Part II

Technologies

Chapter s

Maintaining Biological Diversity Onsite

CONTENTS

Tables

Figures

Boxes

Chapter 5

Maintaining Biological Diversity Onsite

HIGHLIGHTS

Maintaining plant, animal, and microbial diversity in their natural environment (onsite) is the most effective way to conserve maximum biological diversity over the long term.

- Strategies to maintain diversity onsite have evolved from strict preservation to multiple use. More recently, attention is being given to integrating conservation with development in areas outside protected zones.
- Guidelines for optimum biological design of protected areas are improving. But decisions on design are determined more often by socioeconomic and political factors than by scientific principles.
- Techniques for restoring diversity on degraded sites are being improved as knowledge of natural plant and animal succession increases. However, complete restoration is often not feasible, and partial restoration is usually slow and expensive.
- Opportunities for improving national and global conservation of diversity onsite include 1) promoting an ecosystem approach to protected area establishment and management, 2) encouraging innovative resource development methods that treat conservation as a form of development, 3) supporting multidisciplinary research on the many factors to consider when designing nature reserves, and 4) developing training and job opportunities for experts in all these areas.

INTRODUCTION

Plants and animals can be maintained where they are found, that is, onsite, either by protecting certain sites from change or by managing change to support some portion of the natural biota. Most biological diversity can only be maintained in a natural condition for three reasons:

1. For most species, technologies have not been developed to keep substantial numbers of individuals alive outside their natural environments.
2. For species that can be kept alive in artificial conditions, preserving genetic diversity usually entails maintaining numerous individuals from genetically distinct populations. Such preservation is financially and logistically feasible for only a few of the hundreds or thousands of species of many ecosystems.
3. Species survive gradual changes in their natural environments by continuous evolution and adaptation—processes that are arrested in offsite collections.

Strategies for maintaining biological diversity onsite range from single-species management to protection of complete ecosystems in designated natural areas. The various approaches are complementary. For example, a European nature reserve system established with broad conservation objectives contains some 10,000 sites of plant species that also are useful for breeding and for research into the chemistry of natural substances.

CLASSIFYING AND DESIGNING PROTECTED AREAS

Maintenance of biological diversity per se has often not been the primary objective of protected natural areas, Instead, many such areas have been set aside and managed for other conservation values, such as preservation of scenic landscapes or protection of watersheds (11). More recently, however, the U.S. Congress and other policy makers have begun to authorize actions to address the maintenance of biological diversity directly. With this new mandate, biologists, agricultural scientists, and conservation program managers have started to develop new ways to apply science to the problem of maintaining biological diversity onsite.

The development of techniques for onsite maintenance of biological diversity has so far focused mainly on protected areas. This section is concerned, therefore, largely with where these protected areas should be established and how biological principles can be used in the design and management of protected areas. The technologies appear to be scientifically sound, yet too little implementation has occurred thus far for a conclusive assessment of effect.

Even if the biological techniques are demonstrated to be correct, the actual location, design, and management objectives for protected areas will be determined mainly by social (including economic and political) factors. For example, costs will usually be a stronger consideration than biological criteria in choosing whether to have one large reserve or several small ones, Boundaries usually reflect what area has been made available rather than what would provide the best habitat for flora and fauna,

Development activities other than conservation may also take precedence in decisions to change the boundaries of protected areas. In tropical countries, where diversity is most threatened, many natural areas are occupied by farmers, hunters, gatherers, and fishermen (see ch. 11). Strategies to safeguard biological diversity must recognize that development of natural resources is imperative and must incorporate socioeconomic and political considerations. However, conservationists and resource developers should also view conservation as a necessary component of economic development.

In spite of the powerful influence of social factors, social sciences are applied less often than natural sciences in efforts to maintain biological diversity. Development planning techniques that do use social science data and principles have been proposed, however, and used occasionally to integrate natural resource conservation with other forms of economic, cultural, and social development. Resource development planning is discussed in some detail in the OTA report, Technologies To *Sustain Tropical Forest Resources (83),* A variation of resource development planning, integrated development planning, is described briefly later in this chapter.

Classification Systems for Protected Areas

Strategies to develop a system of protected areas typically begin by classifying and mapping types of ecosystems using data on plant and animal distributions and on climate and soil parameters. This information is compared with the locations of already-protected areas to approximate priorities for allocating the resources available for site protection,

Descriptions of threatened ecosystems are now adequate in every country to undertake effective programs for conserving biological diversity. In nearly all regions, however, continued improvements in ecosystem classification and assessment would facilitate better decisions on where protection is most needed. Preservation priorities need to be based on knowledge of which ecosystems:

- have high diversity,
- have high endemism (a high proportion of the species having a limited natural range),
- are threatened by resource development or degradation patterns,

- are located where social and economic conditions are conducive to conservation, and
- are not adequately represented in existing protected areas.

The major patterns of nature can be described for most terrestrial areas with existing data. Several biogeographic systems have been developed that relate data on distribution of plant and animal species to factors such as climate and natural barriers like oceans, deserts, and mountain ranges. These systems classify the Earth into zones, with each zone containing distinctive ecosystems and life forms.

Much less information is available on aquatic sites, such as lakes and streams, Aquatic ecosystems are difficult to map on a large scale, and the way to integrate them into land classifications is poorly understood. The same is true of riparian vegetation, mountain meadows, and other azonal ecosystems,

Classification systems take two broad approaches. "Taxonomic" methods establish land units by grouping resources or sites with similar properties. "Regionalization" methods subdivide land into natural units on the basis of spatial patterns that affect natural processes and the use of resources (1), The two approaches can be integrated to identify ecosystem diversity in considerable detail.

The taxonomic approach is typified by the Society of American Foresters (SAF) Cover Type Classification system, which aggregates similar stands of forest trees on the basis of the kind, number, and distribution of plant species and the dominance by tree species (19). The basic taxonomic units—forest cover types—are named after the predominant tree species. The Renewable Resources Evaluation of the U.S. Forest Service further aggregates many of the SAF categories into 20 "major forest types, " which are the basis for the only map of forest cover types available for the United States as a whole.

The regionalization approach, on the other hand, begins with a nation or continent and subdivides it into progressively smaller, more closely related units. An example of this is the ecoregions classification system, used extensively by U.S. Federal land-managing agencies (l). Ecosystem regions for North America are defined as domains on the basis of climate. The domains are subdivided into divisions, which are subdivided into provinces on the basis of what plant communities can be expected to develop if the natural succession of species is not interrupted by human activity. Provinces are subdivided into sections on the basis of the composition of the vegetation types that eventually would prevail. Extending this ecoregion classification system to cover the world on a scale of 1:25 million is being considered.

A recently developed system for classification of the world's marine and coastal environments combines physical processes with biotic characteristics (34). This classification system will be used as a basis for selecting U.S. coastal biosphere reserves (13),

Each classification system has advantages and disadvantages for programs to maintain biological diversity. The taxonomic approach identifies and classifies each component, For example, separate taxonomies are used to identify flora, fauna, and soils. This separation facilitates location of natural areas that will conserve concentrations of high-priority components, such as a vegetation type or animal species. The regionalization approach allows scientists to determine whether the same type of ecosystem in distinct biogeographic regions actually represents two different ecosystems (2),

Biogeographic classification maps indicate what ecosystems would be found under natural conditions, but the discrepancy between expected and actual features is often great because of human intervention, Sparse grasslands may occur where climate, physical features, and species distribution records suggest tropical moist forest should grow, Furthermore, the major classification systems cover only broad zonal features of the environment. Azonal features—e.g., wetlands, riparian areas, and coral reefs—cannot be included. So conservation strategies must take a different approach to identify priorities for these ecosystems. Typically, plans

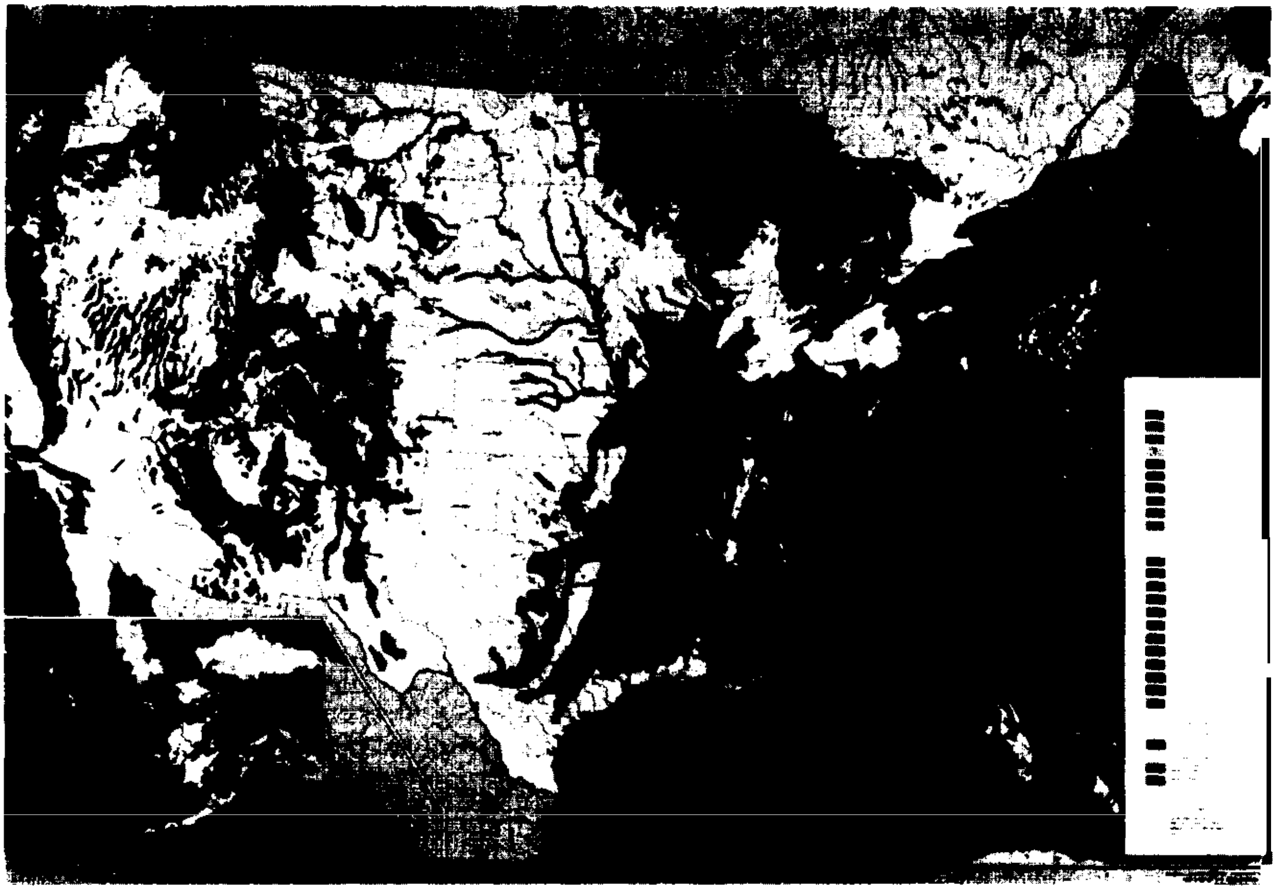


Photo credit' SAF/U.S Forest Service

The Society of American Foresters Cover Type Map, an example of an ecosystem classification system, aggregates similar stands of forest trees on the basis of the kind, number, and distribution of plant species and the dominance by tree species.

for conservation of azonal ecosystems are based on surveys that cut across the biogeographic zones.

Biogeographic classification systems also need to be supplemented with information on endemism. Patterns of endemism vary among taxa and among regions. Some species with restricted distribution are quite common locally, whereas others are extremely rare (26). On the broadest scale, taxa may be endemic to a continent or subcontinent; on a narrow scale, many plant species seem to be restricted naturally to areas as small as a few square kilometers.

Identifying centers of endemism has been an ongoing effort of conservationists, especially tropical ecologists. An area such as an island or a mountain forest may not have an unusually high number of species present, but it may have a high proportion of species not found elsewhere (i.e., high endemism). Such areas are considered valuable for maintaining biological diversity, because they contribute substantially to diversity on a global scaIe,

In sum, a variety of ecosystem classification systems are currently being used by many organizations with different objectives. Although these maps do not indicate the extent of existing ecosystems (e. g., how much forest actually remains), they do correspond roughly to the boundaries of species distributions. Thus, they can be compared with maps of natural areas already protected, and planners can then choose which sites to focus on for more detailed assessment of an ecosystem's contribution to diversity, its vulnerability, and its social and economic significance.

