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ECOLOGICAL GUIDELINES FOR TROPICAL COASTAL DEVELOPMENT

WILLIAM E. ODUM

Published with the support of UNESCO,
the United Nations Environment Programme,
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University of Virginia

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FOREWORD

For many years the International Union for Conservation of Nature and Natural Resources (IUCN) has been engaged in activities directed toward the formulation of ecological concepts, principles and guidelines appropriate to economic development. Studies have been supported and workshops have been held in various areas of the world. The results of these activities have been recorded in a number of publications including Ecological Principles for Economic Development by R.F. Dasmann, J.P. Milton and P.H. Freeman (John Wiley, 1973); Ecological Guidelines for Island Development by E. Towle and J. McEachern (IUCN, 1974); The Use of Ecological Guidelines for Development in the American Humid Tropics (IUCN, 1975); The Use of Ecological Guidelines for Development in Tropical Forest Areas of South East Asia (IUCN, 1975); and Ecological Guidelines for the Use of Natural Resources in the Middle East and South West Asia (IUCN, 1976).

This programme has been carried out in close collaboration with a number of agencies including The Conservation Foundation, Island Resources Foundation, the World Wildlife Fund and the United Nations Environment Programme. It has been supported by funds from the Swedish International Development Authority, Unesco, the United Nations Environment Programme and the World Wildlife Fund.

The application of ecological principles to the process of economic development is of importance in all ecological regions. There is none, however, which has suffered greater abuse from failure to recognize this principle than the coastal zone of the world's continents and islands. Particularly in the industrialized countries of the northern hemisphere, coastal zone development has gone forward in the past without consideration of the effects on ecological processes. As a result there have been severe problems of marine pollution, an impairment of the biological productivity of coastal and other marine environments, a depletion of fisheries, and a growing amount of damage to coastal installations which were developed at great cost.

Recognition of this situation caused the International Union for Conservation of Nature and Natural Resources to devote particular effort to call attention of development agencies and decision-makers to those ecological principles which cannot safely be ignored, particularly in the tropical world where development has not yet proceeded past a point of no return. IUCN has been fortunate in obtaining the services of Professor William E. Odum of the University of Virginia who has long experience with the ecology of coastal zones and the effects of development. His report, presented here, is a welcome addition to the IUCN publication series.

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I. INTRODUCTION

The coastal areas of the world are in the midst of a period of economic development of unprecedented proportions. Much of this development is necessary and has been accomplished in a satisfactory, well planned fashion. In other areas, however, particularly in the heavily industrialized nations, great expanses of the coast have been altered to an extent that little resembles the original, natural state. Frequently, these extreme alterations resulting in considerable economic, recreational, ecological and aesthetic loss, have not been necessary and could have been avoided through better understanding and planning.

This short paper was written with the hope that the same mistakes will not be perpetuated as economic development spreads into tropical coastal regions. The people of these newly emerging areas have a unique opportunity to reap not only the benefits of economic development, but also to retain ecological features of great value.

To understand how development can be made compatible with natural processes, this paper has been organized into four sections. The first deals with basic ecological principles; an understanding of these, no matter how superficial, is the beginning of a realization of how nature works and how she can function to man's advantage. In the second section guidelines are presented which are derived primarily from ecological principles. These guidelines are intended as a beginning point for development or management considerations for specific sites. The third section, with three examples, demonstrates the value of ecological knowledge as a tool in the economic development of environments common to most tropical coasts. The final section combines information from the preceding material into a framework of comprehensive environmental planning. Such an approach allows apparently incompatible uses to coexist on the same stretch of coastline without seriously interfering with each other.

The discussions to follow deal principally with tropical and subtropical coasts. For convenience these are defined as lying between 20°N and 20°S latitude. Of course, much of the information presented here applies equally well to higher latitudes.

II. ECOLOGY, ECOSYSTEMS AND ENVIRONMENTAL MANAGEMENT

Many fields of science and social science are concerned with the understanding and management of the environment. Central among these is the discipline of ecology. As pointed out by Raymond Dasmann, John Milton and Peter Freeman in their Ecological Principles for Economic Development, ecology is neither an emotional state of mind nor a political point of view. Ecology is a science complete with a large body of knowledge, principles to organize the knowledge and a potential ability to predict future events.

Ecology, from the Greek root oikos, means literally "house" or, more accurately, "household". Thus, ecology is the study of "houses and households" or, more broadly, environments and environmental components. A modern emphasis is to define ecology as the study of the structure and function of nature, with man, of course, as an integral part of nature.

Ecologists are concerned, in a general sense, with studying and understanding nature at four different levels of complexity. The simplest level is that of a single population, in other words, a group of organisms, plants or animals, all of the same species. The second level, more complex than the first, is that of the community which, in the ecological sense, includes all of the populations of a given area. The community and the non-living environment (water, soil, nutrients, etc.) function together as an ecological system or eco-system. Finally, the biosphere is that portion of the earth which is biologically inhabitable and in which individual ecosystems exist.

For those interested in manipulation and management of the environment, it is convenient to choose one of these levels of complexity as a standard unit for orientation and understanding. Considerations of large-scale atmospheric pollution require a biosphere level of orientation; certain types of fish and game management are most easily carried out at the population level. In general, however, the biosphere level is too large and complex while populations and communities are unrealistically simple. This leaves the ecosystem as the most practical research and management unit.

In a sense, the ecosystem is an abstract unit, since its boundaries are flexible and are defined by the individual investigator or manager to meet his own needs. The only limitations are that certain specific components be present

and that they interact in a prescribed manner. This means that very small areas such as a square meter of pasture or very large areas such as a 20 km^2 lake may qualify as ecosystems.

The simplest definition of an ecosystem includes all of the animal and plant populations of an area in addition to the non-living components. More specifically, for an area to be considered an ecosystem it must have: (1) plants or "primary producers" which are able to manufacture food by combining energy from the sun with simple inorganic substances; (2) consumers, chiefly animals, which ingest other organisms or particulate organic matter; (3) decomposers, principally bacteria and fungi, which decompose the complex compounds of dead animals and plants; (4) inorganic substances (nitrogen, carbon, phosphorus, etc.); (5) organic substances (proteins, carbohydrates, lipids, etc.); and (6) a climate regime (temperature and other physical factors).

Furthermore, to be a complete ecosystem, the organisms and their non-living environment must interact with each other in certain ways. For example, nutrients such as phosphorus and nitrogen are cycled back and forth between living and non-living components. Energy from the sun is fixed in the form of plant tissues, then passed to herbivores and finally several levels of carnivores. Populations of animals and plants interact with each other behaviorally (symbiosis), physically (crowding) and chemically (inhibitory substances). At the same time the physical environment and climate affect the animal and plant populations by encouraging or limiting population growth.

With these requirements in mind, it should be apparent that certain sites qualify as complete ecosystems while others do not. A pond, a stretch of river, a tract of forest or a meadow, all are complete ecosystems. On the other hand, an expanse of ocean bottom at 3,000 meters depth or the assemblage of animals inside a cave cannot be considered as complete ecosystems because they lack plants and are dependent upon food materials washed or carried in from other environments.

Ecosystems, although identifiable as relatively complete units, are not closed systems. Materials, organisms and energy are cycled, move and flow between ecosystems in a regular fashion. A stream can be considered a separate ecosystem from the forest through which it flows, although much of the food energy for the animals of the stream originates from the leaves of the trees in the forest. Linkages or connections between ecosystems may be of great importance in assessing the impacts of proposed alterations and development.

Selection of a management-sized ecosystem

As pointed out previously the dimensions of a particular ecosystem are dependent upon the use for which it is defined. Take as an example a small pond stocked with fish. For the fisheries biologist interested in managing this resource to obtain the greatest annual yield of fish, it may be sufficient to limit the defined ecosystem to the pond by itself and ignore the beach and forest beyond. If the pond's watershed remains in a pristine, undeveloped condition, understanding the relationship within the pond between plants, animals and the physical environment may be sufficient to understand fish production. However, if a manufacturing plant or housing project is located in the watershed, the effects on the pond may be of great importance. In this case the fisheries biologist will find it necessary to consider the pond and its watershed as a single functional unit. With this approach it should be possible to predict the consequences to fish production of human activities within the watershed.

In all cases which deal with land-use management, it is necessary to delineate the management ecosystem according to clear, functional boundaries. There are many possible boundaries; among the most commonly encountered are: (1) edges of watersheds or airsheds; (2) clear physical delineations such as the edges of areas affected by strong physical forces (floodplain boundaries, the transition line from land to water); and (3) distinct vegetation boundaries such as the edge between a forest and an open grassland.

In summary, an ecological system or ecosystem consists of a functional assemblage of plants, animals, decomposer organisms, non-living substances, a climate regime, and, of course, man. It has characteristic biological and physical patterns of organization common to all ecosystems. While functioning as a complete system, it also has inputs and outputs to other ecosystems. All of the users and processors of materials and energy, including man, are a part of the ecosystem and are responsible to a greater or lesser extent for its successful operation.

III. ESSENTIAL ECOSYSTEM PRINCIPLES FOR COASTAL MANAGEMENT

The full understanding of how ecosystems function and how they respond to manipulations from man is a complicated subject. In many cases, explanations are lacking and complete understanding is far in the future. There are, however, a series of basic principles which have been satisfactorily elucidated and which it is useful to mention briefly. This is not a complete list nor are the explanations exhaustive. The important lesson is the beginning of a realization of the delicate nature of most ecosystems, the ease with which they can be disrupted and the potential side effects which may result.

A. The concept of biological productivity and energy flow

Statement: The most important biological process in an ecosystem is the photosynthetic conversion of radiant energy from the sun into stored plant energy. Once energy has been fixed by plants (primary production) it can then be converted to animal flesh by a series of consumers (secondary production).

Explanation: The process of plants converting the sun's energy into stored energy in the form of organic matter can be measured by several different techniques and can be expressed in terms of weight of new organic matter produced per unit area per unit time. For instance, it is possible to measure the primary production of a mangrove forest in grams of organic matter fixed (from CO_2, sunlight and H_2O) per hour per square meter of forest (or in tons per hectare per year).

Measurements of this type allow the comparison of the primary production of different ecosystems and give a partial indication of both their ecological value and their value to man. There are many reasons why one ecosystem produces more plant tissue than another; these will be discussed in the section on limiting factors.

The conversion of plant tissue to animal tissue is accomplished by the plant-eating herbivorous animals. Subsequent conversions take place when the herbivores are eaten by carnivores and then, perhaps, these carnivores are consumed by other carnivores. This step-wise movement of energy from the sun through plants and various levels of animals is called energy flow and the structure through which it flows is called a foodweb. Each time that energy is converted from one form to another, for instance from plant tissue to herbivore tissue, a significant portion is dissipated as heat and lost to the ecosystem. This means that: (1) there can only be four or five conversion levels in the foodweb of an ecosystem because all of the energy is eventually dissipated as heat; and (2) the amount of tissue produced at each level decreases with increasing levels of conversion.

Applications: These considerations have important implications since man often attempts to obtain the greatest yield from an ecosystem. Yield refers to the production which man removes from the ecosystem. By combining the concept of productivity with the characteristics of foodwebs it becomes apparent that a greater yield to man can be obtained by harvesting from the lower conversion levels (plants and herbivores).

Further, if an ecosystem is to function properly and generate a significant yield to man, no matter what conversion level he is harvesting from, the basic sources of primary production must be protected. This can either be accomplished by controlled crop production (agriculture) which may require all sorts of energy subsidies (fertilizers, pesticides, petroleum powered machinery) or the ecosystem can be allowed to function naturally without aid from man. In the latter case the yield will probably be lower, but expensive maintenance and energy subsidy costs can be avoided.

B. Limiting factors

Statement: Whether plants and animals are present in a specific ecosystem and the extent to which they are successful depends upon a complex combination of conditions. Any of these conditions which approaches or exceeds the limits of tolerance of an organism is referred to as a limiting factor for that organism. Usually, more than one factor combine to limit or exclude organisms from an ecosystem.

Explanation: All organisms operate within minimal and maximal tolerance limits. For instance, too much or too little heat, water, light or essential nutrients will restrict or exclude the growth of plants. Animals are limited in the same way by such factors as climate, food availability and interactions with each other.

Organisms may have a broad range of tolerance for one factor, but very narrow for another. A species of plant, for example, may be able to grow upon virtually any type of soil regardless of acidity of the soil or nutrient content. This same plant, however, may require large quantities of sunlight for normal growth; as a result it will be limited to open areas where it does not have to compete with taller plants for sunlight.

Applications: Proper understanding of the principle of limiting factors can be useful during the planning process. First, it explains why some ecosystems have more species present than others and why certain areas are biologically more productive than others. Further, knowledge of the natural limiting factors for an area may provide guidelines concerning future development possibilities. Often the major limiting factors for an ecosystem such as mineral deficiency or lack of rainfall can be altered with fertilization or irrigation. In other cases this will not prove practical.

Finally, it is important to avoid the common mistake of creating new limiting factors during the development process. Frequent errors include the generation of new sources of pollution, ignoring erosion control, and causing local changes in drainage patterns, soil quality, climate conditions and water quality.

C. Carrying capacity

Statement: The concept of carrying capacity is directly related to that of limiting factors; simply stated, it is a measure of the numbers (or weight) of individuals of a given species which an ecosystem is capable of supporting.

