Chapter 5
Islands As Integrated Systems

CONTENTS

Figures

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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.

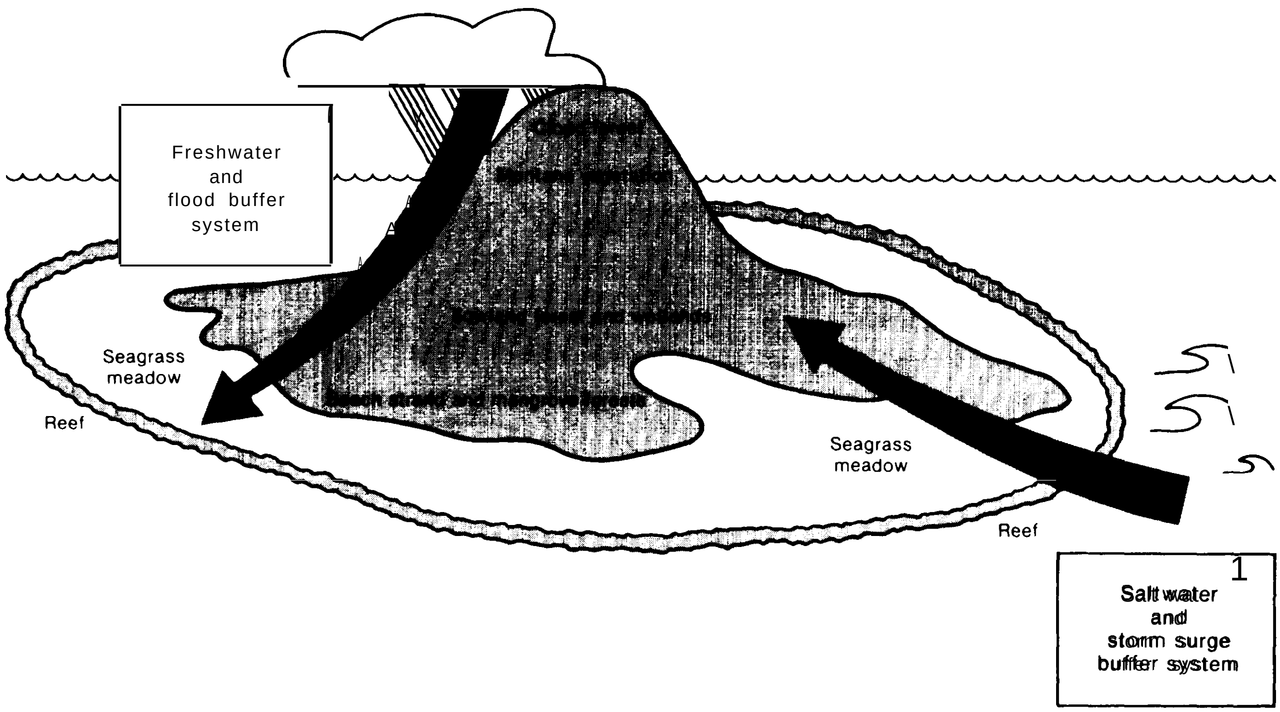
Island resource damages have occurred over long periods of time; many of the corrective actions have taken place relatively recently. These recent encouraging actions seem likely to continue and perhaps expand while certain of the old causes of resource damage probably will fade away. To accelerate this 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.

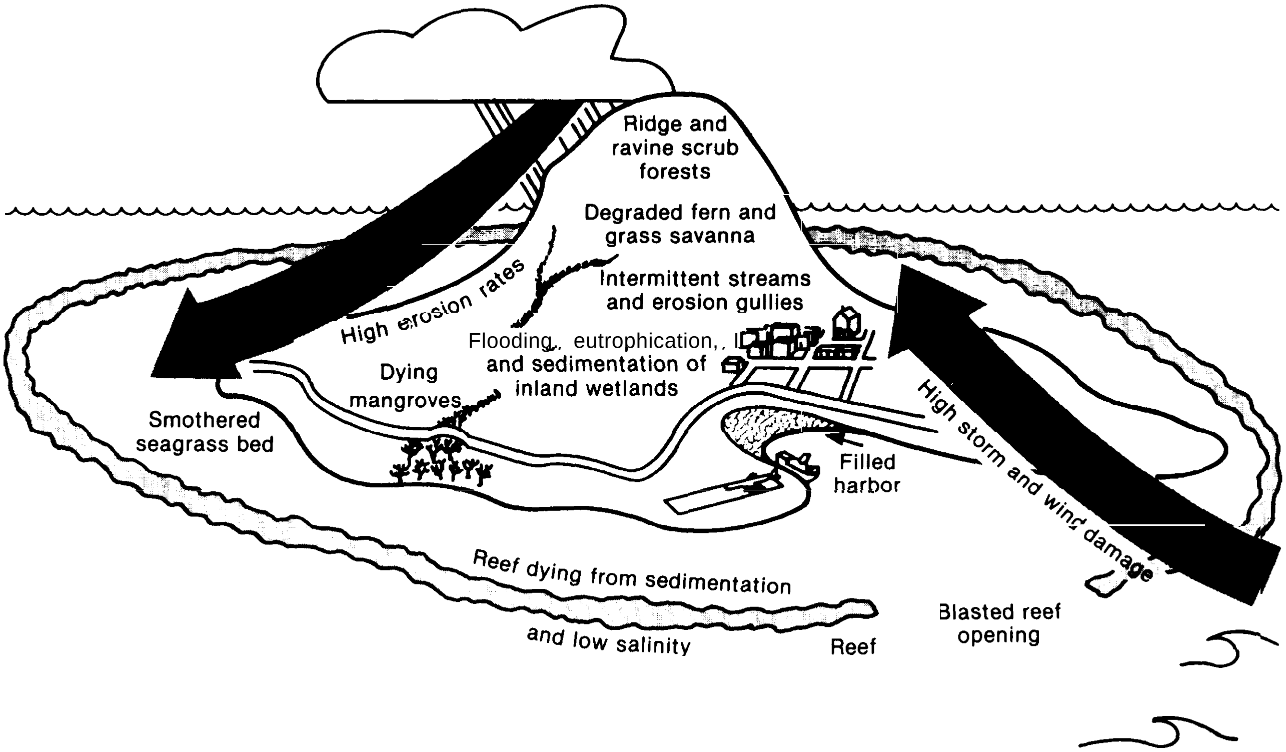
Development activities that modify or degrade parts of these buffer systems may result in repercussive changes to connected ecosystems (figure 5-2). For example, if a part of a reef is mined, the opening which results will allow wave energy to impact directly on the shoreline. The previously quiet environment 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