Design of Protected Areas

The sizes and locations of protected areas are determined first by political and financial constraints. Within those limits, the designs of nature reserves have usually been based on natural history characteristics of the particular species of greatest interest. Recently, however, scientists have begun to develop theories for designing nature reserves to optimize protection of biological diversity rather than protection of particular species. These theories are still based mainly on inferences from general scientific principles and are largely untested, Thus, they are the subject of much academic debate among scientists (53),

Criteria for optimum size and shape for protected areas have been based on information from insular ecology (e.g., refs, 15,16,74,90). These criteria, however, are widely viewed as too simplistic, and the theories are being further developed with information from ecological-evolutionary genetics (24,70,73,79) and from theoretical population dynamics (28,74, 80). These theories focus mainly on terrestrial protected areas and probably have limited use for the design of coastal-marine reserves, The great dispersive abilities of marine organisms and the interconnections of adjacent communities thus complicate decisions concerning the proper size and spacing of reserves. (See box 5-A for discussion contrasting terrestrial and coastal-marine systems,)

Islands and Boundaries

Information on the occurrence and natural distribution of species on islands has been used to formulate theoretical size and location criteria for protected areas intended to maintain diversity. The equilibrium theory of island biogeography (52) maintains that greater numbers of species are found on larger islands because

Box 5-A.—Differences Between Terrestrial and Coastal~Marine Systems

It is difficult to gauge the relative differences in biological diversity in terrestrial and coastal-marine environments. Dry land contains approximately four times the number of species found in the sea; on that consideration alone, terrestrial ecosystems seem inherently more diverse. Differences in faunal diversity between marine and terrestrial environments are primarily due to insects. Without them, marine fauna would be more diverse than terrestrial fauna. However, terrestrial flora clearly exhibit greater diversity than marine flora **(51).**

Viewed from a different perspective, in which the number of higher taxa (particularly animal) indicate degree of diversity, the sea would appear more diverse because many higher taxa (i.e., phyla, classes, orders) are exclusively marine. Implicit in this view is the notion that higher levels reflect greater genetic differences–i.e., a single species maybe the sole representative of an order, class, or phylum, and the loss of one of these species might cause afar greater genetic loss than would the loss of a species in a taxon made up of several hundred or thousand members (51).

Another difference is that many fish and invertebrates that make up the bulk of marine species pass through several life stages from egg to adult. In many of the life stages, the organisms seem unrelated to that of the adult form. These different forms can live in different ecosystems or in distinctly different niches within the same ecosystem. Maintaining one species may therefore require maintenance of several different ecosystems (51).

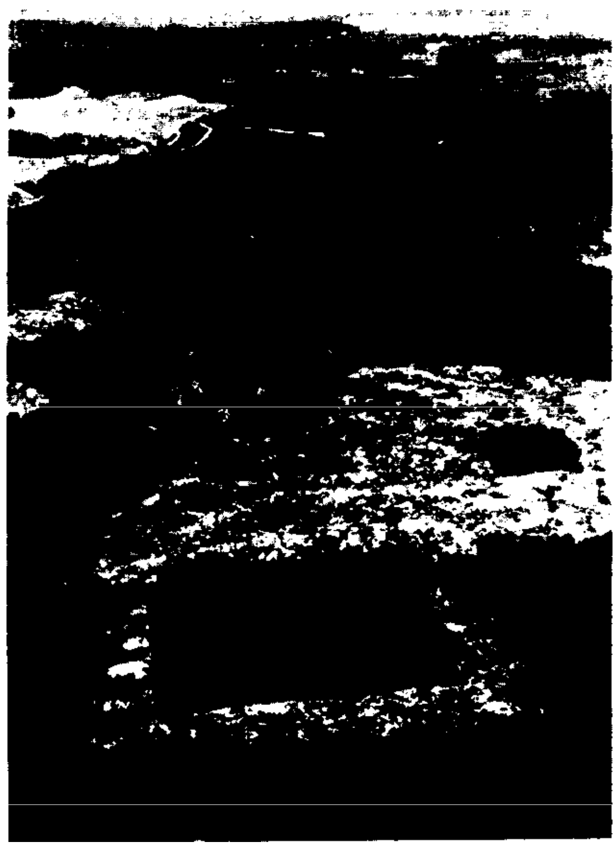
Movement of organisms and materials between different community types—seagrass, coral reef, and mangrove—means that terrestrial and marine communities sometimes cannot be defined simply by their physical boundaries. Effectiveness of efforts to protect one community type may be diminished by failure to protect neighboring communities as well as adjacent watersheds *(40).*

the populations on smaller islands are more vulnerable to extinction. That vulnerability is due to probabilistic nature of individual births, deaths, occurrences of disease, and changes in habitats. Also, islands farther from continents have fewer species, because colonists from large land masses are less likely to reach them. This theory was extended from true islands to their terrestrial analogs (e.g., forest patches in agricultural or suburban areas), and the field of study become known as "insular ecology" to reflect this broader perspective. Scientists do not concur that the theory accurately explains natural patterns of species diversity, and research has been initiated to test the theory. (See Gilbert (27) and Simberloff (76) for reviews of studies that confirm or refute the equilibrium theory.) In any case, the island analogy—that much of the natural diversity is being reduced and confined to small, often isolated areas—is not in dispute,

Nature reserves serve as islands for species incapable of surviving in human-dominated habitats. Isolated natural areas are likely to experience declining numbers of species when their size is reduced by deforestation or similar habitat changes. The analogy between islands and nature reserves was reinforced by findings from some of the early tests of equilibrium theory. These findings led to proposed design criteria for nature reserves intended to minimize the loss of species over time (53). The designs called for large nature reserves near each other, to reduce the effects of small areas and distances on species survival. Other design elements not explicitly derived from equilibrium theory but thought to maintain a greater number of species at equilibrium also exist. However, these are rather academic "all other things being equal" principles, and on the ground, complex habitat differences among areas should weigh more heavily in pragmatic choices of which sites to conserve.

The applicability of insular ecology to conservation is being tested by the World Wildlife Fund's Minimum Critical Size of Ecosystems Project (49). Biologists took inventories of plant and animal life in an Amazon forest area before it was fragmented by development. Various-sized patches of forest were kept intact through coordination with the deforestation and development program, and biologists now monitor plant and animal populations in each patch. Although the project is only 20 years old, changes in the biota are already evident (47,48).

The guidelines for optimum biological design still have many limitations (72). Most of the relevant research has focused on animals, particularly forest-dwelling birds; too little research has been conducted on plants or on other types



M
W W B az
az
az
az

of habitats. Also, the occurrence and persistence of a species on any particular site may be governed not only by the populations on that site but also by whether groups of loosely connected populations can survive in the region (46,71). This sort of scientific question requires long-term study, which is only beginning to be conducted.

As the Earth increasingly becomes a patchwork of natural and developed areas, the effects of activities on or near the boundaries of protected areas are becoming more important. Small areas and those with angular boundaries have a higher proportion of boundary-to-interior than larger or more circular areas. Nature reserves seldom have sharply defined natural boundaries like oceanic islands. Instead they have political boundaries that can do only so much to prevent movements in and out. Many species can migrate across nature reserve boundaries, and the results of human activities (e.g., pollution) may enter by air, water, or land. Consequently, another theory on the optimum design of protected areas, "the boundary model," has been proposed. It accounts for the boundary effects, including the effects of human activities (69).

Designated protected areas include both political and biological boundaries. Some of the biological boundaries are the natural edges between ecosystems; others result from human activities, most of which originate outside political boundaries. Those biological boundaries that fit the ecological definition of an "edge" (box 5-B) may increase local diversity as edge-adapted species prosper. Over time, however, survival of species in the interior may be reduced if edges are enlarged, because the habitat for species adapted to less-disturbed conditions is reduced. Poor protection at the political boundaries generally shifts the biological boundaries toward an area's interior.

Zones where resource-conserving development activities are encouraged have been tested to buffer the boundary effect (e.g., the united Nations Educational, Scientific and Cultural Organization's (UNESCO) Man and the Biosphere Program). Such buffer zones can help reserves by increasing the habitat area and minimizing the potential exposure to harm. The idea of buffer zones is not new, but implementation has been slow; few evaluations have been done yet to develop guidelines about the necessary character and width of the zones or the shifting nature of boundaries.

Box 5-B.-The Edge Effect

Natural boundaries between ecosystems, or edges, are considered to be ecologically diverse areas. Edges can be created by human manipulation of vegetation in an attempt to encourage maximum local diversity (14). Along an edge, animals from each of the abutting vegetation types may be found, together with animals that make frequent use of more than one vegetation type and those that specialize on the edge itself (41). Game animals commonly are edge-adapted, as are animals of many urban, suburban, and agricultural areas (e.g., birds) (8).

Corridors of habitat to connect nature reserves have been proposed for sites where reserve sizes are below-optimum. These corridors should facilitate gene flow and the dispersal of individuals between protected areas, which should, in turn, increase the effective size of populations and thus raise the chance of survival for semi-isolated groups (6). Also, corridors could increase the recolonization rate if species are eliminated locally (78). Corridors, however, are another theoretical concept, and they may not be appropriate for all sites. As noted earlier, geographic isolation is a cause of genetic diversity. Thus, corridors where none previously existed might cause locally adapted genotypes to be lost due to gene flow. The applicability of corridors is another aspect of design theory now being actively researched.

The use of corridors and boundary zones has been proposed for protected areas in the Western Cascades region of the United States, This area contains the largest tract of uncut forest in the conterminous United States as well as natural riparian habitats (32). The proposal suggests surrounding islands of old-growth forest with zones of low-intensity, long-rotation timber harvesting and then linking the islands by corridors of old-growth vegetation. This design would presumably provide mobility for species like the cougar and bobcat—far-ranging carnivores that would have populations too small for survival and continued evolution if confined to a single habitat island. Proposals like this must be considered planning hypotheses, suggested by general theory; and as such must be subjected to close, case-by-case scrutiny before implementation.

Genetcs

Genetic considerations are another dominant concern in the literature on population viability and conservation. Attempts are being made to determine the smallest number of interbreeding individuals that will enable a species to survive indefinitely—adapting to changing environmental conditions without suffering the negative effects of a small population size (population instability, erosion of genetic variability, inbreeding). Because each individual carries only part of the genetic variation characteristic of its species, the size of a population—and thus, the amount of genetic variation—may determine how much and how fast a population can evolve.

Application of genetics to the issue of population size and viability has led to theoretical estimates of minimum populations for successful conservation of birds and mammals. One such estimate, known as the 50/500 rule, is that effective population size (in genetics sense) of 50 breeding adults is the minimum needed to sustain captive breeding programs over decades or a century (e. g., as in zoos), but a population 10 times as large is needed to sustain a species in its natural habitat as it evolves over millennia to survive changing environmental stresses (25,45),

The 50/500 rule is an approximation based on studies of only a few species. But the effect of population size depends on several factors that differ for various species, such as sex ratio, age structure, mating behavior, and behaviors such as feeding. Thus the rule, when applied to a particular species, could project a need for populations larger than 50/500—perhaps orders of magnitude larger. Empirical or experimental evidence is lacking to determine how resilient a "genetically viable" population would be when confronted with other pressures (e.g., demographic, environmental, or catastrophic uncertainty) (72),

Population Dynamics

Scientists have long recognized that, in general, smaller populations are more susceptible to extinction than larger ones, because death for individual organisms is an event determined largely by change, and populations are collections of individuals. Models of the impact of change on individual births and deaths were developed decades ago (e.g., ref. 21), and these have been applied to estimate the extinction time for particular species under various circumstances. Models also have been developed to evaluate the effect of chance environmental variations and chance population-wide catastrophes.

Recently, more sophisticated models of stochastic population dynamics have been formulated specifically to investigate questions of population viability. These models do not give specific prescriptions for minimum population size to assure survival, but they are leading to a better understanding of the role of chance in populations. They indicate that to avoid extinction resulting from the impact of chance on individual births and deaths may require only a few hundred breeding individuals. But larger, perhaps much larger, population sizes are necessary if the condition of the species' environment varies, and still larger populations are needed for species that are susceptible to catastrophes (72).

The modeling approach is useful but has significant limitations. First, data for population models encompassing both environmental and genetic factors exist for only a few species. Also, species experience the effects of chance at individual, environmental, population, and genetic levels. But models that could simultaneously simulate all these factors would be too complex for existing analytical capabilities, Even if such models were developed, they could prove very costly to use (72).

The theoretical population models are yielding other plausible hypotheses, some of which have important implications for conservation. Extinction probabilities depend critically on population growth rates, on environmentally induced variability in this rate, and on particular catastrophic scenarios to which the species are subject. One recent analysis employs a stochastic population model and the general relationships between body-size and population growth rates and between body-size and population density to estimate the sizes of populations and habitats necessary for mammals to have a 95 percent probability of persistence for 1,000 years.

The preliminary results from this analysis are startling. For larger animals, the viable population size is smaller, but the necessary habitat must be larger to support the requisite populations. Thus, smaller mammals can have a viable population size of a million individuals but a habitat requiring only tens of square kilometers. The largest mammals, on the other hand, may have a viable population with only hundreds of individuals but may need a million square kilometers of habitat (3).

These are preliminary analyses, But even if subsequent work reduces the estimates by two orders of magnitude, larger mammals may need contiguous habitats of tens of thousands of square kilometers to survive indefinitely, Few protected natural areas are that large, implying that conservation strategies for certain species should not depend as much on protected reserves as on monitoring and managing larger areas (24).

ESTABLISHMENT OF PROTECTED AREAS

Since the world's first two national parks were established in the 1870s, some 3,500 protected areas have been set aside for conservation, covering some 4.25 million square kilometers (1,050 million acres) (35). (See figure 5-1 for rate of growth.)

Growth in the number and size of protected areas was slow at first. It accelerated during the 1920s and 1930s, halted during world War II, and regained momentum by the early 1950s. The number doubled during the 1970s, but growth has slowed over the past few years (33). Before 1970, most protected areas were located in industrial countries. But for the past 15 years, the Third World has led in both numbers added and rates of establishment.