Explanation: Carrying capacity is usually expressed as a measure of density, as for example, two cattle per hectare. This means that a particular ecosystem can support two cattle per hectare indefinitely if conditions do not change. Another ecosystem may have a much lower carrying capacity for cattle due to lower primary productivity caused by insufficient rainfall.

Carrying capacity can be considered at several different levels. The subsistence level is often used to denote the absolute or maximum capacity which an ecosystem can support; it is usually characterized by a large number of individuals, low individual growth rates and prevalent disease. At the other extreme is the optimum level referring to a number or density at which all individuals have an adequate supply of the essentials for existence and, as a result, demonstrate maximum individual growth and general good health.

Application: The concept of carrying capacity can be applied to almost any situation -- cattle on a ranch, deer in a national park or fishes associated with a coral reef. It is important to recognize that it is not a fixed value but fluctuates with changes in successional stages, changes in climate or other limiting factors such as fires and floods. The carrying capacity for deer in a forest might be one deer for 100 hectares prior to a forest fire, but change to one deer for 10 hectares shortly after the fire. This increase in carrying capacity is a result of the increase in succulent deer food which was scarce or absent from the forest but which quickly invaded the burned area shortly after the fire.

For man, carrying capacity is an important tool, particularly in the fields of game management and fisheries. With accurate estimates of carrying capacity it is possible to carefully regulate both population size and exploitation intensity so as to obtain the greatest possible yield. In situations where deer are managed, for instance, the optimal carrying capacity for a tract of land is determined first and then game regulations are established to maintain that density of animals.

D. Subsidized and unsubsidized ecosystems

Statement: Ecosystems receive energy either directly from the sun or in the form of some sort of stored solar energy (fuel). Although both are likely to be used in most ecosystems, one source usually predominates; this allows the classification of ecosystems into solar powered and fuel powered categories based on the major energy input to the biological community.

Explanation: Energy is, as already pointed out, essential for the operation of all ecosystems. The sources and quantities of energy determine to a great extent the types and numbers of organisms which will be present and how they will interact with each other. Direct solar energy provides a dilute but steady source of energy, which supports a relatively low density but efficient assemblage of organisms in ecosystems such as the open ocean. At the other extreme, fuel-powered ecosystems depend upon potent, highly concentrated fuels as energy sources. This allows the development of high densities of organisms, but at great ecological and economic cost.

E.P. Odum (1975) had identified and discussed four basic types of ecosystems based upon sources and levels of energy.

(1) Unsubsidized natural solar-powered ecosystems -

These are systems such as the open ocean or certain large forests which function largely or entirely on the direct rays of the sun. They are unsubsidized or, in other words, there are no important alternate sources of energy to enhance or supplement solar radiation. These ecosystems generally have a low productivity per unit area because of the inefficiency of plants in converting solar energy (about one percent). However, because of their huge extent and their absolute non-dependence upon man, they can be regarded as the basic life-support system for the earth. They purify the air, recycle water, control climates, modify the weather and produce a portion of man's food and fiber.

(2) Naturally subsidized solar-powered ecosystems -

Included in this category are ecosystems such as estuaries, coral reefs and certain rainforests which utilize direct solar energy, but also receive natural energy subsidies in the form of tides, flowing water and steady rainfall. In an estuary, where fresh and salt water mix, the back and forth tidal flow of water performs much of the necessary work of recycling nutrients and transporting foods and wastes. This allows the estuarine plants to utilize solar energy more efficiently. In a similar fashion ocean currents flowing over a coral reef reduce maintenance costs by removing wastes and importing food. Excess rainfall allows the plants in a rainforest to devote less energy to the prevention of desiccation and concentrate upon maximum rates of photosynthesis (primary production).

As a consequence of these natural energy subsidies, the recipient ecosystems are extremely productive. Estuaries, coral reefs and rainforests, therefore, function as important life support systems and provide large quantities of food and fibers, all at no direct economic cost to man.

(3) Man-subsidized solar-powered ecosystems -

Agriculture, forestry and aquaculture are examples of this category of ecosystem. Unnaturally high yields of food and fiber are maintained by large inputs of fuel (or human and animal labor) in the form of cultivation, irrigation, fertilization, genetic selection and pest control. In other words, artificial energy subsidies are utilized to enhance or extend ecosystem productivity and overcome natural limiting factors. It is important to recognize that most of man's recent spectacular advances in crop production such as miracle rice, wheat and the so called "green revolution", are due to partial subsidization from other energy sources such as coal and petroleum products which make possible large scale irrigation, cultivation and use of fertilizers, pesticides and planticides. If for any reason these subsidies should be terminated, this type of ecosystem will not function normally and cannot be expected to produce much of value.

(4) Cities: fuel-powered ecosystems -

Cities can be regarded as incomplete ecosystems dependent upon large quantities of food and fuel imported from outside the system. These imported fuels completely replace, rather than supplement, the energy of the sun. As cities are now managed, solar energy is, to a great extent, a nuisance which may generate excess heat and smog. Hopefully, in the future solar energy can be utilized to supplement or even replace imported fuel in cities.

Applications: Fuel supplemented and totally fuel-powered systems require enormous amounts of imported materials and fuels. These come from surrounding solar-powered ecosystems and from limited energy reserves beneath the earth's surface. This means that for every square kilometer of fuel-powered ecosystem many square kilometers of self-sustaining solar-powered ecosystems must be available to act in a life-support capacity. It is no accident that most of the world's great industrial cities are located on sea coasts, large estuaries, rivers or lakes -- all of which have a great capacity to provide waste assimilation, cheap transportation, food and recreation.

These considerations are of critical importance for tropical coastal areas, both at the local level and for entire nations. At the local level it is imperative to plan development so that cities and heavily subsidized agricultural ecosystems are balanced with extensive areas of minimally developed, naturally productive, solar-powered life-support regions. At the national level this principle is even more essential. If heavily subsidized ecosystems dominate a country and natural areas cannot satisfy fuel and material needs, it will be forced into a continual cycle of importation from other countries which in turn will create an unbalanced economic situation.

E. Ecosystem development (succession)

Statement: Ecosystems pass through a series of developmental stages much in the same manner than an individual organism grows from youth to adulthood. This orderly, predictable sequence of stages is called ecological succession and culminates, at least in theory, in a stabilized stage at which maximal possible control is exerted by plants and animals over the physical environment.

Explanation: The easiest way to visualize ecological succession is to begin with an abandoned, freshly plowed field (Fig. 1). In a short while the field will be invaded by grasses, a mixture of herbaceous plants, shrubs, small trees and populations of small mammals such as mice and shrews. This is an early successional stage, a young ecosystem. At this point the living components have very little control over extremes of temperature, moisture or wind velocity.

In a few years shrubs and small trees totally replace the grasses, creating another successional stage with different animals present and the beginnings of control over physical forces. The increasing bulk of vegetation gives greater protection from extremes of rain and wind. Humidity and temperature fluctuate less. New animals appear to exploit the opportunities offered by different and larger plants.

Finally, after many years the trees take over completely and create a mature ecosystem with considerable resistance to perturbation. Because of the presence of the forest, temperatures and relative humidity fluctuate less and there is greater protection from severe storms.

The exact pattern of successional change varies, but the general pattern is universal. In certain tropical situations succession may be greatly accelerated, with the result

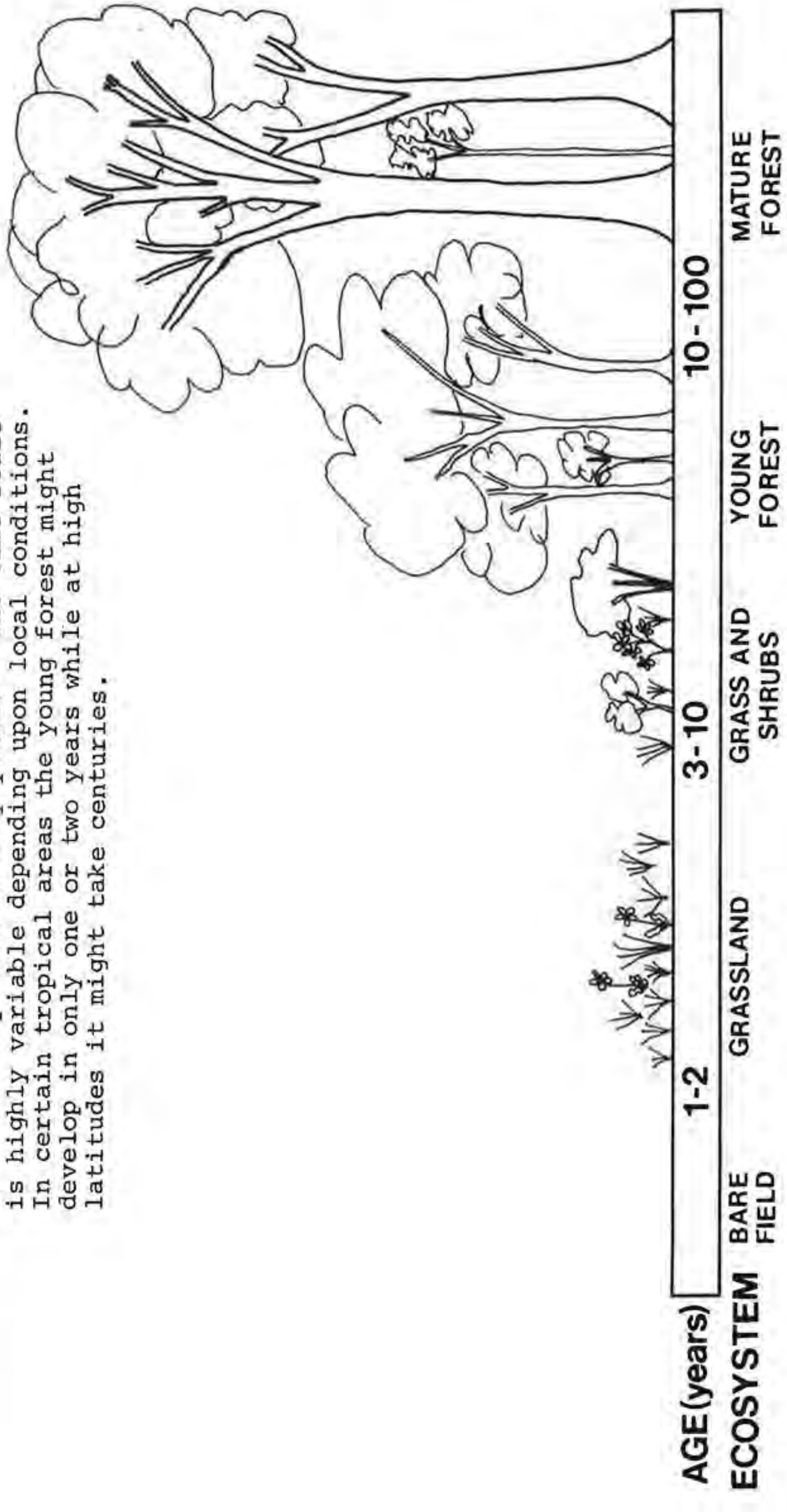


FIGURE ONE. This schematic representation of the process of ecological succession depicts the sequence of communities which might develop on a single site over a period of many years. The time scale is highly variable depending upon local conditions. In certain tropical areas the young forest might develop in only one or two years while at high latitudes it might take centuries.

that a large forest is regenerated after a short period of time. Although succession occurs more rapidly, the pattern is the same.

Extreme events such as fires, severe storms and manipulations by man are all capable of interrupting succession and causing a return to an early successional stage. In some cases this can be beneficial for man, while in others it may cause more trouble (erosion, loss of productive land) than was anticipated. The important point is that since succession is a predictable, orderly process, proper planning before an alteration of an ecosystem is attempted should insure predictable, orderly results.

Applications: Man, of course, has a great ability to disrupt, alter and control ecosystem development. Almost all farming practices depend upon arresting succession in the earliest, most productive stages. Modern forestry avoids the later successional stages because they are the least productive. As a result, most of the "developed" countries retain very little land in mature stages of ecological succession. This allows greater food and fiber production, but may have other drawbacks. Mature ecosystems, such as an ancient forest with its complex structure and assemblage of unusual species, often have great ecological and aesthetic value. If properly protected in national parks and other preserves, these areas may be a considerable economic asset. Once destroyed or altered they can take hundreds of years to regenerate. For these and other reasons it often proves wise to retain significant tracts of mature ecosystems intact.

F. Physical versus biological control of the ecosystem

Statement: Many ecosystems are dominated by physical factors such as extremes of temperature, rainfall and wind velocity. Ecological succession in these systems tends to be prematurely terminated with the result that little control is achieved by the biological components and mature successional stages are never reached. Other ecosystems are not subject to such great physical extremes and are able to reach mature successional stages characterized by considerable control of physical factors.

Explanation and application: There are situations where the physical elements are so overwhelming that ecosystem development cannot proceed far. On an open beach or sand dune, for instance, the grass and small shrub stage predominates and is never replaced by a forest of trees because the latter cannot withstand exposure to continual salt spray or the impact of large storms with their associated wind and water damage. Similar situations exist on steep mountain slopes, flood plains of rivers, deserts and shrub forests which frequently burn during the dry season.

There is an interesting lesson here for man, a creature which does not thrive under adverse physical conditions. All too often economic development has taken place in locations which are dominated by some strong physical factor, with the assumption that suitable protection can be engineered. At best this has proved expensive and, at worst, totally unsafe. Rather than frequently repairing or attempting to prevent damage from waves, floods or fires, it is perhaps more logical to use these areas for less intensive purposes such as recreation or wildlife management.

