowland areas free from droughts and floods requires that protection be given priority in mountain areas. There may also be more endemic species in these higher elevation habitats.

Cloud forests cover very limited areas on those islands where they occur, and their main value, apart from their often unique species, is in water retention and erosion control.

Riverine and swamp forests play important roles in erosion and flood prevention and the stabilization of water flow, roles that generally outweigh the alternative uses for the small amount of land they usually occupy.

Mangrove forest has such importance for fisheries productivity and coastal protection that it should be maintained as a productive resource. Some limited wood cutting may be a sustainable use compatible with these functions. A small part of the mangroves on an island could probably be converted to other productive uses such as aquaculture ponds, but at least half should be assured of some protected status. The gradual nibbling away at mangrove areas for land reclamation should be avoided. The agricultural use of such land has seldom proven sustainable, and the sites are too low and flood-prone for wise urban use.

Atoll/beach forest and **scrub** have already been replaced by coconuts or other human uses in most areas except where they stabilize the sand and provide protection along the coast. Most of the species are widespread and not in danger, and many places where they still occur have no development potential. They can be an important habitat for seabird breeding in remote areas, in which case the area should receive protection.

Scrub communities are seldom in danger on islands, and if anything may spread as secondary regrowth after land disturbance. Scrub lands should be protected from fire, which can lead to serious erosion.

Savanna and grasslands are relatively unproductive ecosystems maintained by frequent burning. They seldom represent the best sustainable use of island land resources except in some of the driest areas or for limited livestock production (in which case they should be intensively managed). If fires can be controlled, grasslands should preferably be reforested.

Wetlands and fresh water environments frequently harbor food species and species of considerable conservation interest in the islands. The importance of fresh water supplies makes protection and careful management of these resources essential. Wetlands also help to prevent flooding during

tropical downpours by accumulating excess water and thus regulating runoff. Accelerating runoff by stream or drainage "improvement" may damage coral reefs and other coastal resources. These values of natural systems are frequently not appreciated when land is developed, resulting in greater human catastrophes. None of these environments should be modified or reduced in size without careful study of the consequences.

Coral reefs must be carefully protected and managed to maintain their geological and biological productivity, as they can be a significant renewable resource for many islands. This requires both preventing damaging uses within coral reefs areas themselves, and controlling the external factors such as land runoff, sedimentation and pollution which are frequently responsible for degrading reefs. On smaller islands and atolls the entire reef may represent a single system with fish migrating and populations and materials exchanged over the whole area of reef and lagoon. The sustained use of reef resources thus requires management of the complete coastal system. While some parts can be altered or developed with only minor impacts, critical habitats must be protected, and these are often not well understood. Coral reef fisheries have proven particularly susceptible to overfishing despite the impression of great fish abundance, and fishing pressure must be regulated carefully for sustainable yield.

Lagoons and shallow bottoms support important fisheries, but the small volume of the overlying waters makes them easily affected by pollution. As with other coastal resources, the sustained use of these productive resources requires management on the land as well as in the sea.

Goals for protected area establishment and management

Protected areas like national parks and reserves are one approach to the conservation of species and ecosystems through legal protection controlling entry into and use of the area. There are different kinds of protected areas adapted to different requirements for the use and conservation of resources. Where a species or ecosystem is sensitive to any human interference, then a strict nature reserve is appropriate. Large areas where conservation is compatible with recreation and education can be made national parks, and small areas natural monuments. 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 interest of inhabited areas can maintained through declaration as protected landscapes. Temporary resource reserves can be established in areas where decisions on development must await further study. Marine reserves permit the protection and management of important coastal resources. If local inhabitants want protection of their traditional life-style and resources from outside interference or development pressures, then an anthropological reserve or customary protected area can be created. Areas requiring the careful balancing of different resource requirements such as watershed protection, hunting and the gathering of traditional forest products can be made into multiple use management areas. It is thus possible to adapt the kind and degree of area protection to almost every local circumstance.