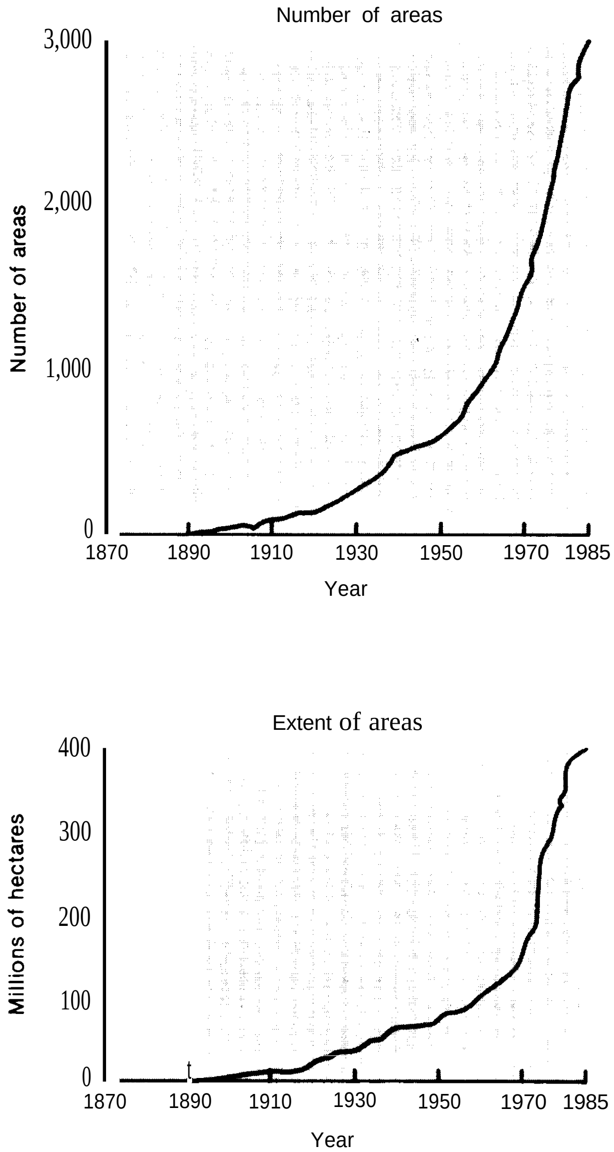
Designation as a protected area does not necessarily mean that protection is effective, of course. The extent of actual protection in the 3,500 areas has not been determined, but anecdotal evidence indicates that illegal or unmanaged hunting, fishing, gathering, logging, farming, and livestock grazing are common problems (83). Thus, data on designated areas exaggerate the scope of conservation actually being achieved.

Acquisition and Designation

Most protected areas are established by official acts designating that uses of particular sites will be restricted to those compatible with natural ecological conditions. At the Federal level in the united States, designating a land area or water body for conservation involves making a formal declaration of intent to assign a certain category of protection and then providing an opportunity for extensive public comment on the proposed action. Other governments use similar processes, although the extent of public participation varies.

The degree of protection depends partly on the objectives of the acquisition or designation. There are many different types of designations. Kenya, for example, has national parks, national reserves, nature reserves, and forest reserves. The wildlife sanctuaries in Kiribati in the South Pacific are very different in conser-

Figure 5-l.— Growth of the Global Network of Protected Areas, 1890.1985



SOURCE: International Union for the Conservation of Nature and Natural Resources, *The United Nations List of National Parks and Protected Areas* (Gland, Switzerland: 1985).

vation terms from wildlife sanctuaries in India. Designated national parks of the united Kingdom are quite different from national parks in the united States. And in Spain, national parks, nature parks, and national hunting reserves indicate different types of protection.

To clarify this situation and to promote the full range of protected area options, the International Union for the Conservation of Nature and Natural Resources (IUCN) provides a series of 10 management categories (37,38). Protected areas are categorized according to their management objectives, rather than by the name used in their official designations (see table 5-1). Thus, the national parks of the United Kingdom are placed under category V (protected landscape or seascape), rather than under category II (national parks). Standardization of the categories also facilitates international compar-

able 5.1.—Categories and Management Objectives of Protected Areas

1. *Scientific reserve/strict nature reserve:* To protect and maintain natural processes in an undisturbed state for scientific study, environmental monitoring, education, and maintenance of genetic resources.

II. *Nationa/ park;* To protect areas of national or international significance for scientific, educational, and recreational use.

III. */Vatural rnonurnent/natura/ /andrnar/c* To protect and preserve nationally significant features because of their special interest or unique characteristics.

IV, *Managed nature reserve/wildli~e sanctuary:* To assure the conditions necessa~ to protect species, groups of species, biotic communities, or physical features of the environment that require specific human manipulation for their perpetuation.

V. *Protected /andscape or seascape:* To maintain nationally significant landscapes characteristic of the harmonious interaction of humans and land, while allowing recreation and tourism within the normal lifestyles and economic activities of these areas.

V1. *Resource reserve:* To protect the natural resources of the area for future use and prevent or contain development activities that could affect the resource, pending the establishment of objectives based on knowledge and planning.

V1l. *Natura/ biotic area/anthropological reserve:* To allow the way of life of societies living in harmony with the environment to continue.

VIll. *Mu/tip/e-use management area/managed resource area.'* To provide for the sustained production of water, timber, wildlife, pasture, and outdoor recreation, with conservation oriented to the support of the economic activities (although specific zones may also be designed within these areas to achieve specific conservation objectives).

IX. *Biosphere reserve:* To conserve an ecologically representative landscape in **areas** that range from complete protection to intensive production; to promote ecological monitoring, research and education; and to facilitate local, regional, and international cooperation.

X. *Wor/d heritage site.'* To protect the natural features for which the area was considered to be of world heritage quality, and to provide information for worldwide public enlightenment.

SOURCE: J.W.Thorsell, "The Role of Protected Areas in Maintaining Biological Diversity in Tropical Developing Countries, " OTA commissioned paper, 1985 isons and provides a framework for all protected areas.

Criteria for Selection of Areas To Protect

Protected areas can be located and managed to protect biological diversity at three levels:

1. at the ecosystem level: by protecting unique ecosystems, representative areas for each main type of ecosystem in a nation or region, and species-rich ecosystems and centers of endemism;
2. at the species level: by giving priority to the genetically most distinct species (e. g., families with few species or genera with only one species), and to culturally important species and endemic genera and species; and
3. at the gene level: by giving priority to plant and animal types that have been or are being domesticated, to populations of wild relatives of domesticated species, and to wild resource species (those used for food, fuel, fiber, medicine, construction material, ornament, etc.).

Ecosystem Approach

Conserving ecosystem diversity maintains not only a variety of landscapes but also broad species and genetic diversity. Indeed, it may be the only approach to conserving the many types of organisms still unknown to science.

A strategy to maintain ecosystem diversity generally begins with the biogeographic classification system described earlier, The system can be used to identify which ecosystem types need to be acquired or designated to achieve more complete protection of biological diversity.

The extent to which diverse U.S. ecosystems are represented within protected areas is being assessed on a State-by-State basis by the natural heritage inventory programs of the different States (see ch, 9). Recent estimates of the proportion of major terrestrial ecosystem types that are not protected in the Federal domain vary from 21 to 51 percent, depending on the size and number of each type thought to be needed for adequate protection (13),

The extent to which the world's terrestrial ecosystems are included in protected areas has been crudely estimated using the Udvardy biogeographic classification system, which divides the world's land into 193 biogeographical provinces, Since each province typically contains many distinct types of ecosystems, the degree to which province locations correlate to protected area locations gives only an approximation of where greater protection is needed. The 3,514 protected areas listed by IUCN are located in 178 provinces. The coverage is patchy: several provinces have few protected areas, which implies that numerous unique ecosystems have yet to be included in the worldwide network of protected areas (see table 5-2) (33). An estimate of the cost of completing this network is $1 billion (17).

Ten provinces have fewer than 1,000 square kilometers protected but more than five protected areas, while another 29 have more than 1,000 square kilometers but only five or fewer separate protected areas, Determining the extent of the patchiness requires better figures for analysis, such as accurate estimates of province sizes. In addition, aquatic and azonal ecosystems (e. g., wetlands and coral reefs) do not fall easily within this system.

A U.S. effort that helps maintain representative aquatic ecosystems is the Marine Sanctuary Program conducted by the National Oceanic and Atmospheric Administration of the Department of Commerce. Potential marine sanctuary sites were listed after consultation with scientific teams familiar with the different ecological values of sections of the coastal zone (86). All current and future designations into the marine sanctuaries will be made from the site-evaluation list, Maintenance of community or ecosystem diversity is not a specific objective of the Marine Sanctuaries Program, but if all sites on the list were designated sanctuaries, coastal ecosystem diversity would be significantly protected.

An international effort that contributes to conserving representative ecosystems is UNESCO's

Table 5-2.—Coverage of Protected Areas by Biogeographic Provinces

Provinces lacking any protected areas:
- Arctic Archipelago, Arctic Ocean
- Argentinean Pampas, Argentina
- Ascension/St. Helena, South Atlantic Ocean
- Baikha, U.S.S.R.
- Burman Rainforest, Burma
- Greenland Tundra, Greenland
- Laccadive Islands, Laccadive Sea
- Lake Ladoga, U.S.S.R.
- Lake Tanganuika, Africa
- Lake Titicaca, Peru
- Lake Turkana, Kenya
- Maldives/Chagos Archipelago, Indian Ocean
- Pacific Desert
- Revillagigedo Island, Alaska
- South Trinidad

Provinces with five or fewer protected areas and a total protected area of less than 1,000 km^2 (247,000 acres):
- Aldabra, Seychelles
- Amirante Isles, Seychelles
- Aral Sea, U.S.S.R.
- Araucania Forest, Chile
- Atlas Saharien Steppe, Algeria-Morocco
- Cayo Coco, Cuba
- Central Polynesia, Pacific Ocean
- Cocos (Keeling) Islands, Christmas Island, Australia
- Comoros, Indian Ocean
- East Melanesia, South Pacific Ocean
- Fernando de Noronha Archipelago, Brazil
- Guerrero, Mexico
- Hindu Kush Highlands, Afghanistan-Pakistan
- Insulantarct ica
- Kampuchea
- Lake Malawi, Africa
- Lake Ukerewe (Victoria), Africa
- Malagasy Thorn Forest, Indian Ocean
- Mascarene Islands, Indian Ocean
- Micronesia, North Pacific Ocean
- Patagonia, Argentina
- Planaltina, Brazil
- Ryukyu Islands, Japan
- Sichuan Highlands, China
- Sri Lankan Rainforest, Sri Lanka
- Taiwan, ROC
- Tamaulipas, Mexico
- West Anatolia, Turkey

SOURCE J. Harrison, "Status and Trends of Natural Ecosystems Worldwide, " OTA commissioned paper, 1985

Man in the Biosphere (MAB) Program. MAB has established a network of biosphere reserves in a global system of protected areas (see ch. 10). The objective is to have a comprehensive system covering all 193 biogeographic provinces, The MAB program exists in 66 countries, and approximately 256 biosphere reserves have been designated thus far (61).

Species Approach

Natural areas are also selected to conserve the habitats of rare or endangered species or to protect areas with high species endemism. using species presence as the criteria for protected area location and management is useful for several reasons (62,82):

- Certain species can be used to indicate the effectiveness of management. If the more conspicuous rare species cannot survive, then the design and management of the reserve should be changed.
- Species provide a focal point or objective that people can readily understand.
- Some species have an appeal that wins sympathy, an important factor in raising funds and public awareness.

Protection of an area to conserve a rare or endangered species should be based on the best existing evidence on its location and habitat needs. The United States has accumulated a great deal of such information as a result of the Endangered Species Act and the work of The Nature Conservancy. For other regions of the world, information on endangered species ranges from precise (in northwestern Europe) to nonexistent (in the Amazon Basin). At the international level, the IUCN'S Conservation Monitoring Center tracks the status of species and publishes its findings in the Red Data Books (10).

Genetic Resources

Genetic variation within species needs to be conserved because it enables species to adapt to changing conditions and provides the raw material for domestication of plants and animals and the continued improvement of already domesticated crops and livestock.

Protected areas designated specifically to protect genetic variability of particular species are often called in-situ genebanks. They may be established as separate areas for particular crop relatives, timber trees, animal species, and so on. Or, the maintenance of genetic diversity of important species may be one of several objectives of a protected area (63).

India and the Soviet Union have expressed commitment to in-situ conservation of the wild relatives of crop species (63). India has designated the first gene sanctuary, for citrus, and some Indian biosphere reserve areas are expected to have genetic conservation as a major objective. For example, a reserve area has been proposed for the Nilgiri Hills area, which is rich in wild forms of ginger, tumeric, cardamom, black pepper, mango, jackfruit, plantain, rice, and millets, The Soviet Union has reportly designated 127 reserves for protection of wild relatives of crops and has proposed an additional 20 areas for protection. Expeditions to a region known as the Central Asian gene center have found 249 species of wild crop relatives (63).

In East Germany, an inventory is being made of important genetic resources within the country's nature reserves, including 24 forage crop species, 51 medicinal plants, and 27 fruit species, As noted earlier, the inventory is expected to identify about 10,000 places within the country's reserve system where protection is afforded for plants relevant to breeding, breeding research, and study of the chemistry of natural substances (68).

Trade-Offs

In selecting areas for onsite maintenance of biological diversity, trade-offs occur when any of the above criteria are given priority. If the strategy is to protect areas where rare and endangered species are found, then the diversity of ecosystems that exists may not be maintained adequately because only certain types include identified rare species. Concentrating on biogeographic categories for broad coverage of ecosystem types may not protect habitats for rare or endangered species sufficiently or for centers of endemism. The third criterion, protecting genetic variability, includes consideration of economic and social factors that may contribute less to the objective of maintaining maximum diversity but aid the larger goal of conserving resource opportunities for human welfare.

In practice, other objectives and various social and economic constraints prevail in the decisions on where to locate protected areas. Other objectives include preservation of scenic resources, provision of recreation opportunities, and protection of watersheds, Constraints include budgetary feasibility, competing demands for use of the area, and opportunity for local support of protected status.

The literature on conservation strategies contains few objective methods to evaluate these trade-offs, except to note that the three biological approaches—ecosystem, species, and gene pool—are both complementary and necessary. Decisions are often initially made by the intuitive judgment of conservationists but ultimately by the political processes that lead to the official protected area designation.