Biologically controlled ecosystems, such as a mature forest, where the impact of physical factors has been greatly reduced, present a more subtle problem. These areas are usually easy to alter and develop, but often the development process is accompanied by the loss of highly desirable features such as weather modification and erosion control which were due to the living components. As an alternative, it is often possible to retain much of the biological structure during the development process and at the same time retain the beneficial side effects.

It is possible, for example, to construct a housing development or a tourist resort in a forested area without removing very much vegetation or changing the ecological character of the site dramatically. Modern tropical forestry practices allow the removal of individual trees without destroying the basic structure, biogeochemical cycles and energy flow patterns of the forest. This may cost a little more money and profits may be lower, but the basic objectives of housing construction and wood production are accomplished without destroying a productive ecosystem.

G. Biogeochemical cycles

Statement: Many of the chemical elements, including nitrogen, carbon, phosphorus and all of the essential elements of protoplasm, circulate back and forth between organisms and the non-living environment by more or less circular routes which are called biogeochemical cycles. Unlike energy which flows through ecosystems in only one direction, materials may circulate indefinitely within the ecosystem or be exchanged with nearby systems and used over and over.

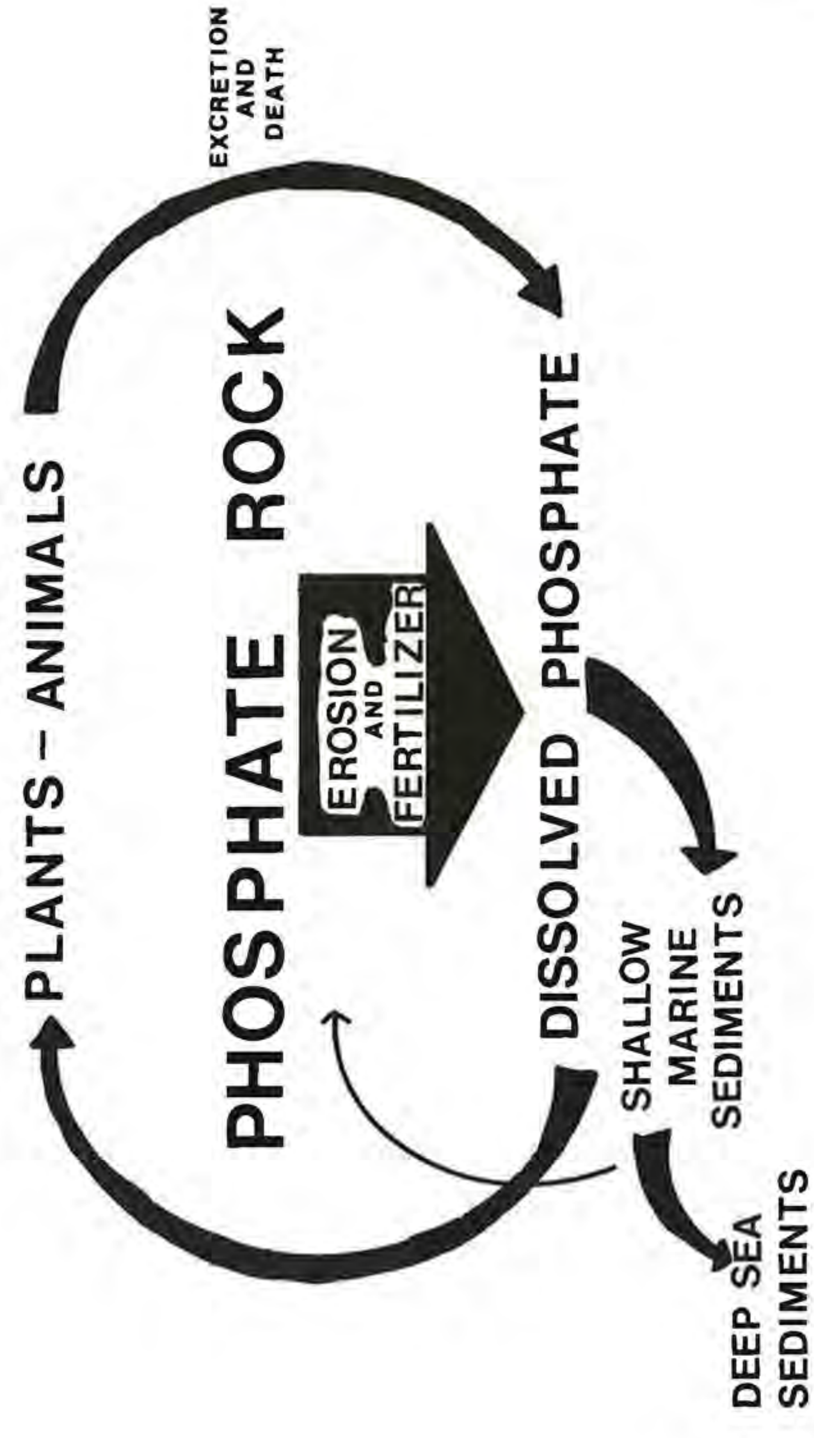


FIGURE TWO. The biogeochemical cycle for phosphorus, greatly simplified.

Explanation: Chemical elements tend to circulate through ecosystems in characteristic cycles. As an example, the cycle for phosphorus, greatly simplified, is shown in Fig. 2. An individual atom of phosphorus may at one time be contained in an animal's body, at a later time be dissolved in an ocean and still later become part of another animal. The phosphorus cycle is characteristic of most biogeochemical cycles in that at any given moment the material is not homogeneously distributed in the ecosystem but is tied up in several reservoirs or "pools" with varying amounts of material in the pools and varying rates of exchange between them. Much of the material in these storage pools is not readily available for use by the majority of the world's organisms. Phosphorus, for example, is stored in relatively unavailable places such as rocks and deep ocean sediments.

Under normal conditions, elements circulate within ecosystems in such a manner that losses to semi-permanent storage pools are balanced by return processes such as erosion of rocks and volcanic action. Man, unfortunately, has the ability to upset this balance by accelerating biogeochemical cycles. For example, through poorly managed agricultural practices tons of easily mined phosphate rock are dug up and spread onto fields only to have most of the phosphorus wash off the fields into nearby streams and rivers, where it creates serious pollution problems before washing into the sea and being lost, at least temporarily, to the deep-sea sediments.

Applications: A full understanding of the functioning of biogeochemical cycles is imperative before large-scale environmental manipulations are attempted. By simply clearing forest cover from a tract of land, the amount of essential elements (e.g. calcium, nitrogen, phosphorus) washed off the land annually by normal rainfall can be increased one hundredfold. In addition to creating water pollution problems in nearby bodies of water, the nutrient loss from erosion and timber removal (vegetation may contain a large percentage of available nutrients, particularly in the tropics) may make it impossible to regenerate a forest on the same site due to the nutrient depleted soils which remain. With proper planning there are ways to avoid most of these problems through selective cutting of certain trees and techniques to prevent or reduce soil erosion.

H. The ecotone and edge effects

Statement: The transitional area between two ecosystems, which is called an ecotone, usually has features from both

systems and, in addition, may have its own special characteristics. Often, both the number of species and the population density of certain species is greater in the ecotone than in either adjoining ecosystem. The phenomenon is known as the edge effect.

Explanation: If you travel in a straight line out of one ecosystem into another, for instance from a forest into an open field, you will pass through a transitional zone which is different from both the forest and the field. This transitional area or ecotone may contain grasses and sedges characteristic of the field and also trees and shrubs from the forest. Small mammals and birds from both environments will be present plus unique species which are found only in the ecotones.

Ecotones form relatively narrow fringes wherever two ecosystems meet: between the land and sea, at the edges of lakes, and on the periphery of coral reefs, underwater seagrass beds and mangrove forests. For a variety of reasons they tend to support more individuals of certain species and more total species of animals and plants than the ecosystems on either side. For many animals they offer cover and safety immediately adjacent to productive feeding areas. A number of gamebirds, for example, utilize the forest-field ecotone for refuge between forays into the relatively open and dangerous fields to obtain food.

Applications: Any considerations of gamebird and small mammal management must include an understanding of ecotones and the edge effect. In most situations it is a simple fact that by increasing acreage which exists as ecotones, small game populations will also be increased. A common technique is to increase the amount of ecotones in homogeneous areas such as dense forests or open fields by creating small clearings in the forest or by planting hedgerows in the fields. Such manipulations, if properly executed, may not only increase game animal production, but also can improve the aesthetic value of an area by increasing visual diversity (e.g. the attractive hedgerows of the European countryside).

Ecotones are equally important in aquatic ecosystems where they provide food and shelter for a host of immature fishes and invertebrates. The transitional area between mangroves and open water is a good example (Fig. 3). Here the combination of shallow water, protective roots and plentiful attached algae creates an environment highly conducive to the survival of juvenile fishes, crabs and shrimps. If this type of ecotone is destroyed, for instance by bulkheading (Fig. 4), it should be no surprise to find drastically lowered numbers of adult fishes, crabs and shrimps.

FIGURE THREE. Stands of mangrove trees create a valuable protective zone in the shallows of many tropical estuaries and coastal areas.

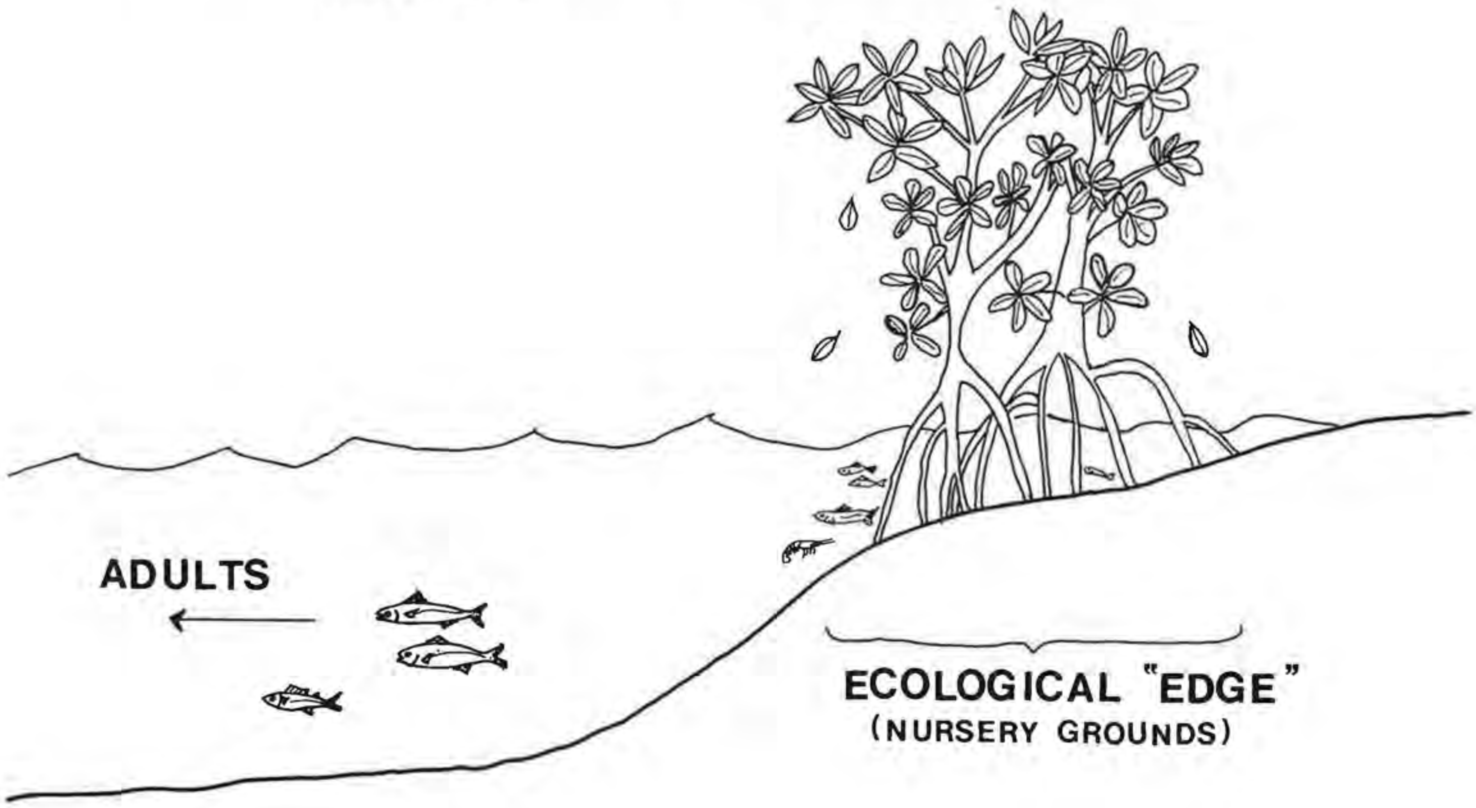
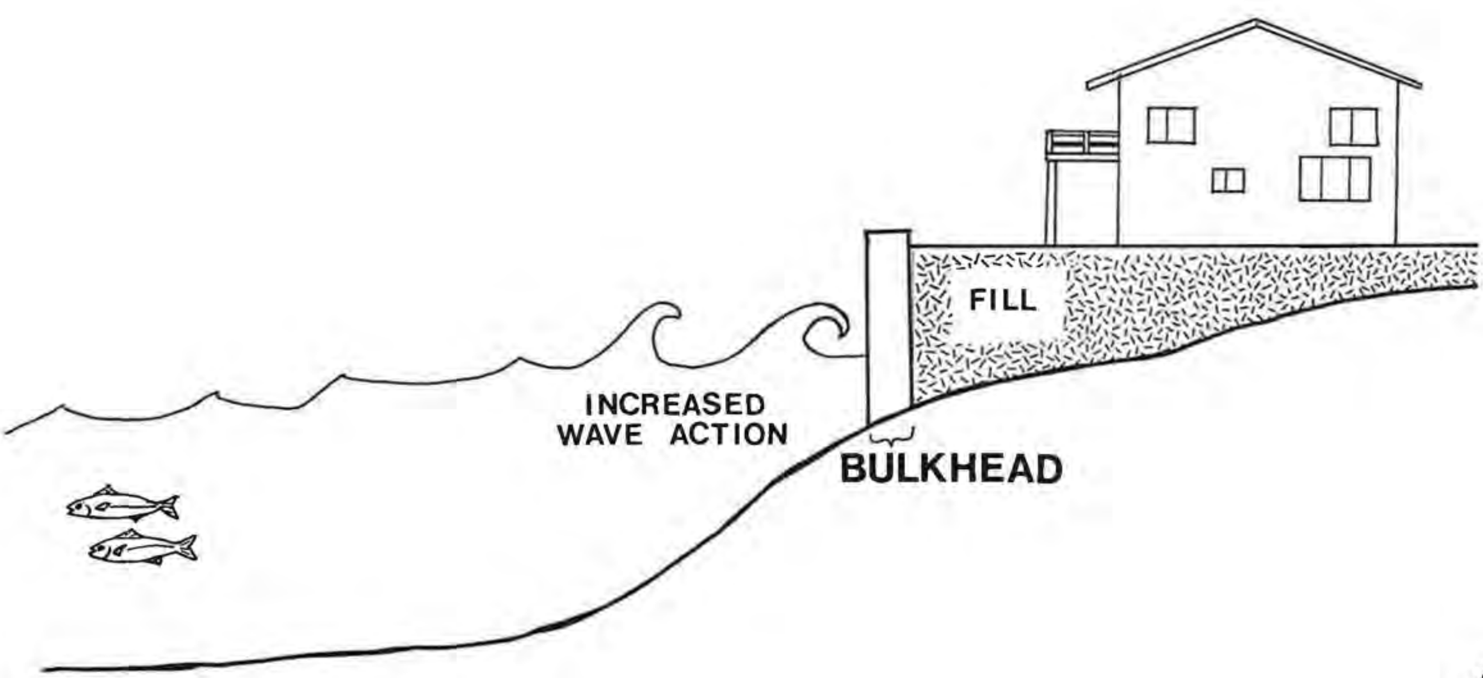