Goals for species protection

Since many species requiring conservation measures cannot be localized only in reserves, they may require direct legal protection. This is particularly important for endemic species that are rare or endangered, as well as species endangered on a world basis, and those subject to such heavy local use that

they may be driven to extinction on the island. Any extinction of a species is an irreparable reduction in the world's genetic heritage, and the disappearance of a species from an island means a reduction in that island's resource base and perhaps its ecological stability. Endangered species should be given protection from all disturbance and use. For rare species with culturally-important traditional uses, it is often possible (and politically necessary) to allow limited taking for those traditional uses only, as long as such use does not threaten the survival of the species. Other species may require permits limiting the number of users, limits on the numbers taken, or closed seasons on taking (usually during the breeding season) in addition to the inclusion of the necessary habitats in protected areas.

Traditional resource management and conservation

Traditional island cultures, particularly in the Pacific, developed elaborate systems for the management of their local resources which include some useful models for sustainable management and conservation on islands. Where resources were abundant relative to the local population or the technology for taking the resource, enough was taken for immediate use, and the rest was left for the next time. Wealth was accumulated as traditional money or obligations, not as resources, which were shared according to need. Where a resource was scarce, different types of conservation measures were practiced, including: restricting the number of consumers; restricting access to the resource; creating taboo areas (reserves), temporary closed areas or closed seasons; and using the resource only on limited occasions (for ceremonies or in times of famine).

Land was not owned as it is in western countries. The land and reefs belonged collectively to a village or family, and each individual had a complex set of rights to grow crops on certain plots of land and to hunt or fish in certain areas. Clearing land often established the right to use it, while land left unused might eventually revert to the common holding. The peoples' collective attachment to their land, the home and burial place of their ancestors, is very strong, making the taking of land even for essential public purposes very difficult.

Each village had its own local experts on forests, agriculture, fisheries and other practices or resources who advised on their use and management. The knowledge of these local experts compared favorably with the best of modern science (Johannes, 1978; Dahl, 1985a). Unfortunately, the cumulative impact of missionaries, colonial administrators, school systems and the import of western values and technologies has largely destroyed these traditional management systems and the knowledge on which they were based. The cultural loss has generally been greater in the U. S. territories then in many other island countries with less outside impact.

Modern attempts to manage island resources for sustainable use must take into account these traditional factors as much as possible. Traditional management practices may have proven their worth over centuries, while the track record for modern resource management is not very good. The western concept of ownership is too inflexible for islands where a small amount of land must be shared among many multiple uses, just as making everything below high water mark the public domain destroyed the careful management of reef and lagoon areas that accompanied traditional collective ownership. While it is not possible to return to the closed world of the traditional island society, it may be possible to seek inspiration there for new approaches

better adapted to island problems. Where new resource management technologies are seen to reinforce traditional ways or ideas, they will have a better chance of success, while foreign ways imposed from outside are doomed to failure.

This is particularly true of protection technologies for island land and native species. There is strong resistance in the Pacific Islands for any government taking of land or imposition of land-use controls like zoning. The same applies to anything seen as interfering with what is perceived as a traditional cultural practice, such as hunting native birds. Protection of any resource in the islands will only work if it has the support of the local population, and particularly the resource users, the traditional leaders, and the heads of the land-owning families. Thus a great deal of patient work in education and public information is necessary to lay the foundation for conservation action. Even if protection measures are put in place, enforcement cannot work where everyone is a friend or relative of the enforcing officer. In the islands, without public support, enforcement is impossible; with it, enforcement is hardly necessary.

While the inhabitants of the Caribbean islands are not as deeply rooted in traditional cultures, the requirements of island life have led to similar social constraints and opportunities. Only in Puerto Rico is the scale of the island community so large that much of the discussion here of social and cultural factors is of limited applicability. However the situation there is less foreign to the American experience then that of the very small islands.

GUIDELINES FOR THE ESTABLISHMENT AND MANAGEMENT OF PROTECTED AREAS

It should be clear from the above sections that protected area establishment cannot be the same on islands as it is in the continental United States. Both the nature of the protected areas and the means by which they are created and managed must be modified to suit the social, cultural and ecological conditions of the islands. The following are some guidelines for creating and managing protected areas in the U.S.-affiliated islands.

Information

Great progress has been made in the last few years in the preparation of inventories of resources for the U.S.-affiliated islands. Some are complete and others are still in progress. However there are gaps in the inventories for some resources and for some areas. Also, the inventories have concentrated on the most obvious organisms, and many less evident but ecologically important groups have not yet been studied.