PLANNING AND MANAGEMENT

Planning and management strategies for onsite maintenance seek to conserve either the species and genetic diversity within a given area or the diversity of ecosystems across a geographic region. Planning tools range from mathematical models that simulate how an area's biological resources are likely to respond given different management options to written plans for natural area management. Management is concerned both with managing external pressures affecting a protected area and with managing the natural succession of plant and animal communities within the area, Management activities range from no intervention to active manipulation of an ecosystem,

Planning Techniques

Planning for protected areas can begin before designation is finalized, Biologists generally agree that plans to maintain diversity need to begin with site surveys to determine the following information (65):

- the number, abundance, and distribution of species, and the interactions between species and community types;

- the types, extent, locations, and effects of human uses, the degree of dependence of local inhabitants on these uses, and the possible alternatives for activities that are harmful to the site;
- the present and potential threats from activities outside the immediate area of concern;
- the opportunities for making the site more useful to local inhabitants; and
- the best approach for law enforcement on the site.

Agency budgets and policies for management planning often omit some of these surveys, considering them fundamental research rather than pragmatic planning activities, For example, the U.S. Bureau of Land Management's Resource Management Plan process does not include collection of detailed site data if no deleterious human impact or other problem is known. Biologists argue, however, that the problems cannot be fully identified without the surveys.

Historically, the specific plans to conserve biological diversity were left to the area manager to devise and implement. This approach still prevails in many regions of the world, In the United States, conflicts in land and water management and the increasing need to justify all management activities to a governing institution have resulted in specialized tools for planning the conservation of biological resources, Much of this development of planning techniques has occurred in the Federal land management agencies.

Modeling

A recent innovation in planning techniques is the use of mathematical models, The models are highly simplified versions of natural environments. Biological data are used to develop equations that represent assumptions about cause-and-effect interactions between plant and animal populations and their habitats, Numerous equations interact, and the outcome projects responses of the biological resources to different management options. The accuracy of the projections depends on how well the equations and the data reflect the situation in the natural environment,

Various kinds of wildlife-habitat models have been used, and recently, the population simulation models described earlier have begun to be used widely. These population models predict how management activities would affect population size, structure, and recovery rate. They can describe, for example, the probable size of a fish population before and at various times after a specified fishing season.

Wildlife-habitat models are built from natural history data on species distribution and abundance in various habitats, from which cause-and-effect relationships are deduced to predict how wildlife populations will change as a result of changed habitat conditions. Indicator Species Models, for instance, focus on one or a few species known to reflect broader ecosystem qualities. Another example is the Habitat Evaluation Procedure used by the U.S. Fish and Wildlife Service to describe the responses of vegetation and, hence, wildlife habitats to certain management options such as timber harvesting (75),

Geographic Information System models also account for the changes in vegetation or wildlife habitats that result from different management options, but the output *is* presented on maps, which facilitates evaluation of cumulative impacts by area. A complementary technique being developed by U.S. National Park Service personnel, the Boundary Model, is intended to assess not only management activities but also the effects of human actions outside the protected areas (69).

Biologists warn that the accuracy of models is constrained by the need to reduce complex, often poorly understood interactions to assumptions simple enough to be represented with mathematical equations. Often, data are too limited to test all the assumptions. None of the natural area models can predict all the possible ways that biological resources might respond to habitat changes. Thus, models are best used to make the assumptions and logic of scientists, managers, and natural-area users explicit, so that final plans and management decisions can be based on clear, thorough, and objective understanding of all perspectives,

Management Plans

Management plans can help avoid typical protected area problems, such as inappropriate development; sporadic, inconsistent, and ad hoc management; and lack of clearly defined management objectives. Management planning also serves to review existing databases, to encourage resource inventories, and to identify other needed research and monitoring activities. Unfortunately, such plans do not exist for many of the world's protected areas, which constitutes a major constraint on maintaining diversity (82).

Species-specific management plans identify actions for maintaining healthy, reproductive populations of a particular species, Often, the species are either economically valuable or are rare, endangered, or sensitive to certain lander water-management practices. The Office of Endangered Species of the U.S. Fish and Wildlife Service is the lead agency for recovery plans to restore populations listed on the Federal Threatened and Endangered Species List, For example, two Federal agencies, two State agencies, one university, and two agencies from British Columbia cooperated in development of the Selkirk Mountain Caribou Management Plard Recovery Plan, This plan provides details on caribou population dynamics, behavior, and habitat in Idaho, Washington, and British Columbia, It describes past and present caribou management activities, specifies management goals and objectives to recover the species, indicates priorities for action, and assigns these to specific agencies (87).

Site-specific management plans outline the options for maintaining biological resources within given locations, commonly parts of natural areas. For example, the Bureau of Land Management developed a plan to maintain resources within the Burro Creek Section of the Kingman Resource Area in Arizona (88). The plan has clearly stated management objectives. It describes the resources of the site, presents the management issues pertaining to the area, details the management practices that will be used on the site, and indicates what other resource activities will be allowed (e. g., mining) (88),

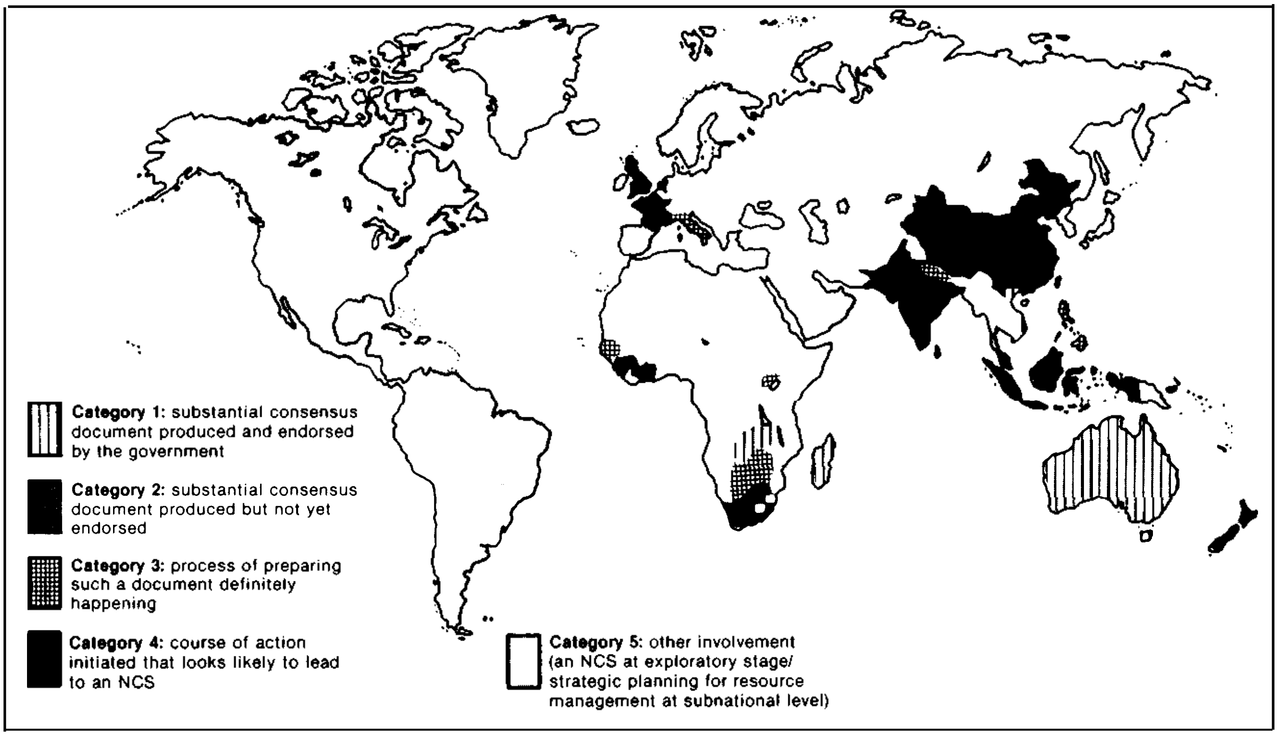
Large-area planning documents can include maintaining diversity as one objective to be balanced with others, but they generally do not recommend site-specific actions. Examples include the plans prepared by the U.S. Forest Service for national forest management, plans by the Bureau of Land Management for resource area management, and plans by the National Marine Sanctuary Program for the management of marine sanctuaries. These planning processes generally involve numerous experts from various disciplines who identify and weigh management options. The planning document then describes resources, the options available for managing those resources for various uses, the trade-offs that would be made in various resource-use scenarios, and finally, the proposed management strategy.

National and subnational conservation strategies (NCSS) tend to be generic documents that may include but are not limited to conserving biological diversity. Some 30 countries had begun to develop national conservation strategies by the end of 1985 (62) (see figure 5-2). To date, only a few NCSS have been completed. The United States, for example, does not have a plan for conservation of biological diversity,

One example of a completed countrywide plan is the Zambia National Conservation Strategy, which identifies the major environmental issues and ecological zones that need immediate attention in that country (29). Objectives of the strategy are to maintain the essential life support systems, maintain genetic diversity of both domestic and wild species, promote wise use of natural resources, and maintain suitable environmental quality and standard of living, To accomplish these objectives, plans and policies for sustainable management of natural resources are to be integrated with all aspects of the country's social and economic development. The strategy outlines schedules of action for the major agencies and identifies necessary interagency linkages to assure cooperation, The official status of this plan and the extent to which it is being implemented is not clear.

Management plans vary in geographic scale and levels of specificity. Plans at the more general levels require less detailed information on

Figure 5-2.—National Conservation Strategy Development Around the World, July 1985



SOURCE *IUCN Bulletin Supplement* (Gland, Switzerland: IUCN, 1985)

the characteristics of species but greater understanding of larger cause-and-effect relationships and of social, economic, and political factors,

Management Strategies

Increasingly active management of factors affecting biological diversity will be needed to overcome the effects of human activity and the gradual fragmentation of natural areas (89). Natural areas change over time, as various plant and animal communities succeed one another, and gradual change in the components and quantity of biological diversity occurs. To sustain particular components, such as game animals or songbirds, protected-area managers therefore need to intervene in the natural processes. The interventions vary with objectives, and conflicts may occur. For example, developing optimum habitat for a particular species may not be compatible with maximizing the diversity of community types.

Manipulating habitats to manage particular species sometimes involves controlling populations of certain animals—removing an exotic fish from a lake, for example. More often, the intervention involves modifying vegetation. If the target species are grazing or browsing animals such as deer, intervention might mean cutting trees to prevent woodlands from evolving to the climax stage; for prairie birds such as cranes, it could mean burning grasslands to prevent encroachment by woody plants. Certain plants may be propagated for food or cover for the target species. The U.S. Fish and Wildlife Service uses such management techniques in national wildlife refuges, which are the only extensive federally owned lands managed chiefly for conserving wildlife,

Management to maximize the diversity of community types involves similar interventions. Again, a basic consideration is the variety of plant succession stages to be maintained within an ecosystem. Manipulation management is likely to be needed to preserve communities representing early stages of succession. For example, savanna ecosystems are maintained by fire, wildlife, and human influence. Management techniques to conserve savanna systems include regulating animal numbers and species and using controlled burning. Rain forests in a mature successional stage require little intervention, but they are likely to need active protection because they are not generally resilient if cleared in large areas (82).

Where the U.S. Forest Service manages land with wildlife diversity as a goal, it attempts to provide an appropriate mix of successional stages within each plant community (84). The approach of the U.S. National Park Service is to maintain natural processes to the extent possible, including catastrophic changes such as localized fire, to allow a relatively natural mix of succession stages to occur.

Management strategies have evolved from strict preservation and protection to multiple-use approaches and, more recently, to integrated approaches. Strict preservation strategy entails setting aside large blocks of natural areas where designation and protection alone would be expected to achieve conservation objectives. Protection would mean severely restricting the uses of, and the changes within, an area to ensure the continued natural condition of its biological resources and regular policing of boundaries to prevent trespassing or poaching. Where possible, fences would be erected to restrict access by humans and livestock.

Moderate versions of this strategy maybe effective in some locations, particularly where the land is owned by an individual or nongovernmental organization. In many areas, strict controls are impractical. It has not been very successful in developing countries. Moreover, neither fences nor patrols can prevent all external influences from damaging a protected area. Regular patrols of a marine sanctuary could not stop the effects of water pollution, for example.

Strict preservation of biological diversity is not an explicit objective of any federally protected area in the United States. The objective closest to it is protection of "biological resources" or "ecological processes" on lands in the National Wilderness Preservation System, which is an evolving system of public lands relatively undisturbed by humans and large enough to have potential for wilderness recreation. (Most wilderness areas contain at least 5,000 acres, although some in the Eastern United States are smaller.)

Other countries also have extensive areas set aside for preservation while allowing some human access. Examples include large segments of Antarctica and isolated parts of the Amazonian forest. Some natural areas, such as Wood Buffalo National park in Canada and Salonga National Park in Zaire, have wardens to guard the boundaries and prevent trespassing (61), But increasingly, countries cannot afford to designate large areas for strict preservation. Particularly in developing countries, adequate fences, patrols, or other means to deny access to designated areas are seldom logistically, economically, or socially possible. In addition, preservation strategies have exacerbated perceived conflicts between conservation and development,

Another strategy for protected areas is to incorporate multiple uses or objectives. This strategy is usually based on one or two approaches: developing an optimum mix of several uses on a local parcel of land or water; or creating a mosaic of land or water parcels, each with a designated use, within a 1arger geographic area.