FIGURE FOUR. Removal of the mangrove "edge" habitat destroys an important ecological asset and may result in lowered production of fishery products from nearby bodies of water.



This phenomenon has occurred in many places in the United States as a byproduct of poorly planned residential and industrial development. One example is Lake Worth, Florida, where intensive development and alteration of the shallow ecotone areas at the edge of this estuarine embayment during the 1950s was accompanied by a nearly complete disappearance of the three most valuable gamefishes. This occurred even though the open water areas of the estuary were only slightly altered and remained relatively pollution free.

IV. MANAGEMENT GUIDELINES BASED ON ECOLOGICAL PRINCIPLES

By combining basic knowledge of the type presented in the previous section with practical management experiences, it is possible to outline a series of broad management guidelines. These guidelines are necessarily short and incomplete. They are presented as examples of the range of potential problems which might arise and which can be avoided. Many of these considerations do not apply in all situations. A more comprehensive and complete understanding of the problems associated with a specific site can be obtained with the cooperation of one or more expert consultants.

A. <u>Protection and wise utilization of valuable ecosystems</u>

(1) Areas of <u>naturally high primary productivity</u> such as wetlands, underwater grass beds and well developed, luxuriant forests should receive high priority for preservation or management. Wherever destruction or serious alteration is contemplated, benefits and costs should be carefully compared.

(2) Will the proposed development or alteration result in the <u>loss of productive farmland</u>? Is this land highly productive or only of marginal quality? Are there nearby areas of comparable quality available for farming? Will there be enough food produced in the region to support the human population without depending upon costly imports?

(3) Is <u>recreational land</u> going to be lost? Do sufficient alternate areas exist for projected populations in the future?

(4) Will features with unusual <u>aesthetic value</u> be degraded or destroyed? Are these important to an existing or potential tourist industry?

(5) <u>Mature ecosystems</u> such as aging forests can be easily destroyed without proper protection. Although these areas may have low ecological productivity from a forester's viewpoint, they often possess great natural beauty and require hundreds of years to recreate.

(6) Along the same lines, is the sequence of ecological succession likely to be seriously disrupted or retarded? What will be the consequences? Will it be possible for natural processes to repair the damage?

(7) Will important wildlife habitat be damaged or lost? Critical areas include: (a) feeding areas; (b) protective "cover"; (c) spawning and breeding grounds; (d) nesting and nursery areas; and (d) dry or wet season refuge areas.

(8) What changes in the animal community might be expected to accompany development? Will valuable species be lost? Will pests or disease vectors such as mosquitoes become more common?

(9) Are there endangered species dependent upon the area to be developed? Can they be protected by recognizing and preserving features which are necessary for their survival? Should they be protected directly from exploitation?

(10) Will animals or plants which form key links in foodwebs be properly protected? A key link is an organism upon which a number of other organisms are dependent. A good example of a key link is the coconut palm which provides food and shelter for a variety of animals including man.

(11) Does the area under question support or will it support significant commercial fisheries? Is fish production an important factor in the local economy? Could it become important in the future?

(12) Can the area be utilized for aquaculture operations? Will the proposed development limit or preclude this potential industry?

(13) Can a healthy ratio of subsidized to unsubsidized ecosystems be maintained? In other words, will sufficiently large natural areas which are not dependent upon direct human management be retained? Have the political and economic consequences of failure to do this been anticipated?

(14) At least moderate diversity of animal and plant species should be maintained. Extensive

monocultures associated with farming, forestry and landscape planning ought to be avoided so as to limit large scale disease and pest outbreaks.

(15) Chemical herbicides and pesticides are valuable when utilized properly. Guidelines for their use should include: (a) avoidance of compounds which have been demonstrated to be extremely toxic or persistent in the environment; (b) use only in situations where there is no other suitable alternative; and (c) application by trained and skilled technical experts.

(16) The accidental or thoughtless introduction of new plant or animal species must be avoided at all costs. Damage from introduced species such as red deer in New Zealand and schistosomiasis in Puerto Rico has been of astronomical proportions. There are cases where the introduction of a new species can be beneficial, but these are the exception rather than the rule. They should be allowed only after careful study and when there is a compelling reason for the introduction.

(17) If the carrying capacity of either humans or animals is to be increased significantly, the potential consequences should be well understood. Will basic needs such as water, food and shelter be sufficient to meet the demand? Will the quality of life or the health of individuals be seriously lowered?

(18) Does the area to be developed contain sites or ruins of historical significance? Will preservation and, perhaps, renovation of these sites receive proper consideration?

(19) Are there existing human inhabitants of the region? Will their traditional rights and needs be considered in a just and fair manner? To what extent are they dependent upon natural populations of plants and animals for their existence? Will these species be affected by the proposed development and if so, how will the people be compensated?

B. Prevention of adverse alterations of air and water quality

(1) Can accelerated rates of cultural eutrophication of waterways be avoided? This will require careful planning to control nutrient sources such as runoff of excess fertilizers from agricultural fields and dumping of improperly treated domestic sewage and industrial organic wastes.

(2) Will heavy metals (lead, mercury, cadmium, etc.) radioisotopes, toxic chemicals and other industrial by-products be disposed of properly? Generally, this will mean some type of containment disposal and no releases into the environment. If dilute effluent release is contemplated, all potential mechanisms of biological concentration should be carefully investigated.

(3) The release into waterways or the air of pathogenic bacteria and viruses must be prevented. These originate most commonly from improperly treated human sewage, but may also be derived from farm and industrial wastes.

(4) Release of excess organic compounds (sewage, sugarcane wastes, etc.) into streams, lakes and coastal waters can quickly deplete dissolved oxygen concentrations which may, in turn, cause large scale mortality of fishes and invertebrates. Organic wastes should either be oxidized in a controlled manner before discharge or else released in such dilute quantities that no damage will occur.

(5) Fine particulate materials such as crushed bauxite ore when dumped into bodies of water can cause extensive damage to aquatic animals and plants due to suffocation, irritation and clogging of delicate membranes. These problems can be avoided by disposing of slurries and fine particulates on the land.

(6) Anything which increases water turbidity to unnaturally high levels for extended periods of time will destroy aquatic animals and plants. Damage from carefully controlled dredging for navigation channels may be kept at minimal levels, but extensive dredging and filling of underwater sediments or erodable above-water sediments can lead to permanent ecosystem degradation.

(7) Accidental oil spills from ships, wells, pipelines or holding facilities are, of course, highly destructive. Careful planning can soften the impact of damaging spills through locating industrial facilities and ship channels at as great distances as possible from vulnerable areas (i.e. mangrove forests and coral reefs).

(8) Unnatural salinity alterations should not be allowed to occur in coastal waters. They may result from increased or decreased release of freshwater from the land due to water diversion projects (i.e. dams, irrigation projects) or from the dumping of saline brine from desalination plants.

(9) Extensive and significant water temperature increases from release of heated effluents from electrical power generating stations can cause widespread damage to aquatic ecosystems and should be avoided.

(10) Acceptable air quality is essential for good human health and should be maintained. Badly degraded air can lead to respiratory diseases, acid rainfall and reduced visibility.

C. Physical factors to be considered

(1) Will the proposed development cause accelerated soil erosion? This is likely to occur on construction sites, farming land, strip-mined tracts, on steep slopes or any other location where the protective vegetative cover has been removed. Hundreds of tons per year of valuable soil can be lost from a single hectare. This eroded soil, in turn, creates a multitude of new problems in the streams, lakes, estuaries and coastal waters into which it is deposited. Eroded sites should be repaired as well as possible by preparing the soil with fertilizers and mulches and replanting with species which are capable of controlling erosion.

(2) Wherever surface drainage patterns or run-off rates will be altered, the consequences must be anticipated. For example when large areas are paved with asphalt, infiltration rates are greatly reduced and the run-off rate accelerated. This means that a small stream which prior to

construction might be adequate to handle run-off from even the heaviest rains would become a dangerous flood threat after construction due to inability to accommodate a more sudden and greater run-off.

(3) Wise management of subsurface water resources is essential for most coastal areas. Many coastal cities are dependent on subsurface freshwater aquifers which, if misused, may become depleted or contaminated with saltwater or pollutants. The recharge areas for aquifers may be hundreds of kilometers inland and also must be protected.

(4) A basic consideration during the preliminary stages of planning concerns potential vulnerability to strong physical processes. Generally, permanent structures should not be planned for locations such as river flood plains, slopes subject to mud slides or low-lying areas which might be inundated by storm surges. In situations where structures are absolutely necessary, they should be properly engineered by being elevated and reinforced so as to minimize the effects of destructive events. This is usually an expensive undertaking.

(5) Certain types of development can lead to climatic change both on a local and world-wide scale. The repercussions of large scale manipulations such as removing most of the vegetation of the Amazon basin are not well understood. Changes in temperature extremes and rainfall patterns over small geographical areas caused by such factors as vegetation removal, increases in large paved areas or release of particulate material from smoke stacks, are well documented, partially understood and may be avoided in some cases with careful planning.

(6) Inshore currents and patterns of sediment deposition in coastal and estuarine waters can be seriously affected by the construction of jetties, causeways, certain type of fish traps, piers and similar structures. This can lead to accelerated beach erosion and filling-in and stagnation of lagoons, embayments and shipping channels. Where these structures are absolutely necessary they can often be designed to allow better water movement so that little resistance to currents is offered and sedimentation transport and deposition are not affected.

(7) Natural beach erosion patterns should be understood before development is attempted; this is particularly true near high wave energy beaches. It is not unusual for land on beachfront property and near the ends of sedimentary islands to erode at rates as high as several meters per year. In locations where this occurs the vulnerable zone should be set aside as an undeveloped buffer area and used for activities such as recreation which may require little or no permanent structures.

(8) Bulkheads and rip-rap walls lining shorelines and canal banks should be placed with care so that wave reflection does not endanger nearby benthic vegetation, increase water turbidity or accelerate erosion of adjacent natural shorelines. Often it is cheaper and more attractive to utilize wave damping mangrove or marsh fringes along waterways in place of concrete bulkheads.

D. Manipulations which may be ecologically beneficial

Not all development-induced alterations need be damaging to the environment. In certain situations it may be possible with proper understanding and planning to increase the ecological value of an area. The following ideas suggest just a few of the possibilities.

(1) It is often possible to increase the diversity of plant and animal species present in an environment. This is particularly desirable for homogeneous ecosystems such as even-aged second growth forests or late successional stage wetland areas. Carefully designed clearings in the forest or excavated ponds or waterways in higher portions of marshes or upland mangrove swamps can result in markedly higher fish and wildlife production in addition to increased aesthetic value due to greater visual contrast.

(2) Creation and enlargement of ecotones between ecosystems can result in dramatically increased fish and wildlife populations. Hedgerows or bushy "edges" between agricultural fields and marsh or mangrove strips along canal banks are examples of artificial ecotones.

