Part I
Introduction and Background

Chapter 2
Importance of Biological Diversity

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Importance of Biological Diversity

HIGHLIGHTS

- **Biological diversity benefits human welfare directly, as various organisms are used to satisfy basic human needs, and indirectly, as diversity supports many processes essential to human survival and progress.**
- **The constituency for maintaining biological diversity is large but fragmented because many groups focus on various aspects of biological resources rather than on diversity per se. Constituents who are politically articulate in support of diversity are usually motivated by its intrinsic values rather than its substantial economic values.**

Human welfare is inextricably linked to, and dependent on, biological diversity. Diversity is necessary for several reasons: 1] to sustain and improve agriculture, 2) to provide opportunities for medical discoveries and industrial innovations, and 3) to preserve choices for addressing unpredictable problems and opportunities of future generations. Actual and potential economic uses range from subsistence foraging to genetic engineering. The essential services of ecosystems, such as moderating climate; concentrating, fixing, and recycling nutrients; producing and preserving soils; and controlling pests and diseases are also dependent on biological diversity. Finally, diversity has esthetic and ethical vaIues.

DEFINITION

Biological diversity refers to the variety and variability among 1iving organisms and the ecological complexes in which they occur. Diversity can be defined as the number of different kinds of items and their relative frequency in a set (97). Items are organized at many levels, ranging from complete ecosystems to the chemical structures that are the molecular basis of heredity, Thus, the term encompasses the numbers and relative abundance of different ecosystems, species, and genes. (Box 2-A describes major components of biological diversity.)

Species diversity, for example, decreases when the number of species in an area is reduced or when the same number exists but a few become more abundant while others become scarce. When a species no longer exists in an area, it is said to be locally eliminated. The extreme effect of species diversity loss is extinction—when a species no longer exists anywhere.

Biological diversity is the basis of adaptation and evolution and is basic to all ecological processes. It contributes to research and education, cultural heritage, recreation and tourism, the development of new and existing plant and animal domesticates, and the supply of harvested resources (table 2-1). The intrinsic importance of biological diversity lies in the uniqueness of all forms of life: each individual is different, as is each population, each species, and each association of species. Major functional and utilitarian benefits of ecosystem, species, and genetic diversity are described in the next five sections; evaluation of diversity and the constituencies of diversity are discussed in the final sections.

[illegible]

- [illegible] the required combination of food, [illegible] water, and other resources to meet its [illegible] logical needs. Each species is [illegible] to a specific arrangement [illegible] of essential resources.
- A population is a subset of all the [illegible] of one species. It consists of [illegible] uals that are found in a distinct portion [illegible] the species range that interbreed with [illegible] regularity. Thus, the members of a popula- [illegible]

[illegible] if that species is removed.

- Communities are part of a higher level of organization called ecosystems. An ecosystem is a dynamic complex of plant and animal communities, which along with their abiotic environment, constitutes one functional whole. An understanding of ecosystem functioning can greatly influence the kinds of conservation and management applied.

Table 2.1 .—Examples of Benefits From Ecosystem, Species, and Genetic Diversity

Ecological Drocesses	Research	Cultural heritaae	Recreation and tourism	Agriculture and harvested resources
Ecosystem diversity				
Maintenance of productivity; buffering environmental changes; watershed and coastal protection	Natural research areas; sites for baseline monitoring (e.g., Serengeti National Park, Zambesi Teak Forest)	Sacred mountains and groves; historic landmarks and landscapes (e. g., Mount Fuji; Voyageurs Park, Minnesota)	700 to 800 million visitors per year to US. State and national parks; 250,000 to 500,000 visitors per year to mangrove forests in Venezuela	Rangeiands for livestock production (e.g., 34 in the U.S.); habitats for wild pollinators and pest enemies (e.g., saving $40 to $80 per acre for grape growers)
Species diversity				
Role of plants and animals in forest regeneration, grassland production, and marine nutrient cycling; mobile links; natural fuel stations	Models for research on human diseases and drug synthesis (e.g., bristlecone pine, desert pupfish, medicinal leeches)	National symbols (bald eagles); totems; objects of civic pride (e.g., port orford cedar, bowhead whale, *Ficus religiosa)*	95 million people feed, observe, andlor photograph wildlife each year; 54 million fish; 19 million hunt	Commercial logging, fishing, and other harvesting industries ($27 billion/year in U.S.); new crops (e.g., kiwi fruit, red deer, catfish, and Ioblolly pine)
Genetic diversity				
Raw material of evolution required for survival and adaptation of species and populations	Fruit flies in genetics, corn in inheritance, and Nicotiana in virus studies	Breeds and cultivars of ceremonial, historic, esthetic, or culinary value (e.g., Texas longhorn cattle, rice festivals (Nepal))	100,000 visitors per year to Rare Breeds Survival Trust in the United Kingdom	Required to avoid negative selection and enhancement programs; pest and disease resistance alleles

SOURCE: Office of Technology Assessment, 19S6.

BENEFITS TO ECOLOGICAL PROCESSES

Ecological processes include—

- regulation: monitoring the chemistry and climate of the planet so it remains habitable;
- production: conversion of solar energy and nutrients into plant matter;
- consumption: conversion of plant matter into animal matter;
- decomposition: breakdown of organic wastes and recycling of nutrients;
- protection processes: protection of soil by grasslands and forests and protection of coastlines by coral reefs and mangroves, for example; and
- continuation of life: processes of feeding, breeding, and migrating.