Inventories tend to be lists and static descriptions at one point in time; much less is known about the ecosystem dynamics and the broader functioning of the island systems. The sustainable use of resources requires both knowledge of the appropriate techniques for their use, and quantitative information on how much use is sustainable. The quantitative information is largely lacking, particularly since island conditions can be quite variable from year to year. Only experience with long time series of basic environmental information will make it possible to say if what seems sustainable this year will also be sustainable next year.

An island system is also more than the sum of its parts. While there may be sectoral descriptions of different island resources (forests, wildlife, the coastal zone), there is a lack of information on the interrelationships

between ecosystems that make up the whole island system, such as transfers of nutrients, the water cycle and water movement, the transport of soil or sediment, and the distribution of the seeds or young of island plants, animals and marine life. If resources are to be sustained in the long term, the whole island must be managed as a unit to ensure that essential life-support systems like the fresh water supply and reserves of soil and nutrients are not degraded.

Implementation of protected areas

A network of protected areas should be a basic component of island management, protecting sensitive parts of the island system from overuse. Since the heavy demand for resources on a small island makes it difficult to dedicate areas exclusively to single uses, protected areas need to be planned to combine species and ecosystem protection with other requirements for resource management so as to make the most efficient use of island resources. Indeed, in the context of traditional collective land tenure and the modern lack of tenure in the marine environment, protected areas of appropriate kinds may be one of the best ways to manage resources in the implementation of comprehensive island management plans.

In an island situation such as that in the Pacific where land is limited and has been held in customary ownership for generations, protected areas that exclude people and their activities can be difficult to implement. There may be no land available to exchange for that requiring protection, and no monetary payment can fully compensate for the spiritual ties to the land of one's ancestors. It is hard to displace people when there is no other place available on their island that they can call their own. Even controls on land use or development may mean lost opportunities difficult to replace when there are few alternatives available.

Conservation is also difficult in the face of population pressures. If an island's population approaches or exceeds its carrying capacity, no resource will be left untouched and restrictions on exploitation become impossible to enforce. Managing the human population is as much a part of the sustainable utilization of an island as is managing any other resource.

Participation by local people

Protected areas can only be effective on an island if local people participate from the beginning in the conception of the areas, the definition of their boundaries, the preparation of management plans and regulations, and the enforcement of the controls adopted. There is now sufficient experience in both the Pacific and the Caribbean to demonstrate that there is no substitute for public support and involvement (SPREP, 1985; Geoghegan, 1985).

The protected area concept also needs to be adapted so that it can be applied to land in individual or collective ownership with the agreement of the owners. This carries public support to its logical conclusion, and avoids the problem of cutting people's cultural and spiritual ties to their land. The law should provide the necessary authority and guarantees; the need for protection can be identified by the government or by the local people; regulations and management plans are decided by a committee of land owners in consultation with the government authorities; the protected area agency provides technical advice and perhaps some financial support or management assistance; and enforcement is by the land owners and/or park staff, as appropriate. With this approach, protection can be achieved in a culturally-acceptable fashion, and at less cost than if government acquisition of the land were required.

Monitoring

Resource management requires periodic reports on the state of the resource, just as financial management requires regular accounts. Resource inventories and monitoring are essential for the management of protected areas, and for the control of activities in adjacent areas that might have an impact on the protected area. However, most studies or surveys on islands have been made by scientists visiting for short periods. Few islands have a local scientific capability for such monitoring, and visiting scientific teams are expensive. Effective resource management will therefore require the development of resource inventory and monitoring techniques that can be supplied cheaply or carried out locally with available manpower. Techniques that allow local people without scientific training to monitor coral reefs have been developed (Dahl, 1981) and similar approaches could be evolved for other resources. The rapid development and improving resolution of remote sensing technologies also hold great hope for economical island monitoring (Bour et al., 1985).

Again, it is important that local people be involved in monitoring. When they see for themselves what is happening to a resource, they will be motivated to control their own behavior (assuming they have options open to them). There will be no suspicion or questioning of the wisdom of outside experts. They will be able to judge if the protected area is achieving the goals for which it was established, or if its regulations or boundaries need modification. Monitoring information will be put to use in the most immediate and direct way.