(3) In special circumstances the successful introduction of a plant or animal species from another geographical region may prove beneficial. Species introductions should always be preceded by careful feasibility studies. There must be an empty ecological niche for the new species. Any potential side effects must be anticipated, trial studies should be made in enclosed areas and, most important, there should be a sound economic or ecological reason for the introduction. In the past most species introductions have not been studied in advance and, as a result, the species has either failed to become established in its new environment or has "backfired" ecologically and caused more trouble than good.

(4) Desirable and beneficial plant species can be encouraged and undesirable plants discouraged with the aid of certain management practices. These include carefully controlled fertilization, selective cutting, controlled burning and discriminate use of herbicides by trained experts. The results can include increased aesthetic values and greater economic return from increased plant and animal production.

(5) The yield from wildlife and fish populations can be optimized by means of carefully enforced hunting and fishing regulations. The level of harvest can be adjusted so as to obtain either the greatest biological or economic yield or alternatively to provide the greatest number of large fishes for sport fishing.

(6) Pest organisms can be controlled effectively in certain cases either by protecting the predators which feed upon them or through environmental manipulations. Mosquitoes can be controlled by draining or allowing tidal water to flush the stagnant pools or moist soil where they breed. The introduction of small fish which consume mosquito larvae can have the same effect. Many bothersome insects can be excluded from the vicinity of dwellings by trimming and thinning bushy vegetation and the lower limbs of trees to a height of a few meters above the ground.

(7) Land which has been devastated by strip mining and other destructive practices can be reclaimed through soil preparation and revegetation to yield useful recreational, agricultural and urban landscapes. The problems and technology associated with this type of management are highly variable depending upon soils, underlying rock, the climate regime and local vegetation.

(8) Watershed run-off can be controlled through water resources management with carefully engineered devices so as to provide flood control, soil erosion control, and more dependable and stable freshwater supplies. However, if poorly designed, this type of engineering can cause more trouble and cost far more than the original, unaltered situation.

(9) Spoil material from dredging operations can be used in imaginative ways to provide recreational land near the water or to construct vegetated marshes in areas of low ecological value.

(10) The usefulness of artificial reefs has been demonstrated successfully many times. These structures, which are usually constructed of low cost materials such as used automobile tires, concrete pipes or surplus ships, attract concentrations of plants and animals which are of direct benefit to both sport and commercial fishermen.

V. MANAGEMENT EXAMPLES

FOR SPECIFIC TROPICAL COASTAL ECOSYSTEMS

To obtain a clearer understanding of the ecological principles and guidelines presented in the previous sections, we now turn to three specific environments as illustrative examples: a mangrove forest, an open beach and a coral reef. For each we will: (1) present pertinent ecological characteristics; (2) consider the natural benefits which might be available for man; (3) detail the types of alterations which may be particularly destructive; and (4) attempt to find optimal uses for that particular environment.

A. Mangrove dominated coastlines

A significant percentage of the world's tropical coastlines are fringed by forests of mangrove trees. These forests vary in width from a few meters to many kilometers depending upon the slope of the land, the extent of tidal fluctuation and other factors. They are populated by a number of species of trees, all collectively referred to as "mangroves". These trees have in common the ability to grow and flourish on damp, frequently flooded and water-logged soils -- soils which usually have an appreciable salt content.

Certain mangroves are early successional species which grow on the seaward edge of the forest and extend into the water to a depth of a meter or so. They have elaborate networks of "prop roots" (Fig. 3) which support the tree and also collect debris and sediments in the spaces between the roots. With time, if conditions are correct, these mangroves will increase in size, create new land and extend the forest further into the water. Once the land has been stabilized and tidal inundation reduced, other species of mangroves will invade and replace the early colonizers. Eventually, even these species may be replaced as more organic soil accumulates and tidal inundation becomes less frequent.

Typically, the mangrove forests are intersected by many winding tidal channels and small streams. These stream networks function as a circulatory system which removes some of the dead leaf material and waste products on the outgoing tide and imports relatively clean, oxygenated water on the rising tide. These streams also provide a transportation

route for the myriads of fishes and invertebrates which move in and out of the mangrove ecosystem.

Natural benefits - Mangrove dominated ecosystems have several features which make their retention and wise management desirable. (1) They produce a more or less continuous input of dead leaf material to surrounding bodies of water. This leaf-fall typically averages about eight metric tons of dry organic matter per hectare per year. Upon entering the water the leaves slowly disintegrate into fine particles which provide food for a number of small aquatic animals (crabs, shrimps, a few small fishes, etc.). These small animals, in turn, provide food for larger fishes and wading birds. This means that the mangroves are responsible for providing much of the basic food input to the foodwebs of nearby coastal waters. Destruction and removal of the mangrove forests will be reflected by lowered production of fishes and invertebrates in adjacent aquatic ecosystems. (2) The physical structure of the most seaward mangrove trees with their intertwined prop roots and trunks extending into shallow water provides a valuable ecotone or protective region which provides food and protection for many small animals (Fig. 3). (3) Although mangrove forests occur on coastlines which are not subject to continuous physical stress, they do provide occasional protection to inland areas from severe storms. This is because the mass of trunks, foliage and prop roots serve as a physical buffer to the waves and storm surge generated by hurricanes, typhoons and tropical storms. A well known tropical ecologist has recently speculated that thousands of lives would not have been lost during the storm which devastated coastal Bangladesh if many square kilometers of mangrove forest had not been converted into rice paddies. (4) Mangrove wood has a number of uses including the production of charcoal. Proper forestry management utilizing selective cutting allows the retention of functional mangrove ecosystems while at the same time producing a continual supply of mangrove wood.

Development restrictions - Mature mangrove ecosystems are, to a great extent, biologically controlled. Mangroves do not flourish where physical factors such as wave action or tidal currents are too strong. This means that mangrove areas are relatively easy to modify and develop into something else, but once modifications have taken place there may be adverse side effects resulting from the absence of the mangroves. These include, but are not limited to, erosion, increased vulnerability of inland areas to great storms and loss of fish production in nearby bodies of water. In addition, mangrove soils are characteristically difficult to convert to agriculture because of their tendency to become extremely acid when drained and cultivated.

Nevertheless there are situations where mangrove areas must be destroyed and developed. Simply removing mangrove stands and building structures upon the ground upon which they stand is usually not a good idea because of the vulnerability to tidal flooding. The usual procedure is to build a dike around the mangrove forest, remove the trees and fill in the basin with sediment pumped or hauled in from nearby areas.

In most cases, it is best to locate development elsewhere and preserve mangrove forests. To accomplish this it is important that: (1) the mangroves are not diked and permanently flooded; (2) normal tidal flooding not be restricted; (3) the network of circulatory streams be protected; and (4) fine sediment (such as sugarcane waste or crushed bauxite ore) not be allowed to flow into the forest (these coat the root systems and kill the trees).

Mosquitoes can be a problem in certain mangrove forests, particularly when human settlements are nearby. This does not occur where daily tides reach the mangroves, but can be ncreasingly bothersome at the back of the forests where tidal water penetrates infrequently. There are mosquito control methods, including temporary artificial flooding, carefully designed ditching and other techniques, which prevent mosquitoes from breeding successfully in these areas.

<u>Optimal use</u> - The best solution in most cases is to leave mangrove forests in their natural state except, perhaps, for possible mosquito control measures along the landward edges of stands of trees near human populations. This will guarantee the existence of an ecosystem which generates seafood products, gamefishes, wading birds, storm protection and wood production at virtually no maintenance cost to man. Everything is provided free by nature.

In certain situations, usually in or adjacent to cities, high land costs or strategic location may necessitate the destruction of mangrove ecosystems. This should be done only after the benefits of development have been clearly shown to exceed the benefits of preservation.

With careful planning and consideration of the ecological requirements of mangroves, it is usually possible to preserve stands of mangroves immediately adjacent to altered and intensively settled areas. This has been done frequently in south Florida (U.S.A.); the Rookery Bay preserve near Naples, Florida, is an outstanding example (see Clark, 1974b). In this case several thousand hectares of mangrove-lined estuarine waters were preserved between two intensively settled areas which had been dredged, filled-in and completely altered for residential housing projects.

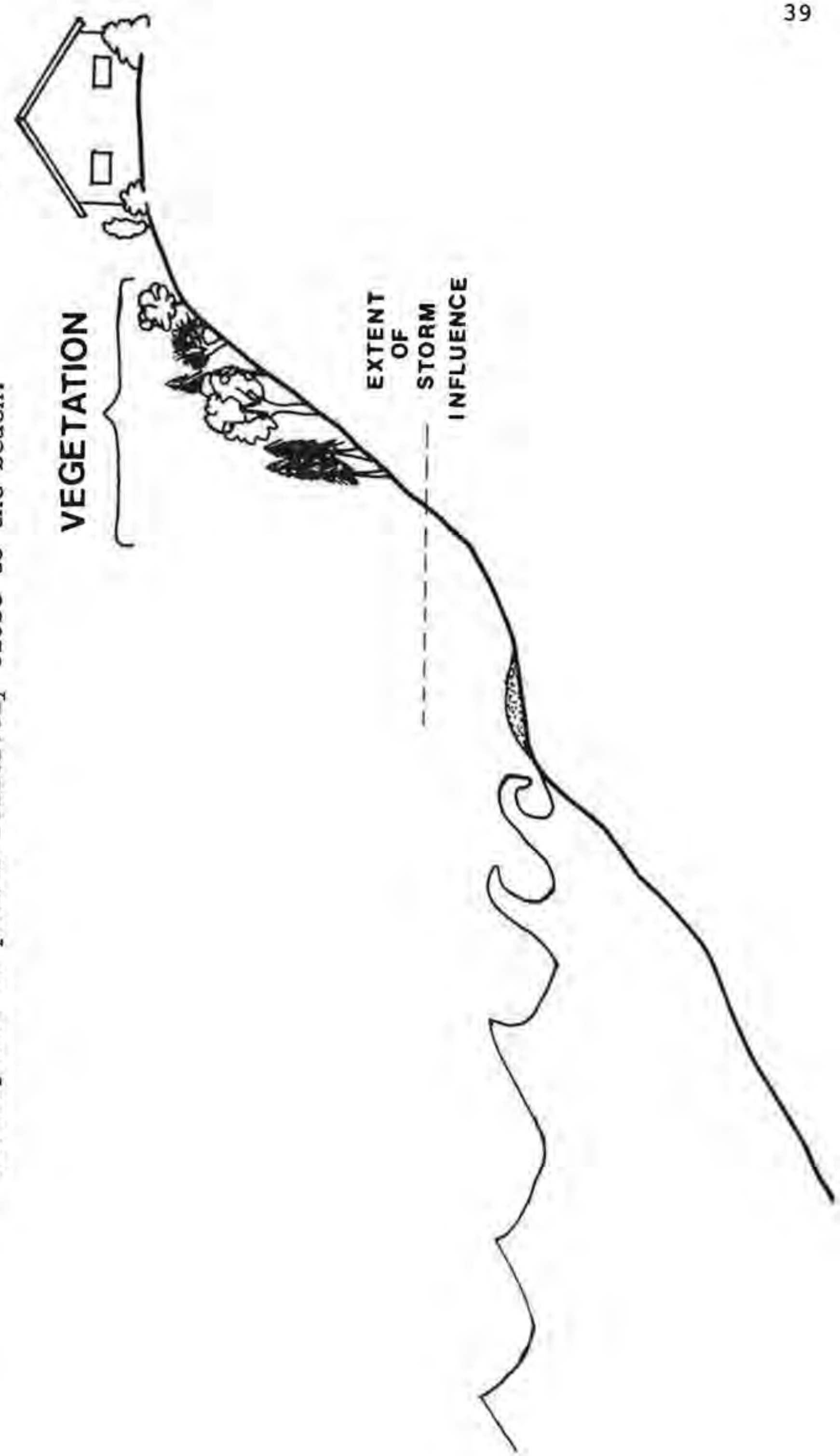


FIGURE FIVE. The influence of the ocean is greatly minimized behind this narrow beach due to the steep nature of the terrain. This may allow carefully planned development at points relatively close to the beach.

B. Open beaches and dunes

All considerations dealing with beaches, whether biological, aesthetic or economic, are overshadowed in importance by one fundamental factor. The beach-dune environment is shaped, controlled and dominated by strong physical forces -- forces such as high winds, salt spray, storm waves and the resulting patterns of erosion and sand deposition. Although this point seems self-evident and obvious, in the past a great deal of money, effort and human life has been lost in attempts to control beaches artificially for specific uses and to place structures as close as possible to the water.

There are, of course, many types of beaches and a great range of conditions which affect them. For the purposes of this paper two contrasting examples are presented (Figs. 5 and 6). The first beach is narrow, steep and, most important, usually lies adjacent to high ground. Wave energy on this type of beach is concentrated in a narrow zone and has minimal impact inland due to the rapid rise in elevation. Development should be located above a level which represents the extent of storm influence (wave and salt spray damage) so that the site is not subject to serious erosion. Care should be taken to preserve as much natural vegetation as possible since these plants are adapted to limited salt spray and exposure to high winds and will help to stabilize the soil and prevent landslides.