Developing an optimum mix of uses in an area requires careful incorporation of each objective so that all can be met, This approach is used by the U.S. Forest Service on national forest lands and by most States on wildIife areas and State forests. In national forests, the potential of each subsection is evaluated for recreation, grazing, timber production, wildlife or fisheries habitat, mineral development, and other uses. Management objectives for each site usually include more than one use. Thus, an area that is managed for timber production may also provide sites for grazing livestock or foraging wildlife. Sometimes, mining or another use will be exclusive, at least temporarily.

The California Desert Conservation Area, managed by the Bureau of Land Management, is an example of the second approach to multiple use, in which protected areas are managed primarily as distinct parcels with different primary uses. The conservation area is broken into different land units and classified according to the level of human activity allowed in each. Research areas, wilderness areas, areas of critical environmental concern, areas of geologic or archeologic significance, and critical habitats of endangered or sensitive plant or animal species are mapped and sometimes identified by markers posted at the sites. The rest of the land is classified for various levels of use ranging from restricted to extensive human use and alteration. Management of the area evolves as human needs for resources of the California Desert change.

The biosphere reserve concept is another example of multiple-use based on buffer zones that would moderate the extent that activities affect the core. The UNESCO Man and the Biosphere Program (see also ch. 10) champions this idea. An idealized scheme includes three areas:

1. The core areas strictly protect ecological samples of natural ecosystems that can serve as benchmarks for measuring long-term changes in ecosystems.
2. The buffer zones have land-use controls, which allow only activities compatible with protection of the core area, such as research, environmental education, recreation, and tourism.
3. The transition areas surround the core and buffer zone and are usually not strictly delineated. In these areas, researchers, managers, and the local population are to cooperate in rehabilitation, traditional use, development, and experimental research on natural resources (30).

The areas should facilitate management by reducing conflicts, because the more incompatible uses would be physically distant from one another. And effectiveness of protection should be enhanced, because conflicting uses could be detected before they spread into the core (see box 5-C).

This approach has not yet been implemented sufficiently to assess its worldwide effect, but plans for such development now exist and await political commitment and implementation in several nations. One example is the development plan for the San Lorenzo Canyon area in Mexico (60). Multiple-use development is indicated for a 225,()()()-acre chaparral and desert area where watershed protection is a primary objective, The plan delineates four zones:

1, a core scientific area to be used for research and watershed protection,

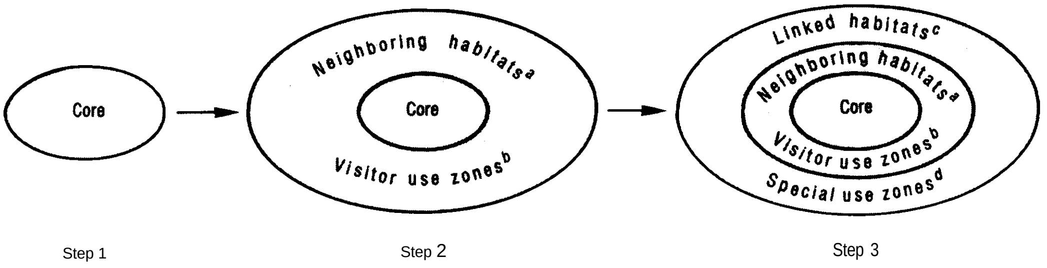
Box 5-C Cluster Conceprt for Biosphere Reserves

In the United States, a promising development of biosphere reserves is the cluster concept. The approach is intetidad to link complementary areas administered by different agencies so they can cooperate in monitoring research, educational, and management activities.

A particularly promising multiple-unit biosphere reserve is emerging in the Southern Appalachians. Efforts are underway to link the existing Great Smoky Mountains National Park, the Forest Service's Cowaeta Hydrological Station, the Department of Energy's Oak Ridge National Environmental Research Park, and other nearby State and Federal agencies managing natural resources to forma Southern Appalachian Biosphere Reserve. The existence of a permanent association of Federal agencies and regional universities has served as a useful mechanism to help coordinate regional resaarch and management activities involving the biosphere reserve.

Another promising example is on St. John, the Virgin Islands, where the National Park Service manages VS. National Park, A cooperative effort involving agencies and institutions from Puerto Rico, the U.S. Virgin Islands, and the British Virgin Islands has coordinated a major research program focused on developing a biosphre reserve on St. John. As the only U.S. national park in a developing region, the area provides opportunities in the transfer of research and resource management technologies suitable for small islands of the region.

Figure 5-3.— Design of a Coastal or Marine Protected Area



[a]Habitats adjacent and linked to habitats of interest by species movements or flows of nutrients
[b]Headquarters; ranger stations; and traditional fishing, recreational, research, and education zones
[c]Watersheds, agricultural lands, urban and industrial developments, rivers, and estuaries
[d]Shipping lanes, commercial fishing grounds, and Intensive use zones

SOURCE R V Salm, *Marine and Coastal Protected Areas A Guide for Planners and Managers* (Gland. Switzerland International Union for the Conservation of Nature and Natural Resources, 1984)

2. a *primitive* area to be used for watershed protection and recreation,
3. an *extensive use* area for recreation and education, and
4. a *natural recovery* area eventually for agricultural and commercial use.

Zoned development seems an especially important concept for marine and coastal areas, which are particularly vulnerable to events outside their boundaries even when they are protected. Figure 5-3 is an idealized design for a coastal- or marine-protected area.

A more recently developed integrated approach holds potential for resolving many of the problems that arise in onsite maintenance of biological diversity. An example is the integrated regional development planning, which is discussed later in this chapter.

Ecosystem Restoration

As degraded ecosystems become more common, restoration will play an increasing role in conserving biological diversity. Underlying most of the discussion in this chapter has been the assumption that protected areas are designated where ecosystems are in a relatively natural condition. Another important approach, however, is to protect and sometimes manipulate degraded ecosystems in order to restore some degree of biological diversity. Restoration techniques are being used by conservation organizations, such as The Nature Conservancy and the Audubon Society, and by government agencies, such as the National Park Service to enlarge or adjust the shape of reserves (43).

Reclamation is action intended to restore damaged ecosystems to productive use (43). Restoration is the re-creation of entire communities of organisms, closely modeled on communities that occur naturally. Reclamation gradually becomes restoration as more and more naturally occurring species are used and as natural plant and animal succession occurs. Restoration technologies, which depend heavily on the knowledge gained from reclamation experience, attempt to accelerate natural succession processes while assuring that indigenous rather than exotic species dominate.

Restoration is an onsite method that provides links with offsite activities to preserve species. Zoos and botanic gardens conserve rare species offsite for reintroduction onsite (see ch. 6), Nurseries and seed facilities provide plants and seeds for a variety of revegetation efforts, although materials for most native plants still must be gathered from the wild (42,44). Reintroductions of animals from captive populations are few but include the Arabian oryx, the golden lion tamarin (a recent effort), and plans to reintroduce Przewalski's horse in Mongolia (see ch. 6, box 6-E). A few plant reintroductions from offsite collections also exist. The Knowlton's cactus *(Pedlocactus knowltonii)* has been returned to the natural environment from cuttings by the Fish and Wildlife Service (55).

Some States, such as Florida, require the use of native species in reclamation, but reclamation work generally falls short of restoration. Reclamation is generally task-oriented, and the objective is usually to establish productive plant cover, such as pasture or stands of trees. Relatively little attention is given to species not directly related to the objective, and relatively few species are used. Consequently, efforts to reclaim land have largely focused on the use of common plant and animal species that are easily propagated and multiply rapidly. Often these are nonnative species; rare or difficult-to-establish species are seldom used. It is easiest and most cost-effective to use those few species that have been shown to be adequate for particular uses, such as for stabilizing beaches.

Tree planting is one of the most frequently used techniques for reclaiming degraded lands, and a wealth of literature on various forms of reforestation exists (23,84). The potential for reforesting degraded forest land is especially great in the tropics (83), But restoring forests with diverse native species is seldom attempted. Instead, most programs use one or a few exotic species, partly because of a lack of seeds and techniques to propagate native trees and partly because of the cost-effectiveness of planting fast-growing tree species known to have commercial value,

The Santa Rosa National Park in Costa Rica is one of the few forest restorations that has been undertaken. The area was a cattle ranch for 400 years, but since designation as a protected area, a dry forest ecosystem of native species has been reestablished from seed sources on nearby mountain slopes, The principal management technique has been to stop the human-caused fires, allowing woody species to reinvade the pure grass pastures. The restorative effect has now been proved and is to be used in the proposed Guanacaste National Park (39).

Prairie restoration offers a kind of prototype for the development and use of ecosystem restoration. Restoration of prairies began early, motivated by concerns such as diversity and community authenticity (43). Techniques developed to restore prairies to moderately high levels of native plant diversity borrow extensively from agriculture techniques used in prairies. One approach to restoring 2 to 40 hectares recommends plowing, followed by disking at intervals of a year to reduce weeds, followed by seeding with a mixture of prairie species (56). In Crex Meadows, WI, restoration of prairie plants and animals was possible with little intervention other than protection and controlled burning, because many native prairie species had apparently continued to grow, unobserved, for decades while the site was forested, Little information on the cost of prairie restoration is available. Up to now, much of the effort that has gone into restoring the highest quality prairies has depended heavily on dedicated volunteers (4).

Photo credit" D Franzen

Planting prairie plants in a restoration project at the University of Wisconsin-Madison Arboretum. The purpose of the experiment is to study competition between species by planting various combinations. The results will be useful in developing techniques for introducing '(difficult" species into prairies as they are being restored and managed.

Although the technology of reclamation has developed rapidly in recent years, partly as a result of legislation such as the Surface Mine Control and Reclamation Act of 1977, restoration has not yet become an established discipline. Restoration research and technology development vary tremendously from one natural community to the next.

The availability of seed and plant stock for varieties adapted to local conditions is a problem. Use of local seeds is not required by law, and the high cost of small, special seed collections often precludes use of local seeds in favor of cheaper, nonlocal ones of relatively few species (3 I ,54). Western nurseries and the Soil Conservation Service's Plant Material Centers have responded to the demand for more native plants, but many species still are not available commercially. For many that are available, germplasm is limited to specialized ecotypes or registered cultivars with limited value for restoration.

The cost of reclamation varies greatly, depending on the extent of disturbance, the extent of restoration, and the type of ecosystem. The average cost of seeding for reclamation of surface mines in seven Western States has been estimated at $620 per hectare (in 1977 dollars) (59). This estimate included fertilization, mulching, and irrigation (the most expensive component), The cost of earth-moving brought the total bill to $10,000 per hectare. Mechanical planting of shrubs costs from $5OO to $2,OOO per hectare in Utah, depending on whether bareroot or containerized stock was used (20). Hand-planting to simulate natural vegetation patterns would further increase costs.

Establishing the same community that occurred on a site prior to disturbance is often not feasible because of the high cost and a lack of information regarding, for example, necessary conditions for seed germination and other aspects of survival and reproduction of native species. Although restoration technologies cannot quickly restore the diversity that existed before degradation, they can be used to break the cycle of resource degradation and to reestablish a community of indigenous organisms. Normal plant and animal succession may eventually lead to a self-sustaining and relatively natural ecosystem that provides most of the values of biological diversity.

OUTSIDE PROTECTED AREAS

Most of the discussion thus far has dealt with protected areas where maintaining biological diversity is a management objective. But the majority of biological resources are found outside these areas. Few strategies have been designed yet for conserving diversity in nondesignated areas. Various resource conservation techniques with other objectives serve to enhance biological diversity, however.

Genetic Resources for Agriculture

Conservation of genetic variability outside protected areas is especially important because so many crop varieties and livestock species and many of their wild relatives are not found in areas designated for protection, In addition, evolutionary processes, such as crop-pest and crop-pathogen interactions, can continue. This type of conservation occurs when farmers have chosen to maintain traditional crop varieties and livestock breeds.

Crop varieties with a broad genetic base and wild relatives of crop plants are mainly located where traditional farming practices prevail. Large proportions of these resources (5o percent or more for many species) have not yet been evaluated or collected for preservation offsite (5o). Germplasm collection programs focus on the world's major staple crops, so many species that are not yet widely grown are unlikely to be preserved offsite. Both these and local varieties of major crops are threatened with extinction as they are replaced by modern varieties, which the economics of agriculture favor.

A diverse mix of local varieties theoretically protects traditional farmers from catastrophic crop losses. And, with locally adapted varieties, farmers depend less on subsidized inputs, such as pesticides, fertilizers, irrigation equipment, and processed animal feed. In many countries, traditional farmers appear to be motivated more by avoiding risk than by maximizing profit. Nevertheless, as agricultural development occurs, farmers are shifting to fewer varieties, modern methods, and higher profits.

One response to this trend is the recently established program to monitor the remaining collections of teosinte, a wild relative of maize found only in Mexico, Guatemala, and Honduras, The habitats for teosinte include some of Mexico's best agricultural land, where it survives in narrow strips of untilled soil along stone fences bordering maize fields. As land use intensifies, these strips are brought into cultivation, And isolated stands of teosinte that interbreed with maize can be genetically "swamped" by the maize and lose their ability to disperse seed. Thus, teosinte populations with unique genetic characteristics of potential value for maize breeding are threatened with extinction.

Fortunately, the international agricultural research institute that focuses on maize, Centro International de Mejoramiento de Maiz y Trigo (CIMMYT), is located near many of the sites where teosinte still grows, The CIMMYT maize staff and colleagues in the Mexican and Guatemala national maize research programs have begun a monitoring program, The status of each teosinte population is checked annually. The intention is to take preservation action whenever a recognized population is placed in immediate danger of extinction (9).