Planning

Information from inventories and monitoring also must be fed into the physical and economic planning processes. This can be relatively simple on islands where organizational structures are small-scale and there are few layers of bureaucracy. Indeed, there is a danger of imposing procedures too cumbersome for the size of the community. Simple short reports and maps or map overlays supplied to the planning office may often be sufficient. Ideally a microcomputer could be programmed to process the data and present it in simple forms which could be used and manipulated by island planners.

Education

Protected areas should themselves become part of the educational process for the island public. In those areas or parts of areas open to the public, interpretive materials should explain what is protected and why. Parks should become environmental education laboratories for school groups. The first protected areas on an island should be carefully chosen and developed to demonstrate the value of parks and reserves to decision-makers and the general public. Further protected areas can then be established as public understanding and support increase. Education is equally important for species protection; the public should come to identify with and want to help their local protected species. Fortunately, the smaller the island, the easier it is to get the message to the whole population.

Alternative protection mechanisms

Achieving effective protection of species and ecosystems on small inhabited islands requires a combination of approaches. Protected areas are useful for critical habitats and areas where human interference must be strictly controlled, but they can never be large enough to assure the long-term existance of all island species and ecosystems. Protecting species

can reduce the direct loss of plants and animals to humans, but does not assure their habitat or their survival against competition from introduced species. Where introduced species are a problem, they may need to be controlled or eradicated all over the island or at least in the most sensitive areas. If the habitat or food supply is inadequate to assure a species' survival, further habitat may need to be created or food sources provided.

On small islands it is often not possible to maintain an adequate physical separation between damaging human activities and natural systems, as is done in continental areas. Activities that are incompatible with the survival of species and ecosystems may simply have to be avoided or prohibited. For instance, the risk of accidental damage may need to be reduced by controlling the importation and use of pesticides and other toxic chemicals, and certain types of industrial development may need to be limited or prohibited for the same reasons. More basically, the development desires of the people must be kept within the limits of what the island and its natural systems can support.

SUMMARY: CONSTRAINTS AND OPPORTUNITIES

The establishment of protected areas in the U.S.-affiliated islands can make important contributions to the sustainable use of renewable resources, but several constraints must be overcome to achieve this.

--- Island ecosystems and species are particularly vulnerable, requiring more scientific knowledge, more careful protection, and sometimes more active management than in other parts of the world.

--- The responsibility for the protection of many endemic species and unique ecosystems must be borne by small populations with very limited trained manpower, often weak local institutions and political structures, and little money. In addition, the small island governments cannot cope with the elaborate procedures and requirements to which large governments are accustomed.

--- Development and population growth increase the demands for limited island resources at the same time that the productive resource base is diminishing from overuse and misuse. Basic human needs often clash with the essential requirements for conservation, and conservation usually loses out. On some islands only fragments of natural areas remain, and many species are endangered.

--- There is little information available on the dynamics of island systems that would allow a clear determination of what level of resource use is sustainable.

--- Protected areas as evolved in large developed countries are seldom appropriate on small islands; the concepts must be modified to suit local cultural and ecological requirements.

--- Island people forced to give up their land or resource uses for conservation cannot easily find other land or resources when all island

space is already occupied. Furthermore, nothing can replace the deep cultural and spiritual ties to ancestral lands.

At the same time, islands do present some special opportunities for the use of protected areas.

--- Many island people still live close to their environment and remember the wisdom of their ancestors in managing resources. With education they can come to see the need for protected areas and other conservation measures to preserve their island heritage. It should then be possible to get them to support and contribute to protected area establishment and to participate in protected area management.

--- The small size of islands makes it easier to study them as complete systems, and should thus make it possible to integrate protected areas into the comprehensive management of island resources.

--- Simpler solutions to many problems are possible in small island communities.

--- New technologies like remote sensing and simple monitoring by non-specialists should permit more rapid studies of the condition of resources and protected areas with immediate feedback into local resource management.

U.S. Federal agencies

The small number of protected areas in the U.S.-affiliated islands would suggest that the Federal agencies responsible for establishing protected areas have not been very active or effective in the islands. Part of the problem is the difficulty of adapting the requirements in American law concerning the different types of protected areas to the situations prevailing in the smaller islands. The primary responsibility may also have been left with local governments who have had neither the expertise nor the means to pursue the

creation of protected areas. The newer more flexible types of protected area such as the National Marine Sanctuary Programme may prove easier to adapt to island needs. U.S. provisions for protected areas also lack a strong role for local people in planning and management such as would be necessary in many island situations.