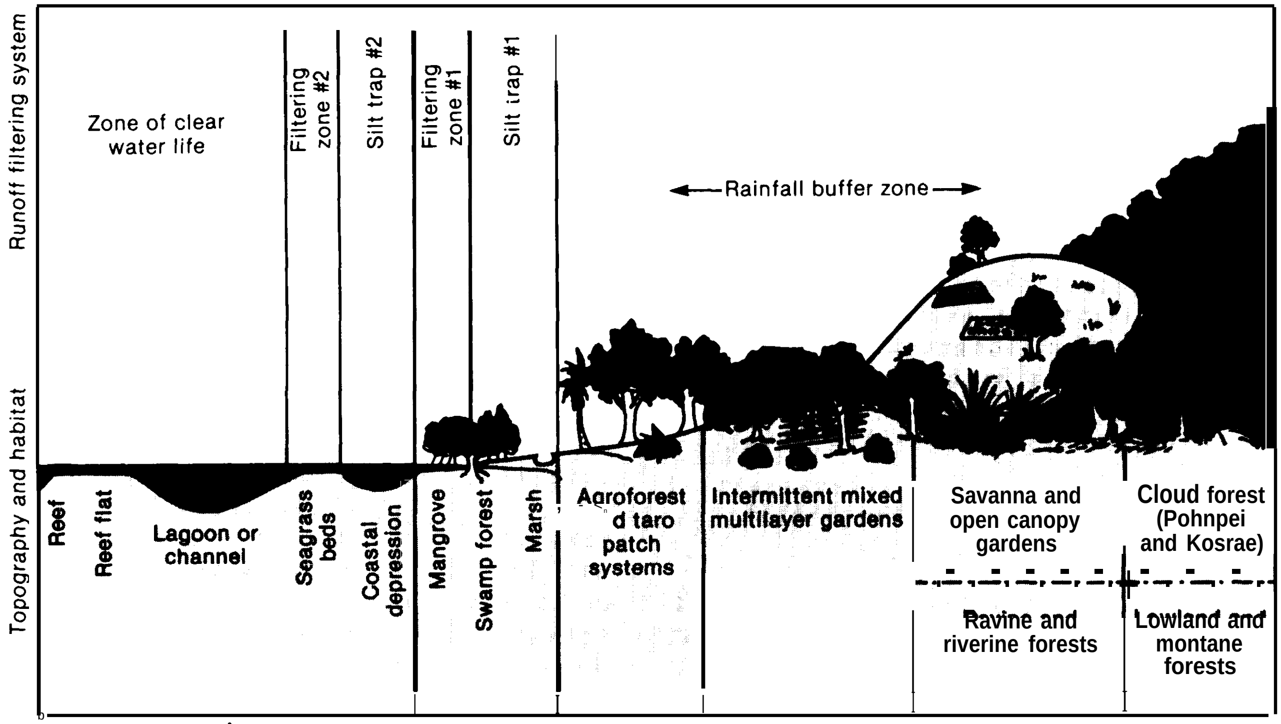
Tropical storms are more violent than those in temperate areas. More water falls per storm, quickly saturating the soil. Consequently, a larger proportion of the rainfall runs off the soil surface. Furthermore, in tropical storms raindrops commonly are larger, thus having great kinetic energy and high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

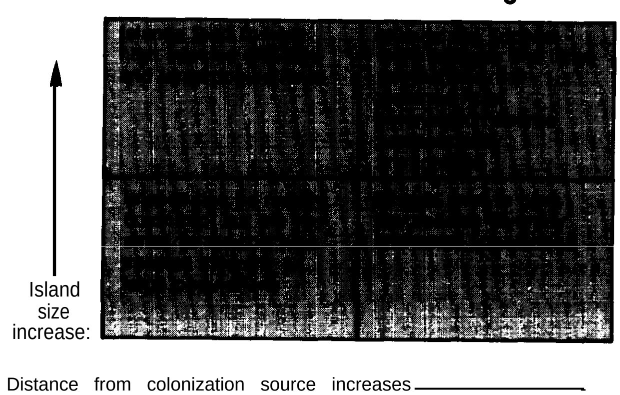
While tropical ecosystems are among the most productive in the world (cf: 1), they are also vulnerable to natural and man-induced disruptions. Because most of the needed and available plant nutrients in the systems are held in the biomass, a high percentage of nutrients can be lost rapidly from exploitation.

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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