Another way to safeguard genetic resources outside protected areas would be to preserve traditional agriculture systems in selected regions. To do this, farming systems must become more productive and produce more cash income. Presumably, higher productivity means applying scientific methods for crop production and genetic development but keeping the local varieties and livestock breeds. Some farming systems research does attempt this. For example, the Centro Agronomic Tropical de Investigaciones y Ensenanza has consulted with the Kuna people of northeastern Panama about agricultural development of their 60,000-hectare, indigenous-reserve area in the context of a park project (91). Similarly, the International Council for Research in Agroforestry in Africa trains researchers to identify opportunities for marginal improvements in traditional farming systems. But such work is outside the mainstream of agricultural development and is at best a modest and poorly funded effort.

A complementary approach is for modern farmers to maintain diverse varieties while relying on other income sources. They generally must turn to off-farm income or other, more modern areas of their farms. In developing countries, where traditional farming is still extensive and crop and livestock diversity are greatest, continued planting of nonprofitable traditional varieties would probably have to be subsidized.

Such an approach is not without precedent. Native American farmers are paid to produce seed of traditional cultivars in Arizona by a nonprofit organization, Native Seeds/SEARCH (58), In developing countries, similar programs might be administered by some of the same agricultural research organizations that maintain offsite germplasm collections. But the agricultural research community has not identified this as a priority for their limited funds. At best, only a very small sample of diversity could be maintained on subsidized traditional farms. It seems that such subsidies would be as cost-effective as marginal improvements in offsite collections.

Conservation As A Type of Development

Maintaining biological diversity by establishing parks is becoming increasingly difficult because of demographic, economic, and political pressures. The preservation approach to conservation may become less common in the future, especially in tropical developing countries where diversity seems to be most threatened. As a consequence, conservation organizations and conservationists within development organizations, such as the Agency for International Development (AID), the World Bank, and the Organization of American States (OAS), have begun to promote the concept that biological diversity can be conserved where natural resources are being developed if conservation is considered a development activity.

A recently published paper of the IUCN Commission on Ecology (64) supports this concept:

> The idea of basing conservation on the fate of particular species or even on the maintenance of a natural diversity of species will become even less tenable as the number of

threatened species increases and their refuges disappear. Natural areas will have to be designed in conjunction with the goals of regional development and justified on the basis of ecological processes operating within the entire developed region and not just within natural areas.

Conservation has long been a criterion in carefully planned development of agriculture, forestry, fisheries, grazing land, and other primary-industry development. But maintenance of biological diversity is relatively new as an explicit development objective. Some innovative approaches are beginning to be implemented, including the use of conflict resolution and systems analysis techniques in resource development planning.

Integrated Regional Development Planning (IRDP), being used by the OAS (60,66), subdivides a region into small spatial units and analyzes the sectoral interactions in each, in contrast to approaches that subdivide issues into sectoral components. IRDP addresses interactions, like competition for the same goods or services by two or more interest groups, and analyzes changes that occur in the mix of available goods and services as a result of activities in one sector that are detrimental to another sector.

IRDP uses systems analysis and conflict resolution methods to distribute the costs and benefits of development activities throughout affected populations or sectors. Integration of all the sectors—including maintenance of biological diversity—is necessary because individual sectoral activities may help, but often hinder, activities of other sectors aimed at appropriating goods and services from the same or allied ecosystems. Decisions about which activities are appropriate or how each can be adjusted to reduce conflict are made through negotiation by parties representing all the sectors that are involved (67).

A major constraint to considering diversity maintenance as a development activity is that the benefits of diversity are hard to calculate. No economic valuation techniques exist that can capture its full value. Thus, biological diversity has not fared well under the standard cost-benefit analyses applied to development activities, Although some efforts have been made to better account for biological diversity values, the results have been unsatisfactory and not widely applied. (See ch. 11 for further discuss on of this topic.)

DATA FOR ONSITE MAINTENANCE OF BIOLOGICAL DIVERSITY

To set priorities and to allocate funds and other resources, decisionmakers need to know how various ecosystems contribute to biological diversity, how vulnerable they are to degradation, how well protected they are by existing programs, and what the social and economic prospects are for local cooperation. Management programs need details on the nutrition, space, and reproductive requirements of organisms. Most such information comes from taxonomy, biogeography, natural history, ecology, anthropology, and sociology. For agricultural species, information is also needed on genetics, microbiology, seed technology, and physiology.

Generally, enough is known to improve substantially the programs for maintaining diversity, But more and better data on many aspects of this subject are badly needed, and funding for conservation falls far short of the needs implied by the apparent rates and consequences of diversity loss (see ch. 3). So investments must be concentrated on the most cost-effective approaches possible, which implies the need to thoroughly understand the ecological, social, and economic aspects of biological diversity (77).

Uneven Quality of Information

The quality of data on biological diversity is uneven for different ecosystems and different parts of the world, For some places, such as tropical South America, data are rudimentary and theories are very tentative. For others, such as temperate North America, information is well developed and theories have been extensively tested. The unevenness is in part due to data being collected for different purposes, stored in different forms, and scattered among different institutions.

In general, both data and theories regarding biological diversity are better for temperate than for tropical biology; better for terrestrial than for aquatic sites; better for birds, mammals, and vascular plants than for the lower classes of organisms; and better for the few major crop and livestock species used in modern agriculture than for the many species used in traditional agriculture. Taxonomic coverage is increasing, but the pace is slow relative to the quantity of unknown organisms. Each year about 3 species of birds, 11 mammals, up to 100 fish, and dozens of amphibians and reptiles are identified for the first time (22,57). Insects are the largest order of organisms, and hundreds of species are newly identified annually (57); nevertheless, estimates of the number of insect species not yet identified range from 1 to 30 million (18).

Information needed to maintain diversity is even more limited on the ecosystem and community levels, partly because ecology is a younger discipline than taxonomy. Moreover, species interactions within ecosystems are so subtle that laborious, time-consuming field research is necessary to understand them. For example, the endangered red-cockaded woodpecker (Dezzdrocopus *borealis)* requires old-growth longleaf and loblolly pine trees for nesting. These pines persist in forest communities where occasional fires destroy the seedlings of other, more competitive species (5). Such fires require accumulation of appropriate fuel to carry the kinds of fires that favor the two pine seedlings. Conservation of red-cockaded woodpeckers, therefore, entails conserving appropriate species to generate the right kind of vegetation and litter on the forest floor.

Databases

Efforts to collect biological information have increased during the last two decades as a result of growing awareness of the importance of services provided by natural ecosystems and of the need for better use and management of natural resources. Biological data are now collected and analyzed at the international, national, and local levels. Databases—the collections of data that are organized for further analyses—can be used to make onsite diversity maintenance efforts substantially more effective.

International databases provide overviews that can identify potential gaps, status, and trends of biological diversity worldwide. The main international organizations involved in collecting biological data are the United Nations Environment Programme (UNEP); the Food and Agriculture Organization (FAO); United Nations Educational, Scientific, and Cultural Organization (UNESCO); the Conservation Monitoring Center (C MC) of the International Union for the Conservation of Nature and Natural Resources (I UCN); the World Wildlife Fund/Conservation Foundation; The Nature Conservancy International (TNCI); and the International Council for Bird Preservation (10). (See ch. 10 for further discussion of international databases.)

The utility of international databases has been limited because they are not readily available to resource planners and other analysts who might use them to advise development decision-makers. To resolve this problem, the UNEP'S Global Environment Monitoring System (GEMS) program is establishing a computerized Global Resource Information Database (GRID). This program will centralize access to numerous environmental databases and will include training in data analysis for developing-country participants.

DaTa for Management of Diversity

Biological data needed to plan management of diversity and other natural resources at the national level are collected by government agencies, academic institutions, and research centers. Completeness of the information varies from country to country. Several countries, such as Australia and Sweden, have compiled comprehensive biological surveys of their flora and fauna. Other countries, such as the Soviet Union and China, and some international regions, such as North, East, and West Africa, have completed or have made significant progress toward completing surveys of their flora. North America is the only part of the north temperate zone that has neither synthesized the data on its plant and animaI resources nor created a national biological database (81).

In fact, the United States has abundant information on its biota at a regional or broad ecosystem level. But data acquisition is designed to serve the specific objectives of various organizations. As a result, many of the databases relevant to biological diversity are widely scattered, are often incompatible, and are in effect inaccessible to numerous potential users. The objective of maintaining biological diversity has been only a tangential consideration in most data-collection efforts. However, files on endangered species assembled by the Smithsonian Institution and the U.S. Fish and Wildlife Service do address an important aspect of species diversity directly.

The only comprehensive nationwide information system dealing directly with both species and ecosystem diversity is the national aggregation of State Natural Heritage Program data. This system is extensively used for decisionmaking on acquisition, designation, and management of protected areas.

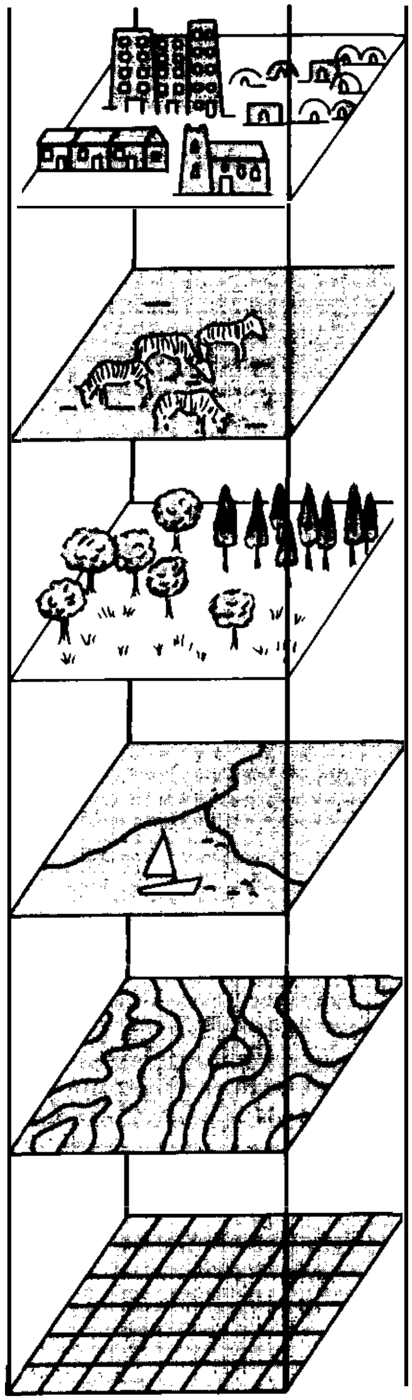
The heritage program inventories are continually updated through a system of information gathering and ranking. They begin with a broad information search of secondary sources for rare species and ecosystems. These are then ranked, and further search, including field work, takes place for the rarest ones. The inventory is made up of a series of manual and computer files containing the species and ecosystem's classification, location, site where it occurs, land ownership of the site, and sites located on already protected land, Inventory data are plotted on U.S. Geological Survey maps to analyze which lands are most important to protect and what impacts specific development projects will have on diversity,

In recent years a great deal of attention has been given to the use of computers for managing biological data. Data management is facilitated by the flexibility of the hardware and by the many types of software on the market today, For example, Geographic Information Systems (GIS) are being used by the Forest Service and the National Park Service to integrate databases with spatial information. This technique produces overlay maps that have great potential to aid efforts to maintain biological diversity (figure s-q). At present such overlay maps are used to assess the extent to which ecosystem diversity is being protected by combining details on ecosystem and species distribution with information on boundaries of various types of protected areas. International and nongovernment agencies are also finding the technique useful: GIS are a basic tool for GRID, The Nature Conservancy (TNC] has recently begun using GIS in its international program, and IUCN'S Conservation Monitoring Center plans to acquire a system, once funding is secured (33).

The data on biological diversity generated at the State level are being aggregated at the national level by TNC. The quality and quantity of information varies from State to State, a few States do not yet have programs, and inventory of species and communities that are not threatened is just beginning. In spite of these limitations, this is the most comprehensive national database on biological diversity, In many geographic areas, TNC is the only institution collecting data on rare, sensitive, or endemic resources that may require special management to maintain their integrity as populations. In these areas, the heritage programs help to fill an important gap in biological data needed for the onsite maintenance of biological diversity.

Selection among such data management technologies as the GIS depends on the financial resources and the objectives of the organiza-

Figure 5-4.—Representation of a Geographic Information System Function Overlavina Several Types of Environmental Data



SOURCE. United Nations Environment Programme/Global Environment Monitoring Systems, *Global Resource Information* **Databases** (Nairobi: GEMS Publication, 1985).

tion sponsoring the data collection. If the objective is to provide an overview of the status and trends of biological diversity in large areas, then remote sensing with sample surveys on the ground for verification and analysis with GIS maybe the most cost-effective approach. If the objective is to design a management plan for a particular area, detailed field surveys are necessary, but tools such as GIS may still prove valuable.

For implementation of resource development, information on biological diversity at a local, site-specific level is most important. Yet this is the level at which the quality of biological information is most variable. For some heavily studied areas, detailed field inventories and analyses of ecosystem interactions have been completed, whereas for others, especially the remote areas, often little detail of biological diversity is known. Development of needed site-specific diversity data is constrained by the common attitude of land managers that diversity assessment is fundamental research that should be limited mainly to land areas where research is the designated major use. This is a problem even for agencies that are sensitive to the issue of biological diversity, such as the U.S. Fish and Wildlife Service.

Coordination

The quantity of biological data may increase as information becomes easier to handle and less costly to acquire and maintain. Linking databases developed for different purposes can greatly increase their utility and thus their cost-effectiveness. Data incompatibility hinders such linking, however, making it necessary to reenter data manually at great cost, or more often to forgo the improved analysis that linked databases would allow. Data sharing in the United States among and within Federal agencies frequently is constrained by a lack of standards. For example, different agencies generally use different terminology to define ecosystem types, This problem also exists at the international level, especially where classification schemes used to aggregate data are not standardized.