Objectives for congressional action

Most U.S. legislation is too complex and its requirements are too rigid for the smaller U.S.-affiliated islands. Application of such laws to the islands can sometimes be a disservice and a hindrance rather than a help, requiring massive paperwork from scarce local staff who then have no time to do their real jobs. Some procedure should be developed allowing the small islands to observe the spirit of the law without necessarily being obliged to follow the letter.

With reference to protected areas and other conservation measures, more appropriate types of protected areas should be defined in law for implementation at the local level with Federal assistance as appropriate. Island governments should be given as much autonomy as possible in the creation and management of protected areas.

All the Federal agencies with responsibilities for conservation should be encouraged to establish special programs of technical assistance to local island governments. The most effective protected area programmes in other island countries have all been started with the help of experienced parks and reserves personnel seconded for periods of one year or more to work along side and train local counterparts in the launching of protected area programs. Opportunities could also be created for island conservation staff to receive a few months of practical on-the-job training in U.S. protected areas.

The United States is seen as responsible to the international community for protecting the genetic heritage of endemic and endangered species in the U.S.-affiliated islands. It should therefore provide incentives and financial support for island government actions in this area. Federal efforts need to be sensitive to the fact that effective protection requires local initiatives and public support, while the economic burden of that protection should not and cannot be borne only by the local people.

Given the strength of American science, the lack of basic scientific information on many aspects of the U.S.-affiliated islands is an embarrassment. Much of what has been done has been mission-oriented work by commercial firms under contract to Federal agencies, and such work seldom addresses the most basic issues. More scientists should be encouraged to work on priority problems of interest to the islands, such as the dynamics of island ecosystems, island carrying capacity, the sustainable levels of resource use, and the status and protection requirements of island species and ecosystems. This may require a special program of research grants for work in the U.S.-affiliated islands to offset the especially high costs of travel to and work in such areas.

Educational efforts to improve local understanding and appreciation of island species and ecosystems are an essential foundation for any successful protected area program, yet local island governments lack the expertise and technical means for such activities, and the non-governmental organizations that make the major effort in this field in the U.S. are weak or non-existent in the islands. Congressional action might help to foster the development of educational programs for the schools and the public based on local island situations in each U.S.-affiliated island territory. Local relevance is essential to the effectiveness of such activities.

Accession by the United States to the Convention on Conservation of Nature in the South Pacific (concluded in Apia in 1976) on behalf of the U.S.-affiliated islands in the Pacific would open the door to closer cooperation in conservation matters with other Pacific Islands with similar problems.

Institutional actions

International organizations. The International Union for Conservation of Nature and Natural Resources (IUCN) can draw on a vast quantity of information and the extensive experience of its world-wide network in identifying priorities and suitable approaches for conservation action. Its help should be called on when needed. Where trade in endangered species is involved, the Convention on International Trade in Endangered Species (CITES) provides a mechanism for action.

Regional organizations. The South Pacific Regional Environment Programme (SPREP) at the South Pacific Commission is one of the UNEP Regional Seas programs, providing assistance to all island governments in the Pacific in various environmental fields including protected areas. It would be the best single source for regional experience with practical problems, and can provide considerable assistance with appropriate educational programs. The Caribbean Regional Seas program and the Organization of American States may serve a similar role in the Caribbean, where regional non-governmental organizations are also important.

U.S. Congress. Congress should find means to modify the application of Federal legislation to be more appropriate to small tropical islands, and should see that they get the support necessary for effective conservation programmes adapted to their needs.

U.S. Federal Government agencies. The agencies with responsibilities for protected area programs (Park Service, Forest Service, Fish & Wildlife Service, NOAA) should make their practical technical experience more readily available to assist island governments. The research agencies (National Science Foundation, Smithsonian Institution, etc.) should support more research projects in the islands in collaboration with island governments. The Environmental Protection Agency should consider special standards for pesticides and other potential pollutants that are adapted to tropical conditions and island vulnerability so different from the situation in the mainland U.S.