The second type of beach, which is broad and has a low profile, functions in a more complicated manner and presents more difficulties for management and wise utilization. These beaches have characteristics which reflect a balanced combination of long-term and short-term factors such as sea level fluctuation, sand storage in the dunes, sand movement on and offshore, longshore currents and the patterns of seasonal storms. In cross section (Fig. 6) they consist of a broad beach behind which may be varying numbers of dunes. During storms much of the energy of the waves is absorbed harmlessly on the broad beach. During extreme events such as typhoons, water and waves may extend into the dune line and even further. Sand may erode from the front of the beach and be carried offshore or along the shore; at other times it may be deposited on the beach. Sand may be moved by wind and waves from the beach into the dunes or the dunes may serve as a sand source to rebuild or extend the beach seaward. The entire system over a period of years may exhibit a net movement landward or seaward.

The important point is that the beach with its associated dunes is a transitional, ephemeral environment. The extent

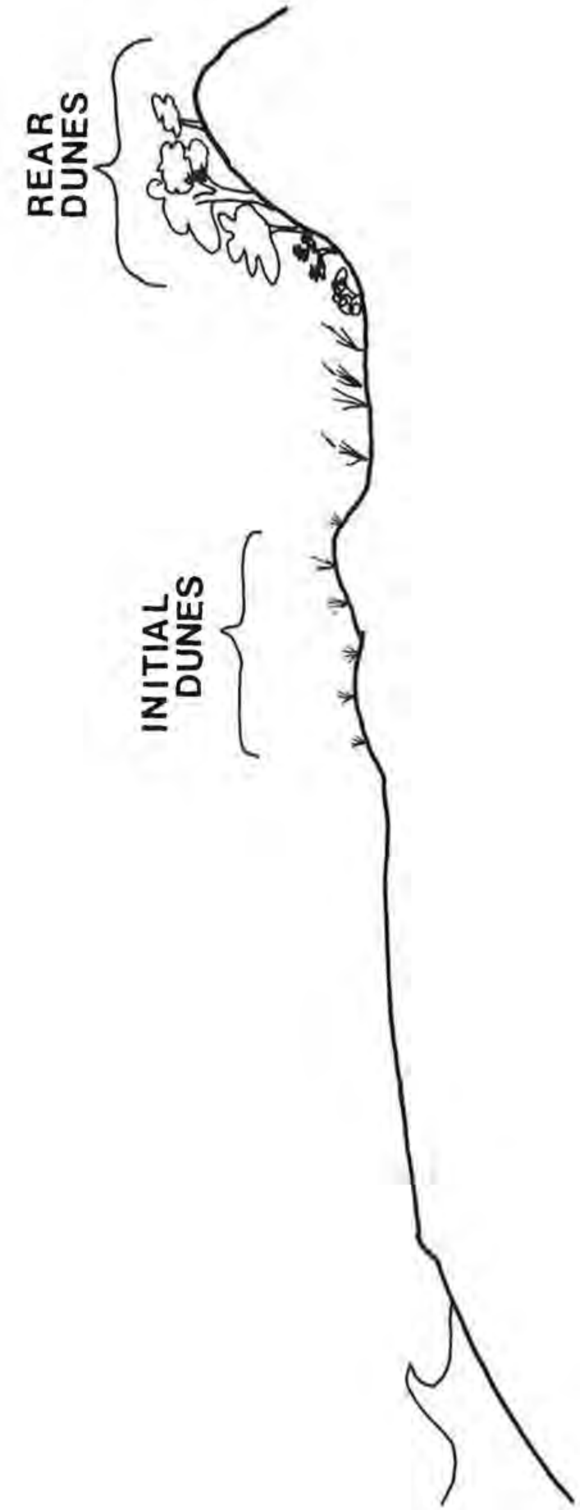


FIGURE SIX. This relatively flat beach has such a low profile that storm-generated waves may reach far inland. The beach itself may be several hundred meters wide and distances of one to two kilometers may separate the rear dune from the water's edge.

of its instability depends upon a number of factors including the location of the beach in respect to prevailing wind and wave action, average wave intensity and the periodicity of moderate and extreme storms. Certain beaches are more protected than others and, as a result, are more stable. Nevertheless they are all subject to modification over a period of time.

Optimal use - Beaches are usually attractive spots and tend to attract development (hotels, residences, etc.) to points as close to the water as seem safe. This often proves to be a mistake (Fig. 7). In this example the transitional nature of the beach has been ignored and the natural relationship between beach and dune tract overlooked. The results are predictable and unpleasant.

A better strategy (Fig. 8) is to keep all permanent structures off the beach and away from at least the most seaward dunes. Permanent buildings should be located well behind the beach in locations where more permanent (later successional stage) vegetation suggests considerable protection and a more stable environment. Even at these sites precautions such as placing buildings on pilings should be used to guard against the type of severe storms which may occur once or twice a century. The beach itself is fairly resistant to perturbation and can be used for light vehicular traffic in areas where traction is good and nesting birds such as terns are absent.

C. Coral reefs

Coral reefs are scattered along the world's tropical coastlines wherever the correct combination of environmental conditions exist. These remarkable assemblages of limestone structure, animals and plants present a colorful and aesthetically pleasing underwater sight. From the ecological viewpoint the coral reef can be regarded as among the most diverse and productive of all natural ecosystems.

Coral reefs are constructed from the calcium carbonate skeletons of layer upon layer of small coral animals and other associated animals and plants. Only the outermost layer of the reef is alive; as it dies it will gradually be covered with a new layer of animals and plants. Over an extended period of time, many thousands of layers will eventually form a reef of great thickness and strength. Growth of the reef, however, is slow and may be retarded periodically by damage from storms, predatory animals and, of course, the activities of man.

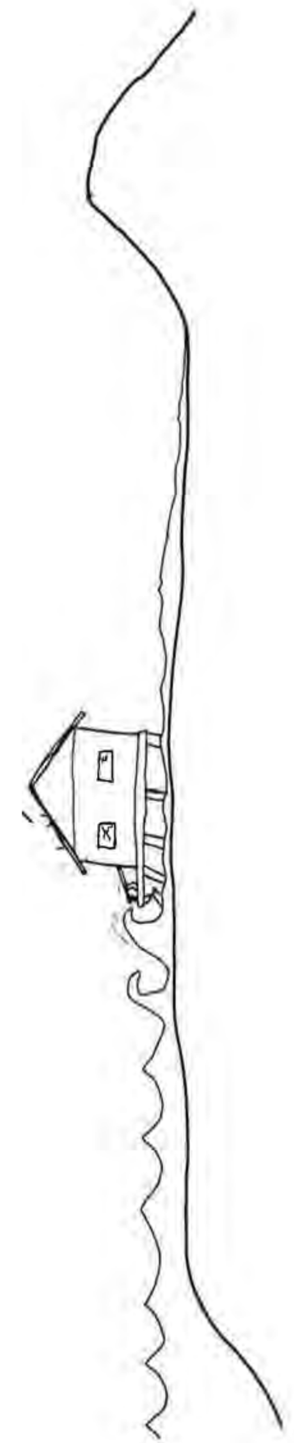


FIGURE SEVEN. In this low profile beach example, development has been located in the first dune line with predictable results during the first major storm.

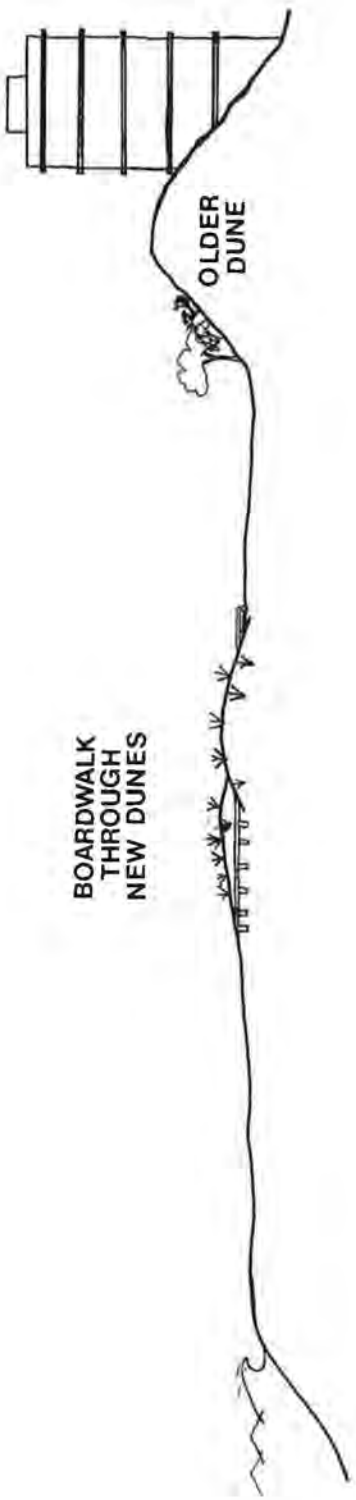


FIGURE EIGHT. A better way to develop low profile beaches is to place major structures well behind the beach in locations which are relatively protected. The boardwalk through the sand dunes protects the dune vegetation (and the dunes) from heavy foot and vehicular traffic.

The complex of animals and associated plants which form a coral reef, although capable of building structures with great strength, are quite fragile and easily destroyed. They flourish only in warm seas where temperatures remain above 20^{o}C and salinity is near that of the open ocean. Further, they must have relatively clear, silt-free water with plenty of light penetration to at least the depth of the reef. Finally, moderate currents or wave action are required and stagnant conditions must be avoided.

Coral reefs are not found adjacent to rivers, near mud bottoms or in stagnant backwaters. Obviously, man has the ability to change conditons by dredging, diking and other alterations so that existing coral reefs are damaged or destroyed.

Depending upon such factors as salinity, current velocity, bottom substrate and light penetration, coral reefs may occur as: (1) fringing reefs just offshore from beaches or rocky shorelines; (2) barrier reefs separated from the shore by lagoons from several hundred meters to many kilometers in width; (3) patch reefs which occupy several hectares or less at suitable spots in the lagoon; and (4) atolls which occur primarily in the Pacific and Indian Oceans where volcanic mountains have gradually sunk below the surface over an extended period of time leaving behind a nearly circular reef with a central lagoon.

Natural benefits - The structure of a coral reef provides refuge for numerous plants and animals, on its surface, within cracks and caves and in the water column above the reef. Moreover, because components of the reef are capable of both photosynthesizing and capturing small particles of food suspended in the water, the reef ecosystem is much more ecologically productive and capable of supporting many more animals than adjacent ecosystems such as the open ocean or the lagoon behind the reef.

The result of this dual role of protection and food production is that a coral reef harbors an enormous variety and quantity of fishes and invertebrates such as spiny lobsters. These, of course, provide excellent sport and commercial fishing, recreational diving and spearfishing. If properly managed with controls on over-fishing and protection from overzealous coral collectors, a coral reef can be a permanent asset with great economic and ecological value.

One aspect of coral reefs which is often overlooked concerns coastline protection. Both fringing and barrier reefs are capable of breaking-up and dissipating even large

FIGURE NINE. This is a healthy coral reef ecosystem situated in clean, silt-free oceanic water. The lagoon acts as a buffer to protect the reef from any minor disturbances originating on the land.