Coordination of data-collection efforts can reduce incompatibilities, lessen duplications, and identify gaps in collection. For example, CMC and UNESCO plan to feed information into the GRID system. TNC'S regional databank has incorporated the classification system used by CMC to improve compatibility between the two data systems (33).

Coordination efforts at the U.S. Federal level have involved formal interagency cooperative agreements. (See OTA Background Paper #2, *Assessing Biological Diversity in the United States: Data Considerations*, for a description of these Federal interagency efforts to coordinate data collection and maintenance.) These efforts have resulted in recommendations and guidelines for standardization of databases. Most agencies would have to invest some personnel and funding to make their databases compatible with those of other agencies, however, which may not occur without specific congressional mandates.

Social and Economic Data

Human activities are the main cause of the accelerated loss of biological diversity, and successful implementation of onsite maintenance methods described in this chapter depends on cooperation of people living on and near the land that is affected. Collection and analysis of social and economic data, therefore, are essential to understanding the changing patterns of biological diversity and to planning and implementing conservation strategies (7).

The complexity of natural ecosystems rivals the complexity of social and economic processes that affect them. Thus, socioeconomic research should be no less rigorous than the biological research. Unfortunately, social and economic data are often the weak link in conservation planning.

Demography is a well-established social science with reliable data sources, theories, and methods to describe population patterns. Theories on how population growth under various circumstances affects biological diversity are lacking, however.

The status of biological diversity is greatly affected by the supply and demand of raw materials, agricultural commodities, and natural products. Natural-resource economic data and analytical methods have been developed for other fields of resource management, such as forestry, fisheries, and agriculture, but application of economics to issues of biological diversity has hardly begun. Some biologists and geographers have started to do economic analyses, but few professional economists are interested in biological diversity.

Data on technological change, especially in agriculture and pollution-causation and abatement, are sometimes assessed as part of the environmental-impact assessment process required when Federal funding is involved in resource development in the United States. Improved methods for such assessment have developed in the years since the National Environmental Policy Act became law. But methods for technology-impact assessment are sorely lacking for other parts of the world, especially for the tropical regions where diversity is most threatened.

Social and political processes influencing how biological diversity is perceived and valued are probably the least well-understood and, in the long run, the most important factors affecting success of onsite diversity maintenance. Geographers, sociologists, anthropologists, historians, and biologists who have ventured outside their field of technical expertise have developed important descriptions of social factors affecting diversity maintenance at specific sites. But the analysis needed to develop a broader understanding and theories from which to generalize has yet to be undertaken,

NEEDS AND OPPORTUNITIES

Onsite management of natural areas has usually been focused on limiting the impacts of outside pressures. In multiple-use protected areas, the technologies used to maintain biological diversity are mainly based on manipulation of habitats or populations to favor particular species, These methods, many of which derive from the fields of natural history and wildlife management, are effective for the target species. Biologists generally agree, however, that broad biological diversity values are not adequately served by species management alone. This approach necessarily concentrates on species with immediate commercial or recreational value and lets too many others, with less obvious values, perish if they do not happen to live in the type of environment maintained for the target species. Thus, technologies are needed to maintain diversity at the ecosystem level,

Onsite maintenance technologies commonly have been developed in relatively well-known temperate zone ecosystems. Plant and animal communities in these ecosystems generally can recover from moderate human disturbances if they are protected for years or decades. But biologists are not sanguine about adapting these technologies to tropical and other ecosystems, such as coral reefs, that are poorly known and that have much less natural ability to recover from disturbances,

Although most existing onsite technologies are focused on natural areas where development is restricted, attention is beginning to be directed beyond simple protected area programs. Resource development planning methods that treat conservation as an integral part of economic and social development have been devised and tested. These strategies hold promise, but they need to be taken from the conceptual stage to practical implementation.

The remainder of this chapter addresses these and other opportunities to improve the research, development, and application of onsite technologies to maintain biological diversity.

An Ecosystem Approach

An ecosystem approach is necessary to maintain biological diversity onsite for many reasons: 1) because the numbers of threatened species and genetically distinct populations is so high, 2) because so little is known about life histories or even the identity of many species, and 3) because many species are interdependent. Yet attempts to develop and implement ecosystem approaches are few,

In the United States, development of onsite maintenance technologies is largely the task of Federal land-managing agencies, such as the National Park Service, the Forest Service, the Fish and Wildlife Service, and the Bureau of Land Management. The mandates of these agencies emphasize species- and habitat-oriented technologies. A shift toward more ecosystem-oriented management would require policy changes within the agencies. Most, for example, consider an inventory of an area's biological diversity and the investigation of species interactions to be appropriate activities for basic research programs but not appropriate as pragmatic resource management activities. Changes in policies to encourage an ecosystem approach to protected areas may not occur without a congressional mandate directing agencies to manage lands and bodies of water in a way that maintains ecosystem diversity.

An important strategy for maintaining diversity is to safeguard representative samples of ecosystems from changes that would reduce their diversity. The United States lacks a comprehensive program for ecosystem diversity maintenance, although some efforts are being made through existing programs. The U. S.-MAB program is attempting to establish samples of ecosystems in the United States. Because the areas are identified on the basis of ecological criteria rather than political boundaries, various Federal, State, and private organizations must cooperate to implement the program successfully, which may explain the sluggish pace. Federal agencies could be directed to give more support to interagency and Federal, State, and private initiatives to support the MAB agenda.

The number and size of additional protected areas required for ecosystem diversity maintenance are unknown. Extensive inventory programs (e.g., the State heritage inventories of The Nature Conservancy) have been initiated to determine how to enhance coverage. But support has been sporadic and progress is slow. TNC'S State-level approach and mobilization of private sector support has been effective, so the Federal Government could continue to support this and similar programs.

International organizations, led by IUCN and the World Wildlife Fund/Conservation Foundation, are promoting conservation of samples of the world's ecosystems. The coverage of ecosystems, indicated by comparing protected areas to Udvardy's biogeographical classification system, is encouraging but still incomplete. The next major step will be to survey the degree of actual protection in the designated natural areas. Such surveys could also identify gaps in ecosystem protection at a finer biogeographic level than Udvardy's classifications, Better information is needed, especially on aquatic ecosystem types such as coral reefs, to develop and implement strategies for international ecosystem conservation efforts. A U.S. Government interagency task force could identify personnel for this task and ways in which their work might serve the objectives of international conservat ion,

Innovative Technologies for Developing Countries

Many onsite technologies have been developed in industrialized, temperate zone countries, and thus, they may not be appropriate for developing countries' ecosystems, which are mostly tropical and where the biological, sociopolitical, and economic situations are fundamentally different, Hence, innovative technologies are especially needed in these areas.

The biosphere reserves concept is one such approach that appears to merit scrutiny and support. Continued U.S. Government support of UNESCO's MAB program and ways to increase support for MAB in developing countries could be explored in congressional committee hearings.

Integrated land management that includes conservation in development activities is another approach that should be encouraged. The OAS Integrated Regional Development planning could provide a model for other development assistance agencies, such as AID or the World Bank.

Long-Term Multidisciplinary Research

The most important problems affecting implementation of biological diversity maintenance efforts are not amenable to resolution by any one field of biology, or indeed by the natural sciences alone. Biological diversity is so broad that its maintenance requires methods from numerous disciplines, such as natural history, population biology, genetics, and ecology. In addition, many other factors—economic, political, and social—contribute to decisions about the sizes, shapes, and locations of protected areas, Application of social sciences to diversity maintenance, for instance, to help communicate the issue's importance to decisionmakers at all levels, is probably the most needed research area,

The formation of a discipline called conservation biology is an encouraging sign of the scientific community's effort to start breaking down traditional barriers among disciplines and in ways of approaching problems. The goal is to provide principles and tools for maintaining biological diversity, Signs that the new discipline is gaining momentum include establishment of a Center for Conservation Biology at Stanford University, the creation of a department of conservation biology at Chicago's Brookfield Zoo, and the development of programs of study at the University of Florida and at Montana State University. More recently, a professional Society for Conservation Biology with its own journal, *conservation Bioiogy,* has been established.

As yet, the National Science Foundation and other research funding organizations have not recognized the status of conservation biology as a discipline by according it a separate funding category. Its impact on resource management should increase as it gradually becomes recognized, encouraged, supported, and broadened to include professional social scientists.

Personnel Development

A major constraint to maintaining diversity onsite is the shortage of personnel—taxonomists, social scientists, resource managers, and technicians with adequate training, motivation, and work experience. These individuals are needed to plan, manage, and explain the need to maintain biological diversity to decisionmakers. Training and institutional development to provide employment opportunities for these kinds of experts are sorely needed, particularly in developing countries.

The number of plant taxonomists working in the world today is estimated at 3,000, for example; but twice as many would probably be needed for an adequate study of the world's flora (12). Moreover, most taxonomists reside in the temperate zone and only study species there.

Even if money were available to train new taxonomists, job opportunities would have to be provided to attract people to the field. The number of taxonomic positions in museums, herbaria, universities, and resource-managing agencies currently is low and may be falling, as research funds are directed at more popular disciplines (e.g., molecular biology). It may be time for the museums and botanic gardens to explore innovative ways to promote the field of systematic biology. These institutions could help by defining systematic biology's role in the maintenance of biological diversity as a way of making the discipline more appealing to potential specialists.

Data To Facilitate Onsite Protection

Decisions on where and how to apply various methods for onsite maintenance of diversity need to be based on accurate data and correct theories on the interactions among numerous biological and human factors. Abundant data exist, especially for the temperate zone regions of the world. The data are being used both to develop and improve theories regarding biological diversity and to make specific decisions regarding resource management. However, use of the existing information is inefficient when data are not collected into readily accessible databases at the scale on which decisionmakers operate.

Thus, a significant opportunity to improve onsite maintenance of diversity, both within and outside protected areas, is to support accelerated development of comprehensive databases, which would include, for example, TNC'S State Natural Heritage Programs and its international conservation data center program. It could also include development of a nationwide description and evaluation of all flora and fauna species in the United States, possibly under the auspices of TNC.

Large gaps in knowledge of tropical species and ecosystems constrain the effectiveness of diversity maintenance efforts in developing countries. Opportunities include increased development assistance support to build institutions and train scientists capable of accelerating progress in the fundamental sciences of taxonomy, natural history, and ecology.

Possibly the most severe information deficiencies relate to the poor understanding of how social, political, and economic factors interact with biological diversity. A great need exists for social scientists trained and employed to develop information on how social and economic conditions can be made conducive to onsite maintenance of biological diversity. Unfortunately, this is a need difficult for biologists and natural resource managers to address. It requires new levels of interest and commitment from social science institutions.

CHAPTER 5 REFERENCES

1. Bailey, R.G. (compiler), *Description of the Ecoregions of the United States* (Washington, DC: U.S. Department of Agriculture, Forest Service, Intermountain Region, 1978). *In*: Crumpacker, 1985.
2. Bailey, R. G., Pfister, R. D., and Henderson, J. A., "Nature of Land and Resource Classification—A Review," *Journal of Forestry* 76(10):650-655, 1978,
3. Belovsky, G., "Extinction Models and Mammalian Persistence, " *Viable Populations for Conservation*, M. Soulé (cd.] (Cambridge, MA: Cambridge University Press, forthcoming).
4. Betz, R., Northeastern Illinois University, personal communications, 1985. *In*: Jordan, et al., 1986.
5. Bonner, F., U.S. Forest Service, Starkville, MS, letter to OTA, May 1986.
6. Brown, J. H., and Kodric-Brown, A., "Turnover Rates in Insular Biogeography: Effect of Immigration on Extinction, " *Ecology* 58:445-449, 1977. *In:* Soulé and Simberloff, 1986.
7. Brush, S., International Agricultural Development Program, University of California, Davis, letter to OTA, June 1986.
8. Butcher, G. S., Niering, W. A., Barry, W, J., and Goodwin, R. H., "Equilibrium Biogeography and the Size of Nature Reserves: An Avian Case Study," *Oecologia (Berl.)* 49:29-37, 1981. *In:* Noss, 1983.
9. Centro International de Mejoramiento de Maíz y Trigo (CIMMYT), "Conservation of the Wild Relatives of Maize, " *CIMMYT Research Highlights, 1985* (El Batan, Mexico: 1986).
10. Collins, M., "International Inventory and Monitoring for the Maintenance of Biological Diversity, " OTA commissioned paper, 1985.
11. Conservation Foundation, *National Parks for a New Generation: Visions, Realities, Prospects* (Washington, DC: Conservation Foundation, 1985).
12. Crosby, M., and Raven, P., "Diversity and Distribution of Wild Plants, " OTA commissioned paper, 1985.
13. Crumpacker, D. W., "Status and Trends of the U.S. Natural Ecosystems, " OTA commissioned paper, 1985.
14. Dasmann, R., *Wildlife Biology* (New York: John Wiley & Sons, Inc., 1964).
15. Diamond, J. M., "Normal Extinctions of Isolated Populations, " *Extinctions*, M.H. Nitecki (cd.) (Chicago, IL: University of Chicago Press, 1984). *In*: Shaffer, 1985.
16. Diamond, J. M., "The Island Dilemma: Lessons of Modern Biogeographic Studies for the Design of Natural Reserves, " *Biological Conservation* 7:129-146, 1975. *In*: Shaffer, 1985.
17. Eidsvik, H., Director of Parks, Canada, personal communications, June 1986.
18. Erwin, T, L., "Tropical Forests: Their Richness in *Coleoptera* and Other Arthropod Species, " *Coleopterists' Bulletin* 36(1):74-75, 1982.
19. Eyre, F.H. (cd.), *Forest Cover Types of the United States and Canada* (Washington, DC: Society of American Foresters, 1980).
20. Fairchild, J., Utah Division of Wildlife Resources, Salt Lake City, UT, personal communication, 1985. *In:* Jordan, et al., 1986.
21. Feller, W., "Die Grundlagen der Volterraschen Theorie des Kampfes urns Dasein in Warscheinlichkeistheoretischer Behandlung, " *Acta Biotheoretica* 5:11-40, 1939. *In:* Shaffer, 1985.
22. Flesness, N., "Status and Trends of Wild Animal Diversity, " OTA commissioned paper, 1985,
23. Food and Agriculture Organisation of the United Nations, *Tree Growing by Rural People*, FAO Forestry Paper No. 64 (Rome: 1986).
24. Frankel, O. H., and Soulé, M, E., *Conservation and Evolution* (Cambridge, MA: Cambridge University Press, 1981).
25. Franklin, J. A., "Evolutional Change in Small Populations," *Conservation Biology: An Evolutionary-Ecological Perspective* M.E. Soulé and B.A. Wilcox (eds.) (Sunderland, MA: Sinauer Associates, 1980].
26. Gentry, A. H., "Chapter 8: Endemism in Tropical versus Temperate Plant Communities, " *Conservation Biology*, M. Soulé (cd.) (Sunderland, MA: Sinauer Associates, 1986].
27. Gilbert, F, S., "The Equilibrium Theory of Island Biogeography: Fact or Fiction?" *Journal of Biogeography* 7:209-235, 1980. *In*: Shaffer, 1985.
28. Ginsburg, L., Slobodkin, L. B., Johnson, K., and Bindman, A. G., "Quasi-extinction Probabilities as a Measure of Impact on Population Growth, " *Risk Analysis* 2:171-181, 1982. *In*: Shaffer, 1985.
29. Government of Zambia and IUCN, *National Conservation Strategy for Zambia* (Gland, Switzerland: 1985).
30. Gregg, B., U.S. National Park Service, Washington, DC, letter to OTA, Sept. 19, 1986.