Insular governments. The governments of the islands have the primary responsibility for resource management and the creation of protected areas on their islands, but they generally lack the expertise and finance, and often the motivation, to concentrate on what are essentially long-term goals. They must be encouraged and assisted to take a leading role in the comprehensive planning and management of island resources including the protection of island species and ecosystems. The development of a local Conservation Strategy based on the principles of the World Conservation Strategy (IUCN, 1980) could help with this. Each government should have at least one officer at a reasonably high level with specific responsibility for the long-term protection of the island's natural heritage. There is also a need for additional legislation for the creation and management of protected areas adapted to local nature conservation needs and cultural restraints. In the school system, materials on local species and ecosystems and on the need for sustainable resource use should be included in the curriculum at all levels.

Private - industry. Industries must assume the responsibility for protecting the environment from their activities. Where they depend on island natural resources, they should ensure that their exploitation of renewable resources is sustainable, and that renewable resources are restored in areas where non-renewable resources have been extracted. Too often in the past, industries have profited from an island resource and then departed, leaving the island to bear the long-term costs. Where industries have land holdings or rights, they should contribute to the protection of species or critical habitats in areas under their control, and governments should if necessary provide tax concessions or other incentives for them to do so.

Academic institutions. The universities and marine laboratories in the islands should increase their research and teaching programs on island ecosystems and species and on the renewable use of resources in both the terrestrial and marine environments. These institutions would benefit from a pairing arrangement linking them to stronger U.S. universities, allowing a regular supplemental input of teaching and research staffs. A program of assistance to interested institutions to cover the extra costs of such arrangements would be a cost-effective way to strengthen research and training in the islands where it is needed the most.

Non-profit institutions. Non-profit organizations have been active in the Caribbean, where the Caribbean Conservation Association and the Eastern Caribbean Natural Areas Management Program continue to be very helpful. They have an important role in technical assistance, public education, and the development of grass roots support, and should be given every encouragement. Such institutions have not developed in the Pacific, where transportation and communications are too costly, except at a small local level. The World Wildlife Fund and other U.S. conservation organizations should be able to

develop and support urgent species and ecosystem protection projects in the U.S.-affiliated islands where governments have been too slow to take the initiative.

Traditional organizations. Where traditional organizations such as councils of chiefs or elders exist, they could carry great weight in the protection of species and the identification and management of appropriate protected areas. Their understanding and support will need to be cultivated through regular and patient contact.

Impacts and consequences of the proposed actions

Islands that fail to maintain their basic renewable resources can be epitomized by Easter Island, where the pre-European population destroyed the forest, leading to soil degradation, social disruption and a great reduction in the capacity of the island to support a populaton, or Ocean Island, where the population had to be evacuated as a result of mining damage. Recent successes in education and the creation of protected areas by traditional land owners are exemplified by the wildlife management areas in Papua New Guinea (Eaton, 1985; Papua New Guinea, 1985) and the iguana reserve in Fiji (Singh, 1985). There are now about a hundred protected areas in the tropical Pacific Islands (Dahl, 1980; IUCN, 1985), but these protect less than 20% of the ecosystems in the region (Dahl, 1985b). An increase in the number of protected areas would prevent tragedies like Easter Island, where no native trees and shrubs remain (IUCN, 1985) and assure the widest range of development options for the future.

The likely consequences of the actions recommended in this paper would be a steady increase in public awareness of the need to protect island species and ecosystems, and of the scientific understanding of their requirements, accompanied by the creation of some parks, reserves and other protected

areas and stronger measures for the protection of endangered species. While there would be costs associated with these actions, there is some evidence that the benefits of protected areas can far outweigh the costs (Van't Hoff, 1985) even disregarding the eventual cost of more island dependence on outside aid. There will still be some species extinctions and the disappearance of some ecosystems where the decline has already gone to far and the threatening factors (such as introduced species) are difficult to control. The broader use of protected areas for resource management will take more time to implement as the legal and institutional foundations for comprehensive island planning and management are developed and as practical experience is acquired 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 those conflicts will determine whether the U.S.-affiliated islands maintain a sustainable base for their populations, or slowly decline in productivity with an inevitable increase in dependence on outside (primarily U.S.) sources of support. The outcome depends in large measure on the extent to which actions are taken rapidly along the lines recommended here.

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