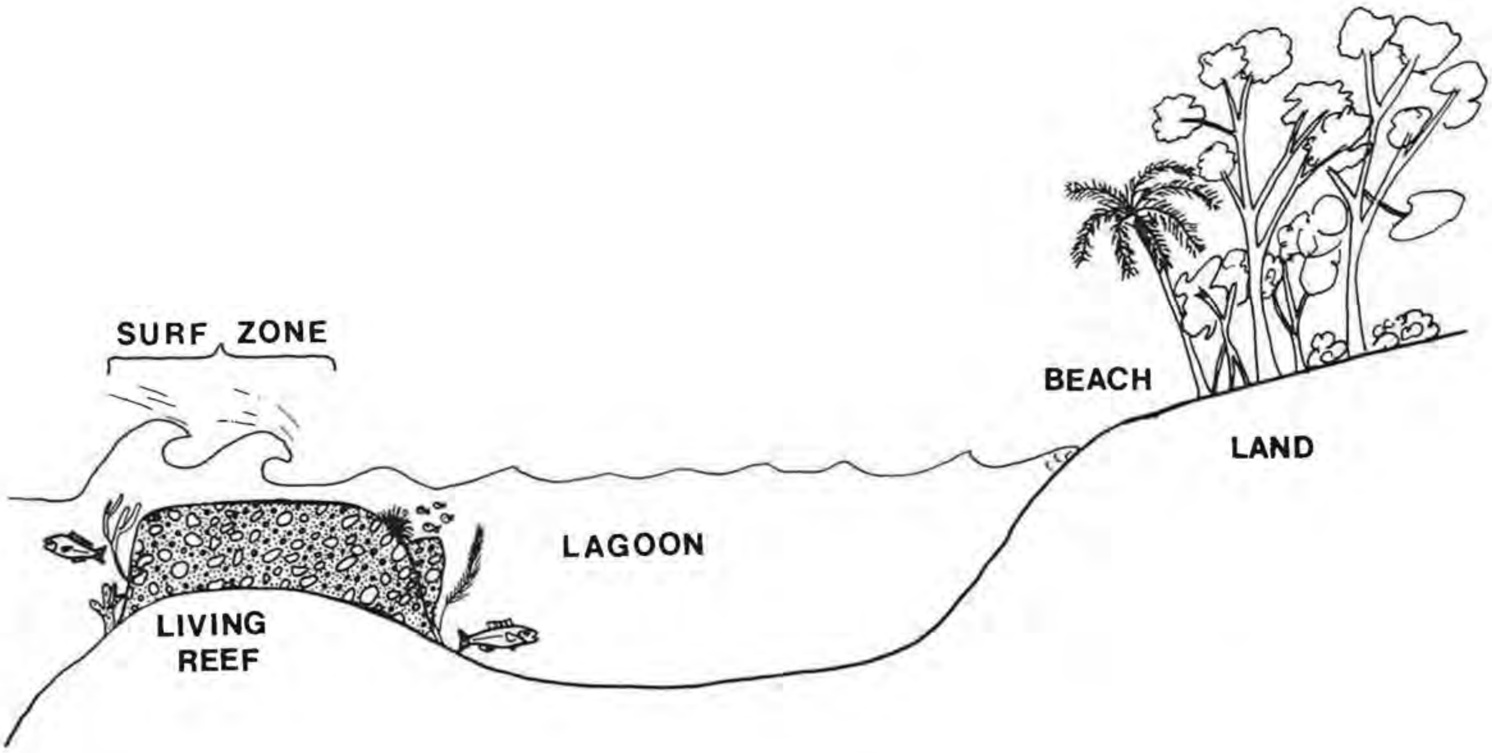
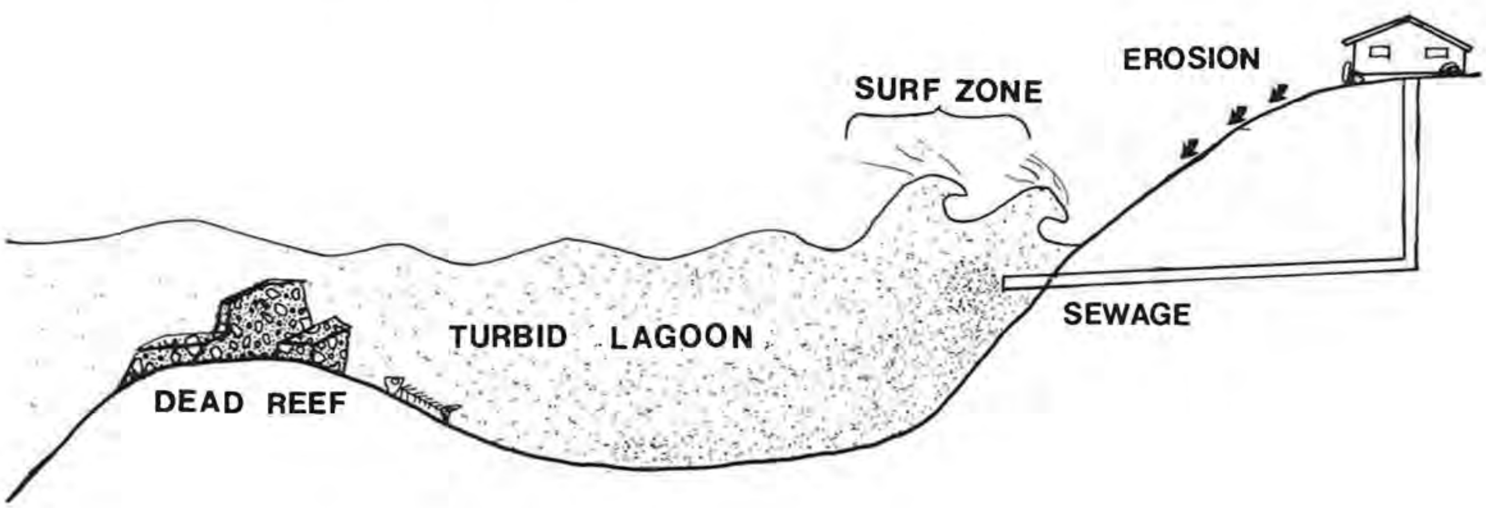


FIGURE TEN. The living reef has been destroyed by heavy loads of suspended solids from soil erosion and dumping of untreated sewage. All that remains is a dead reef composed of coral rubble heavily encrusted with algae.



storm generated waves. The protection afforded by reefs is often sufficient to allow the accumulation of a sand beach on the inner edge of the lagoon. Destruction of the reef may be followed by erosion and loss of much of the beach as has occurred in the U.S. Virgin Islands. In many locations it is no exaggeration to say that a healthy reef means a healthy beach.

Development restrictions - Although capable of withstanding great punishment from certain stresses such as wave energy, the coral reef environment is highly susceptible to damage from other types of stresses including pollution, siltation and salinity reduction. For this reason there should be no development or manipulation such as dredge and fill in the vicinity of a reef. Even development on nearby shores should be carefully controlled. Figures 9 and 10 depict the type of destruction which has occurred at Kanoe Bay, Hawaii (U.S.A.), and other locations where precautions were not taken to prevent sewage input and extensive erosion into the lagoon.

Fisheries associated with reefs, although highly productive, do have their limitations and must be carefully managed. Certain types of fishing gear, particularly traps and spearfishing, are capable of extensive damage to fish stocks and must be regulated. A frequent solution is to restrict spearfishing and fish traps from sections of the reef used for tourist and recreational diving and manage fisheries elsewhere on the reef.

Optimal use - A plan for the optimal use of a coral reef would contain all of the elements of preservation and protection discussed in this section. These include: (a) protection of the reef and its environs from any alteration (oil spills, dredging, sewage pollution, increased input of highly saline water or freshwater); (b) erosion controls on shoreline (and hillside) development adjacent to the reef or its lagoon; (c) management of the reef itself so as to provide the best combination of fish and shellfish, recreation and attractiveness to visitors. The economic and ecological rewards for proper execution of these guidelines will far exceed the economic costs incurred.

VI. COMPREHENSIVE ECOLOGICAL PLANNING - WISE USE OF THE COASTAL ZONE

In the preceding sections of this paper we have briefly examined a few of the more important lessons which ecology has to offer. The concept of the ecosystem has been presented along with the beginnings of an understanding of ecosystem structure and function. Guidelines have been presented based on ecosystem management and examples have been discussed of the application of this knowledge to several specific environments. Now, the final step is to synthesize this information into a general plan which can be applied in specific cases.

There are a number of potential uses which compete for space in the coastal zone. Among these are (1) industry, (2) transportation, (3) housing, (4) recreation, (5) protected natural areas, (6) commercial fishing, and (7) aquaculture. Most of these uses are not compatible with each other. This mutually exclusive quality of, for instance, industry and recreation, emphasizes the need for some sort of land-use planning. The concept of environmental zoning offers a viable solution. Under such an arrangement, areas ranging in size from a few hundred hectares to hundreds of square kilometers are zoned into sectors based first on their suitability for proposed uses and, second, on life-support capacity and compatability with adjacent sections that are to have other uses.

Environmental zoning

The simplest environmental zoning plan divides the management area into three types of sectors.

(1) Areas zoned for intensive development - Environmentally destructive development of all types (refineries, factories, housing, intensive aquaculture and agriculture) are located in and have highest priority in these areas. Of course, not all of these uses are compatible and subdivisions within these larger zones must be made. In certain cases, such as heavy industry, very little can be done to soften the impact on the environment other than preventing the most destructive influences such as pollution from influencing nearby zones. In other cases, housing for example, efforts can be made to retain as much as possible of the natural ecosystem.

(2) Areas zoned for conservation (conservation as used here means wise utilization, not just preservation). - These zones are intended for activities which are based on the theory of maintaining and utilizing renewable resources. Examples include managed forestry, hunting and commercial fisheries. Other uses such as recreation, low density housing and limited development may be feasible at specified locations within the conservation zone.

(3) Areas zoned for strict preservation - These are areas which are judged to have great natural value, usually due to some unusual or unique ecological attribute. A bird rookery (nesting area) of unusual and beautiful tropical birds or a grove of exceptional virgin timber might qualify for this type of zoning. Preservation zones are often extremely fragile and easily destroyed. The only types of alternate uses which might be compatible include scientific research and limited recreation. Recreation which involves heavy foot or vehicular traffic may be too destructive to be permitted.

There are other, more complex environmental planning and zoning systems. However, all of these, no matter how many sub-classifications are used, are basically arranged around the three uses - development, conservation and preservation.

Implementation of zoning

To successfully implement an environmental zoning system, there are two basic requirements. First, there must be a strong legislative and administrative organization with the authority to create, maintain and enforce zoning regulations. One of the greatest problems with any zoning system is the difficulty in maintaining the integrity of the zones. There are often great economic incentives for those who can circumvent zoning ordinances; for instance, a developer may greatly increase his profits by locating a housing project in the midst of an attractive, preserved zone.

Second, there must be a sound method for determing the basis for zoning decisions. These decisions are necessarily of a political nature, but they must be based upon fair and accurate considerations of economic, ecological and aesthetic factors. Balancing all of these priorities and arriving at a good solution requires an exceptionally gifted group of experts. In almost every instance, compromises must be made by the people at either extreme, the economic developers and the environmental preservationists.

An example

A hypothetical case is shown in Fig. 11 A and B. Depending upon your viewpoint, this stretch of coastline can be regarded as either a number of contrasting ecosystems or a series of sites with different development possibilities. Carefully conducted research would show that certain locations, such as the shallow embayment and mangrove forest, exhibit great ecological productivity; others are not so productive, but may have considerable aesthetic and recreation potential. In a similar fashion, some areas are well suited for harbors, some for agriculture and residential housing while others are not so good for these purposes.

By assembling a group of experts from many fields (ecologists, economists, engineers, geologists, hydrologists, foresters, politicians and others) it should be possible to divide the coast into zones based on the priorities of the various interests. For portions of the coastline, solutions are obvious and easy to reach; for other sections the answers are not so obvious. The mangrove forest and shallow embayment have great ecological value but would be difficult and expensive to develop. The deep embayment, however, is ecologically valuable and also highly suitable for intense development.

In the example shown in Fig. 11 B, the group of experts has considered all available information and reached the best compromise. The area with the greatest ecological value, comprising the mangrove forest, the shallow bay and the barrier island system, has been set aside as a conservation area. This does not preclude limited use such as recreational fishing, managed commercial fishing, managed harvesting of mangrove wood from certain areas of the forest and other uses which do not seriously alter these ecosystems. However, the sections of the mangrove forests which contain bird rookeries and sections of the bay bottom with luxuriant growths of underwater grasses, should certainly be designated for strict preservation, with only recreational fishing and birdwatching allowed.

The beach and area immediately behind the beach have been zoned for recreational uses such as swimming, picnicking, sport fishing and boating. Other uses which might interfere with recreation, such as commercial fishing, are carefully controlled so that they take place only during non-recreation times. The remainder of the coastline has been set aside for necessary and appropriate types of development, some intensive and some not so intensive. This does not mean that other uses (i.e. recreation, housing and conservation) may not be feasible in some cases. It does mean that development has the highest priority and cannot be excluded from these zones.

FIGURE 11A. This hypothetical example shows an expanse of undeveloped coastline containing a number of different environments with varying possibilities for conservation or development.