31. Barrington, J., University of Wisconsin, personal communications, 1985. *In:* Jordan, et a]., 1986,
32. Harris, L., *The Fragmented Forest* (Chicago, IL: University of Chicago Press, 1984).
33. Harrison, J., "Status and Trends of Natural Ecosystems Worldwide, " OTA commissioned paper, 1985.
34, Hayden, B. P., Ray, G. C., and Dolan, R., "Classification of Coastal and Marine Environments," *Environmental Conservation 11(3):199-207, 1984.*
35. International Union for the Conservation of Nature and Natural Resources, *The United Nations List of National Parks and Protected Areas* (Gland, Switzerland: 1985).
36. International Union for the Conservation of Nature and Natural Resources, *National Conservation Strategies: A Framework for Sustainable Development* (Gland, Switzerland: 1985).
37. International Union for the Conservation of Nature and Natural Resources, "Categories, Objectives, and Criteria for Protected Areas, " *National Parks, Conservation, and Development: The Role of Protected Area in Sustaining Society,* Proceedings of the World Congress on National Parks, Bali, Indonesia, Oct. 11-22, 1982, J.A. McNeely and K.R. Miller (eds.) (Washington, DC: Smithsonian Institution Press, 1984).
38. International Union for the Conservation of Nature and Natural Resources, *Categories, Objectives, and Criteria for Protected Areas* (Merges, Switzerland: 1978).
39. Janzen, D. H., "Guanacaste National Park: Tropical Ecological and Cultural Restoration, " a report to Servico de Parques Nacionales de Costa Rica from Department of Biology, University of Pennsylvania, Philadelphia, 1986.
40. Johannes, R. E., and Hatcher, B. G., "Chapter 17: Shallow Tropical Marine Environments, " *Conservation Biology,* M. Soulé and B. Wilcox (eds.) (Sunderland, MA: Sinauer Associates, 1986).
41. Johnston, V. R., "Breeding Birds of the Forest Edge in East-Central Illinois, " *Condor* 49:45-53, 1947. *In*: Ness, R., "A Regional Landscape Approach to Maintain Diversity," *Bioscience* 33(11):700-706, 1983.
42. Jones, J. O., Espey, Houston & Associates, Inc., Austin, TX, personal communications, 1985. *In*: Jordan, et al., 1986.
43, Jordan, W., Peters, R., and Allen, E., "Ecological Restoration as a Strategy for Conserving Biodiversity," OTA commissioned paper, 1986.
44. Kollar, S. A., Jr., Hartford Community College, Bel Air, MD, personal communication, 1985. *In:* Jordan, et al., 1986.
45. Lande, R., and Barrowclough, G. F., "Effective Population Size, Genetic Variation and Their Use in Population Management, " *Viable Populations for Conservation,* M.E. Soulé (cd.) (Cambridge, MA: Cambridge University Press, forthcoming).
46. Levins, R., "Extinction," *Some Mathematical Questions in Biology, Lectures of Mathematics in the Life Sciences,* vol. 2, M. Gerstenhaber (cd.) (Providence, RI: American Mathematical Society, 1970). *In*: Shaffer, 1985.
47. Love joy, T. E., Bierregaard, R. O., Jr., Rankin, J, M., and Schubert, H. O. R., "Ecological Dynamics of Forest Fragments, " *Tropical Rain Forests: Ecology and Management,* S.L. Sutton, T.C. Whitman, and A.C. Chadwick (eds.) (Oxford, England: Blackwell Scientific Publications, 1983). *In:* Shaffer, 1985.
48. Love joy, T. E., Rankin, J. M., Bierregaard, R. O., Jr., Brown, K. S., Jr., Emmons, L. H., and Van der Voort, M. E., "Ecosystem Decay of Amazon Forest Remnants, " *Extinctions,* M.H. Nitecki (cd.) (Chicago, IL: University of Chicago Press, 1984). *In*: Shaffer, 1985,
49. Love joy, T. E., and Oren, D. C., "The Minimum Critical Size of Ecosystems, " *Forest Island Dynamics in Man-Dominated Landscapes,* R.L. Burgess and D.M. Sharp (eds.) (New York: Springer-Verlag, 1981). *In*: Shaffer, 1985.
50. Lyman, T. M., "Progress and Planning for Germplasm Conservation of Major Food Crops," *Plant Genetics Resources Newsletter* 60:3-19, *1984.*
51. Lynch, M. and Rey, C., "Diversity of Marine/ Coastal Ecosystems," OTA commissioned paper, 1985.
52. MacArthur, R. H., and Wilson, E. O., *The Theory of Island Biogeography* (Princeton, NJ: Princeton University Press, 1967).
53. Margules, C., Higgs, A. J., and Rafe, R. W., "Modern Biogeographic Theory: Are There Any Lessons for Nature Reserve Design?" *Biological Conservation* 24:115-128, 1982.
54. Matthiae, P., Assistant Coordinator of Natural Areas, Wisconsin Department of Natural Resources, personal communication, 1985. *In*: Jordan, et al., 1986.
55. McMahan, J. A., *Nothing Succeeds Like Succession: Ecology and the Human Lot,* 67th Faculty Honor Lecture (Logan, UT: Utah State University Press, 1983). *In:* Jordan, et al., 1986.
56. Morrison, D. G., *Use of Prairie Vegetation on*

Disturbed Sites, Transportation Research Record 822 Landscape and Environmental Design (Washington, DC: National Academy of Sciences, 1981).

57. Myers, N., "Causes of Loss of Biological Diversity, " OTA commissioned paper, 1985.
58. Nabhan, G. P., "Native Crop Diversity in Aridoamerica: Conservation of Regional Gene Pools, " *Economic Botany* 39:387-399, *1985*.
59. National Research Council, *Surface Mining: Soil, Coal, and Society* (Washington, DC: National Academy Press, 1981).
60. Organization of American States (OAS), OAS General Secretariat, *Integrated Regional Development Planning: Guidelines and Case Studies From OAS Experience* (Washington, DC: 1984).
61. Peine, J., *Proceedings of Conference on the Management of Biosphere Reserves, Nov. 27-29*, 1984, Great Smoky Mountains National Park, Gatlinburg, TN.
62. Prescott-Allen, R., "National Conservation Strategies and Biological Diversity, " a report to the International Union for the Conservation of Nature and Natural Resources, Conservation for Development Center, draft, February 1986.
63. Prescott-Allen, R., and Prescott-Allen, C., "Park Your Genes: Protected Areas as *In-Situ* Genebanks for the Maintenance of Wild Genetic Resources, " *National Parks, Conservation, and Development: The Role of Protected Areas in Sustaining Society*, Proceedings of the World Congress on National Parks, Bali, Indonesia, Oct. 11-22, 1982, J.A. McNeely and K.R. Miller (eds.) (Washington, DC: Smithsonian Institution Press, 1984).
64. Ricklefs, R. E., Naveh, Z., and Turner, R. E., "Conservation of Ecological Processes, " *The Environmentalist 4(8), 1984*.
65. Salm, R. V., *Marine and Coastal Protected Areas: A Guide for Planners and Managers* (Gland, Switzerland: International Union for the Conservation of Nature and Natural Resources, *1984]*.
66. Saunier, R., "Environment and Development A Future Together?" *Development Forum 11 (8), 1983*.
67. Saunier, R., and Meganck, R., "Compatibility of Development and the *In-Situ* Maintenance of Biological Diversity in Developing Countries, " OTA commissioned paper, 1985.
68. Schlosser, S., "The Use of Nature Reserves for *in Situ* Conservation, " *Plant Genetic Resources Newsletter 61* :23-24, 1985.
69. Schonewald-Cox, C. M., and Bayless, J. W., "The Boundary Approach: A Geographic Analysis of Design and Conservation of Nature Reserves, " *Biological Conservation* (forthcoming).
70. Schonewald-Cox, C. M., Chambers, S. M., MacBryde, B., and Thomas, W. L., *Genetics and Conservation: A Reference for Managing Wildlife Animal and Plant Populations* (Menlo Park, CA: Benjamin Cummings Co., 1983).
71 Shaffer, M., "The Minimum Viable Population Problem" *Viable Populations for Conservation*, M. Soulé (cd.) (Cambridge, MA: Cambridge University Press, forthcoming).
72. Shaffer, M., "Assessment of Application of Species Viability Theories, " OTA commissioned paper, 1985,
73, Shaffer, M., "Determining Minimum Viable Population Sizes for the Grizzly Bear, " *International Conference on Bear Research and Management* 5:1 *33-139, 1983*.
74 Shaffer, M., "Minimum Population Sizes for Species Conservation, " *Bioscience 31:1 31-134, 1981*.
75 Shugart, H., "Planning and Management Techniques for Natural System s," OTA commissioned paper, 1985.
76 Simberloff, D., "Biogeography: The Unification and Maturation of a Science, ' *Perspectives in Ornithology*, A.H. Brash and G.A. Clark, Jr. (eds.) (Cambridge, MA: Cambridge University Press, 1983). *In:* Shaffer, **1985.**
77 Simon, J., and Wildavsky, A., "On Species Loss, the Absence of Data, and Risks to Humanity, " *The Resourceful Earth* J. Simon and H. Khan (eds.) (New York: Basil Blackwell Inc., *1984).*
78, Soulé, M, E., and Simberloff, D., "What Do Genetics and Ecology Tell Us About the Design of Nature Reserves?' *Biological Conservation* 35:19-40, *1986*.
79 Soulé, M. E., and Wilcox, B. A., *Conservation Biology: An Ecological-E\ 'olutionary Perspective* (Sunderland, MA: Sinauer Associates, 1980).
80 Stenseth, N, C., "Where Have All the Species Gone? On the Nature of Extinction arid the Red Queen Hypothesis," *Oikos* 33:196-227, *1979*. ***In:*** Shaffer, 1985.
81. Synge, H. "Status and Trends of Wild Plants, " OTA commissioned paper, 1985.
82 Thorsell, J. W., "The Role of Protected Areas in Maintaining Biological Diversity in Tropical Developing Countries, " OTA commissioned paper, 1985.
83 U.S. Congress, Office of Technology Assessment, *Technologies To Sustain Tropical Forest Resources*, OTA-F214 (Washington, DC: U.S. Government Printing Office, March, 1984).
84 U.S. Department of Agriculture, Forest Service,

An Annotated Bibliography of Surface-Mined Area Reclamation Research (Washington, DC: 1985),

85. U.S. Department of Agriculture, Forest Service, *Wildlife Habitats in Managed Forests: The Blue Mountains of Oregon and Washington,* USDA Pub. No. 5531979 (Washington, DC: 1979).
86. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, *National Marine Sanctuary Program: Program Development Plan* (Washington, DC: 1982).
87. U.S. Department of the Interior, Fish and Wildlife Service, "Selkirk Mountain Caribou Management Plan" (Washington, DC: 1985).
88. U.S. Department of the Interior, Bureau of Land Management, "Burro Creek Riparian Management Plan'' (Washington, DC: May 1983).
89. Wilcove, D. S., McLellan, C. H., and Dobson, A. P., "Chapter 11: Habitat Fragmentation in the Temperate Zone," *Conservation Biology,* M. Soulé (cd.) (Sunderland, MA: Sinauer Associates, 1986).
90. Wilcox, B. A., "Insular Ecology and Conservation," *Conservation Biology: An Evolutionary-Ecological Perspective,* M.E. Soulé and B.A. Wilcox (eds.) (Sunderland, MA: Sinauer Associates, 1980).
91. Wright, R, M., Houseal, B., and De Leon, C., "Kuna Yala: Indigenous Biosphere Reserves in the Making?" *Parks* 10(3):25-27, 1984.