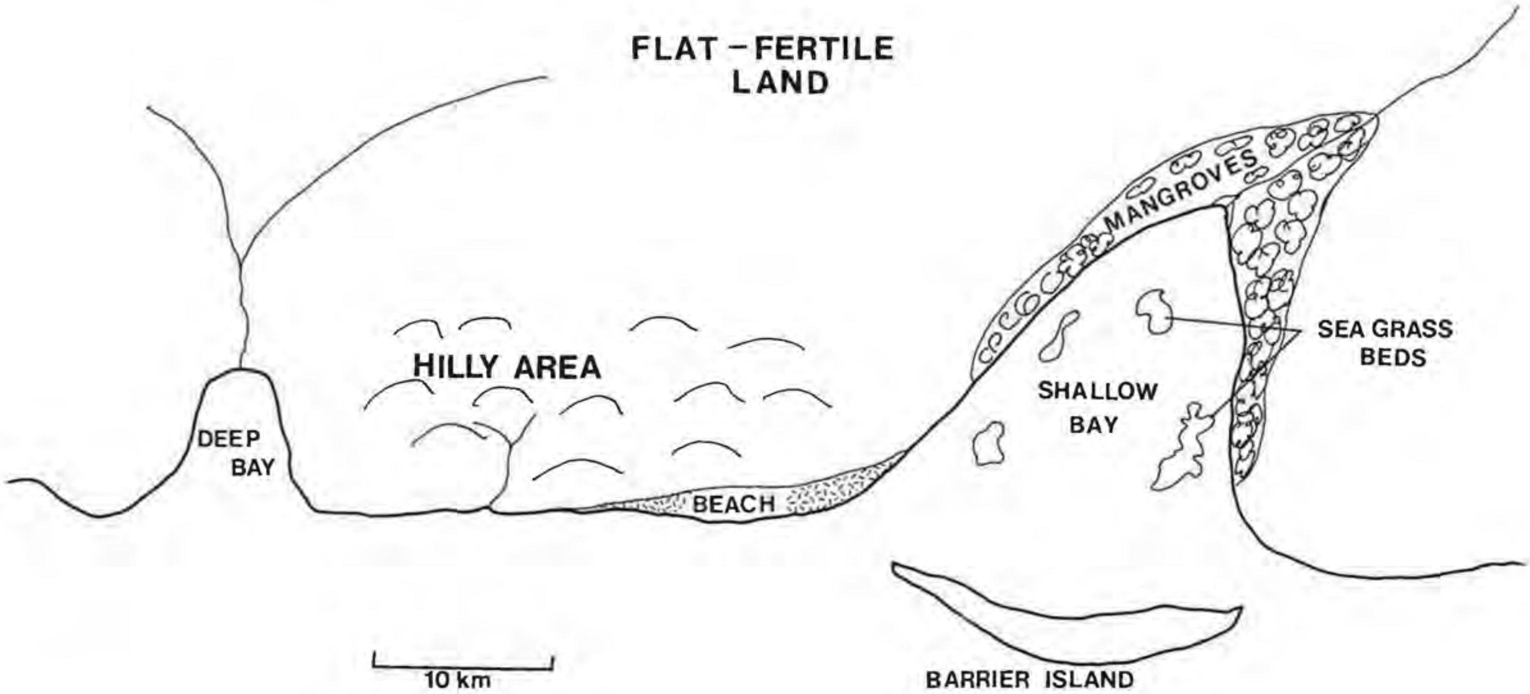
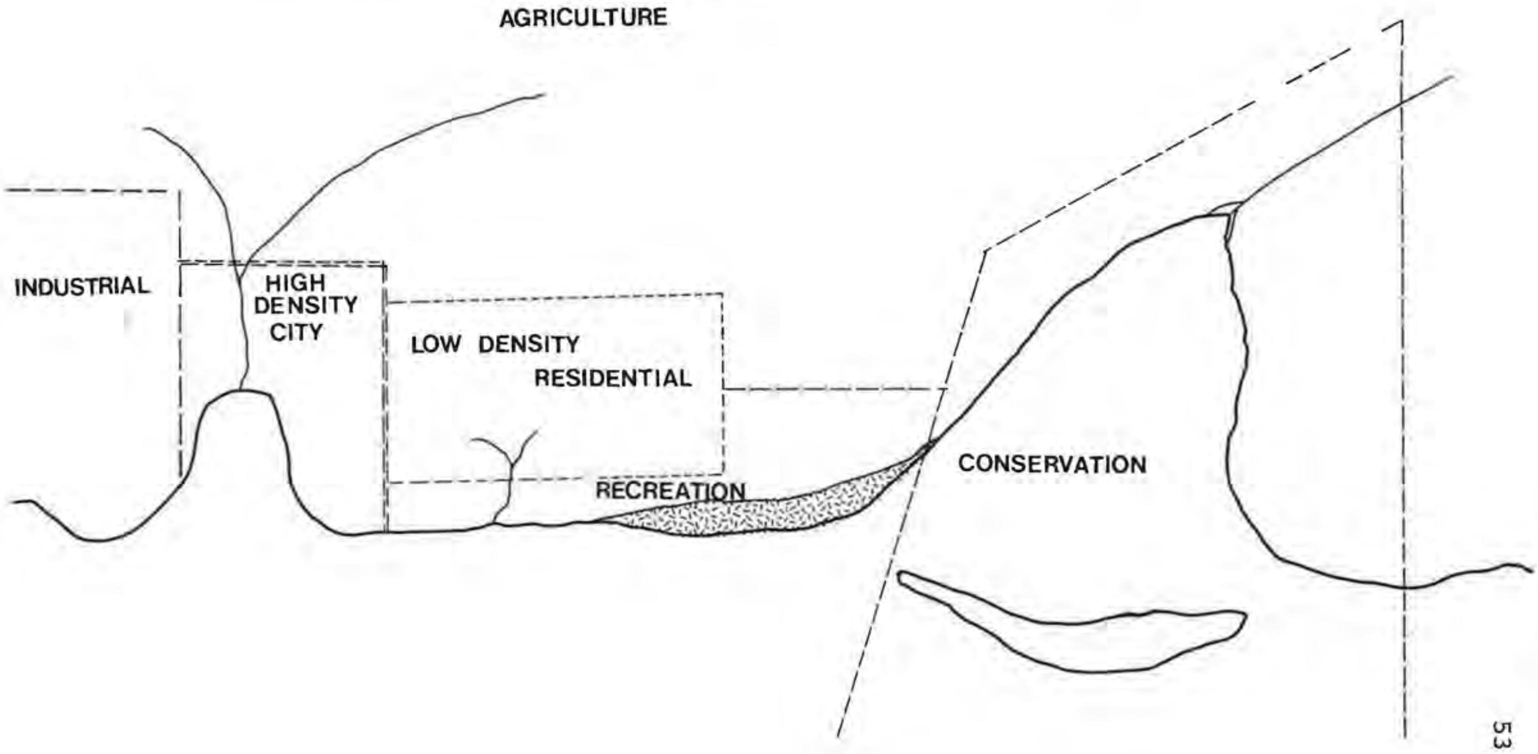


FIGURE 11B. This is one possible management solution for the coastal area shown in Fig. 11A. The conservation zone contains a number of smaller preservation zones which are designed to protect such diverse features as bird rookeries and seagrass beds.



Wherever possible, it is a good idea to: (1) use recreation zones as buffers between conservation and development zones; (2) use recreation, conservation or preservation zones for areas such as beaches and floodplains where intense development is hazardous; and (3) place preservation zones within conservation zones, thereby providing the greatest possible protection.

A final point

Of course, this type of zoning plan, particularly on such a large scale, represents a solution which has in the past rarely ever been entirely achieved. In most areas of the world people and their developments already exist in such a haphazard and unplanned fashion that it is impossible to start the planning process from the beginning. In all but the most extreme cases, however, there is always the potential for creating a workable plan which satisfies both development and ecological demands and at the same time conforms to the existing pattern of human existence.

Lastly, it is important to emphasize that the alternative to planned development is haphazard growth that invariably proceeds too far and too rapidly and results in a continuing series of pollution problems, food shortages, disease, social disorder, overcrowding and other related phenomena. These situations, in turn, are so expensive to correct that the economy of the region will no longer be able to compete favorably with those of regions where resources have not been squandered for short-term gains.

VII. WHERE NEXT? RECOMMENDED READING

The following briefly annotated list of books and articles is necessarily short, but should provide a starting point for those who wish to investigate the material presented here in more depth.

Ecology

Farnworth, Edward G. and Frank B. Golley

1973. Fragile ecosystems: Evaluation of research and applications in the neotropics. Springer-Verlag Pub. Co., N.Y. 258 pp.

This is a useful review of the state of knowledge in tropical ecology. The report is divided into six sections which deal with topics such as ecosystem structure and function, impact of technology on the environment and regional impacts of man.

Golley, F.B. and E. Medina

1974. Tropical ecological systems. Ecological Studies Vol. 11. Springer-Verlag. Pub. Co., N.Y.

This is another useful summary of current ecological knowledge of tropical ecosystems.

Odum, Eugene P.

1971. Fundamentals of ecology. Saunders Pub. Co., Philadelphia. 574 pp.

This is an extensive text both for the beginning and advanced ecology student and can also be used as a reference book.

Odum, Eugene P.

1975. Ecology: The link between the natural and the social sciences. Holt, Rinehart and Winston, N.Y. 244 pp.

This paperback text serves as an introduction to ecology for both laymen and lower level college students.

Odum, H.T. (editor)

1970. A tropical rain forest. Division of Technical Information. Energy, Research Development Administration (A.E.C.), Washington, D.C.

This is a technical tome which contains a large number of scientific papers summarizing several years of work in the rainforests of Puerto Rico.

Odum, H.T., B.J. Copeland and E.A. McMahon (editors)

1974. Coastal ecological systems of the United States. The Conservation Foundation, Washington, D.C.

These four volumes, compiled in the late 1960s, present an exhaustive survey of knowledge concerning ecological relationships and the effects of pollution on a series of aquatic coastal ecosystems.

Richards, P.W.

1957. The tropical rain forest. Cambridge Univ. Press, London. 450 pp.

This classical work presents details of the ecological and botanical aspects of the rainforest ecosystem.

Wood, E.J.F. and R.E. Johannes (editors)

1975. Pollution in the tropical marine environment. Elsevier Pub. Co., Amsterdam.

This is a collection of summary papers which deal with the effects of different types of pollutants on a series of tropical marine ecosystems including coral reefs, mangrove forests and seagrass beds.

Conservation

Björklund, Mona I.

1974. Achievements in marine conservation. Environmental Conservation 1(3): 205-224.

Contained in this article is an up-to-date survey of the world's proposed and established parks and preserves.

Carlozzi, Carl A. and Alice A. Carlozzi

1968. Conservation and Caribbean regional progress. The Antioch Press, Yellow Springs, Ohio. 151 pp.

Numerous aspects of conservation in the Caribbean are discussed in this short book.

Carr, Archie

1973. So excellent a fishe: a natural history of sea turtles. Anchor Natural History Books, Garden City, N.Y. 266 pp.

This fascinating little book emphasizes the difficulties involved in the preservation and wise conservation of a single species, the green sea turtle.

Dasmann, Raymond F.

1976. Environmental conservation, 4th Ed. John Wiley and Sons, Inc., N.Y. 436 pp.

This is the leading introductory college text on the subject and an excellent starting point for anyone interested in an ecological viewpoint of conservation problems.

Technology and environmental problems

Borgstrom, Georg

1973. The food and people dilemma. Duxbury Press. North Scituate, Mass. 140 pp.

The balance between food production and environmental considerations is examined in this short book.

Farvar, M.T. and John P. Milton (editors)

1972. The careless technology: ecology and international development. The Natural History Press. New York. 1030 pp.

This is a compilation of 50 articles which document some ecological costs of promoting technological progress in developing countries.

Phillips, John

1959. Agriculture and ecology in Africa: a study of actual and potential development south of the Sahara. Praeger Press. N.Y. 423 pp.

This book is a forerunner of the idea that development in Africa should consider ecological factors. Emphasis is placed upon ecological hazards which accompany agricultural development.

Phillips, John

1961. The development of agriculture and forestry in the tropics; patterns, problems and promise. Praeger Press. N.Y. 221 pp.

This is an extensive discussion of crop production, conservation and forestry practices from an ecological viewpoint.

Ecological-management considerations

Anonymous

1972. "Environmental priorities". Special issue of CERES, the FAO review. Col. 5, Jan.-Feb., 1972. 65 pp.

Presented in this volume is a short collection of articles concerned with environment and international development.

Anonymous

1974. International development and the human environment. Macmillan Information. N.Y. 334 pp.

This annotated bibliography is an excellent source for information relating to environment, development and the third world.

Clark, John

1974A. Coastal ecosystems: ecological considerations for management of the coastal zone. Conservation Foundation, Washington, D.C. 178 pp.

Intended for the layman, this is an excellent summary of ecological considerations applied to the coastal environment.

Clark, John

1974B. Rookery Bay: ecological constraints on coastal development. The Conservation Foundation, Washington, D.C. 91 pp.

This highly significant report summarizes the conclusions reached after many years of research and study of the Rookery Bay preserve of south Florida. Emphasis is placed upon inclusion of ecological understanding in the planning process.

Clark, John

1977. Coastal ecosystems management: a technical manual for conservation of coastal resources. John Wiley & Sons Interscience (approximately 1000 pages).

Numerous authors have contributed to this extensive manual for management of specific coastal ecosystems. It should become one of the standard reference works on the subject.

Coastal Zone Management Institute

1974. Coastal Zone Management: The Process of Program Development. Coastal Zone Management Institute, Sandwich, Maine, U.S.A.

This is a technical guide for state and local officials involved with the implementation of the U.S. coastal zone management programs. It contains numerous useful references.

Dasmann, Raymond F., John P. Milton and Peter H. Freeman

1974. Ecological principles for economic development. John Wiley and Sons, New York. 252 pp.

The authors explore pertinent interrelationships between development and conservation and demonstrate that both must be based on an understanding of ecology.

Lundholm, Bengt (editor)

1971. Ecology and the less developed countries. Ecological Research Committee Bulletin, No. 13, Swedish Natural Science Research Council. 133 pp.

This volume consists of nine papers and twenty summaries of papers presented at a conference held in Stockholm in 1971. Topics range from "problems associated with protein production from wildlife in Africa " to "economic development and the environment".

McEachern, John and Edward L. Towle

1974. Ecological guidelines for island development. IUCN Publications New Series No. 30. Morges, Switzerland. 66 pp.

This is the first publication in the series of which the present paper is the fourth.

The authors identify the adverse impacts of land use activities on islands and present a set of guidelines to assist planners and decision makers.

The International Union for Conservation of Nature and Natural Resources (IUCN) is an independent international body, formed in 1948, which has its headquarters in Morges, Switzerland. It is a Union of sovereign states, government agencies and non-governmental organizations concerned with the initiation and promotion of scientifically-based action that will ensure perpetuation of the living world - man's natural environment - and the natural resources on which all living things depend, not only for their intrinsic cultural or scientific values but also for the long-term economic and social welfare of mankind.

This objective can be achieved through active conservation programmes for the wise use of natural resources in areas where the flora and fauna are of particular importance and where the landscape is especially beautiful or striking, or of historical, cultural or scientific significance. IUCN believes that its aims can be achieved most effectively by international effort in co-operation with other international agencies, such as UNESCO, UNEP and FAO.

The World Wildlife Fund (WWF) is an international charitable organization dedicated to saving the world's wildlife and wild places, carrying out the wide variety of programmes and actions that this entails. WWF was established in 1961 under Swiss law, with headquarters also in Morges.

Since 1961, IUCN has enjoyed a symbiotic relationship with its sister organization, the World Wildlife Fund, with which it works closely throughout the world on projects of mutual interest. IUCN and WWF now jointly operate the various projects originated by or submitted to them.

The projects cover a very wide range, from education, ecological studies and surveys, to the establishment and management of areas as national parks and reserves and emergency programmes for the safeguarding of animal and plant species threatened with extinction as well as support for certain key international conservation bodies.

WWF fund-raising and publicity activities are mainly carried out by National Appeals in a number of countries, and its international governing body is made up of prominent personalities in many fields.