Knowledge of the relationship between diversity and ecological processes is fragmentary, but it is clear that diversity is crucial to the functioning of all major life processes, for diversity helps maintain productivity and buffers ecosystems against environmental change. Diversity within ecosystems is essential for protective, productive, and economic benefits. Species diversity is necessary for a stable food web. And diversity of genetic material allows species to adapt to changing environmental conditions.

Ecosystem Diversity

Ecosystems are systems of plants, animals, and micro-organisms, together with the nonliving components of their environment (45). It can be recognized on many scales, from biome—the largest ecological unit—to microhabitat (box 2-B). Ecosystem diversity refers to the variety that occurs within a larger landscape. Loss of ecosystem diversity can result in both the loss of species and genetic resources and in the impairment of ecological processes.

In eastern and southern Africa, for instance, the mosaic of ephemeral ponds, flood plains, and riparian woodlands enable antelope, elephant, and zebra to survive long cycles of wet and dry years (16,23). On the American continent, many animal species cope with oscillations in weather and climate by migrating between biomes—spending the rainy season in the tropical dry forest and the dry season in the rain forest, that is, summer in temperate forest and winter in tropical forest. Others use different habitats within the same biome; for example, leaf-eating primates and flower-pollinating bats move from dry sites in the rainy season to evergreen riparian trees in the dry season (32,48).

Several types of ecosystems are closely associated with protective and productive processes of direct economic benefit. Cloud forests, for

Box 2-B.—Scales of Ecosytem Diversity

Several ways exist to classify the many scales of ecosystem diversity. An example using the Pacific Northwest to illustrate four levels of ecosystems is shown below. Animal species characteristic of each level are noted.

1. **Biome:** temperate coniferous forest
   –Rufous hummingbird
   -Mountain beaver
z. **Zone:** western hemlock
   -Coho salmon
   –Oregon slender salamander
3. **Habitat:** old growth forest
   –Vaux's swift
   –Spotted owl
~. **Microhabitat:** fallen tree
   –Clouded salamander
   —California red-backed vole

The fallen tree component of old growth and mature forests illustrates the contribution of ecosystem diversity to ecological processes. Fallen trees provide a rooting medium for western hemlock and other plants that is moist enough for growth to continue during the summer drought, a reserve of nitrogen and other nutrients, and a source of food and shelter for animals and micro-organisms that play key roles in redistributing and returning the ntitrients to the regenerating forest. For example, the rotten wood provides habitat for truffles, and the truffles are eaten by the California red-backed vole, which spreads the truffle spores, so helping the growth of Douglas fir trees, which require mycorrhizal fungi (such as truffles) for uptake of nutrients (56).

example, increase precipitation, often substantially (38). Watershed forests generally reduce soil erosion and thereby help protect downstream reservoirs, irrigation systems, harbors, and waterways from siltation (45). Coral reefs are productive oases in otherwise unproductive tropical waters. Algae living inside coral polyps enable the corals to build the reefs (8,49). The reefs, in turn, support local fisheries and protect coastlines.

Wetlands are another example of an ecosystem with protective processes linked to economic output. Millions of waterfowl and other birds of great economic value depend on the diverse North American wetlands—coastal tundra wetlands, inland freshwater marshes, prairie potholes, coastal saltwater marshes, and mangrove swamps—for breeding, feeding, migrating, and overwintering.

These wetlands also support most commercial and recreational fisheries in the United States. About two-thirds of the major U.S. commercial fish, crustacean, and mollusk species depend on estuaries and salt marshes for spawning and nursery habitat (88,90). Other wetland services include water purification (by removing nutrients, processing organic wastes, and reducing sediment loads), riverbank and shoreline protection, and flood assimilation, Wetlands temporarily store flood waters, reducing flow rates and protecting people and property downstream from flood and storm damage.

For example, the U.S. Army Corps of Engineers chose protection of 8,500 acres of wetlands over construction of a reservoir or extensive walls and dikes as the least-cost solution to flooding problems in the Charles River basin in Massachusetts, It was estimated that loss

Photo credit: U.S. Fish and Wildlife Service—L. Childers

Ecosystems such as these wetlands have protective and productive functions linked to economic output.

of the Charles River wetlands would have resulted in an average of $17 million per year in flood damage (80,88,90), (Data on wetlands ecosystem losses are given in chapter 3.)

Species Diversity

Some species play such an important role in particular ecosystems that the ecosystems are named after them. Zambezi Teak Forest and Longleaf-Slash Pine Forest are examples. But the ecological processes that maintain dominant species often depend on other species. For example, elephants and buffaloes make a crucial contribution to regeneration of Zambezi teak by burying seeds, providing manure, and destroying competing thicket species (72),

Depletion of species can have a devastating impact higher up the food chain. For example, catches of common carp in the Illinois River are one-tenth of what they were in the early 1950s. This decrease appears to be the result of pollution-caused die-off in the 1950s of fingernail clams, may fly larvae, and other river-bottom macro-invertebrates. These macro-invertebrates are still scarce, for river-bottom sediment is slow to recover from pollution, much slower than water quality, for example (44).

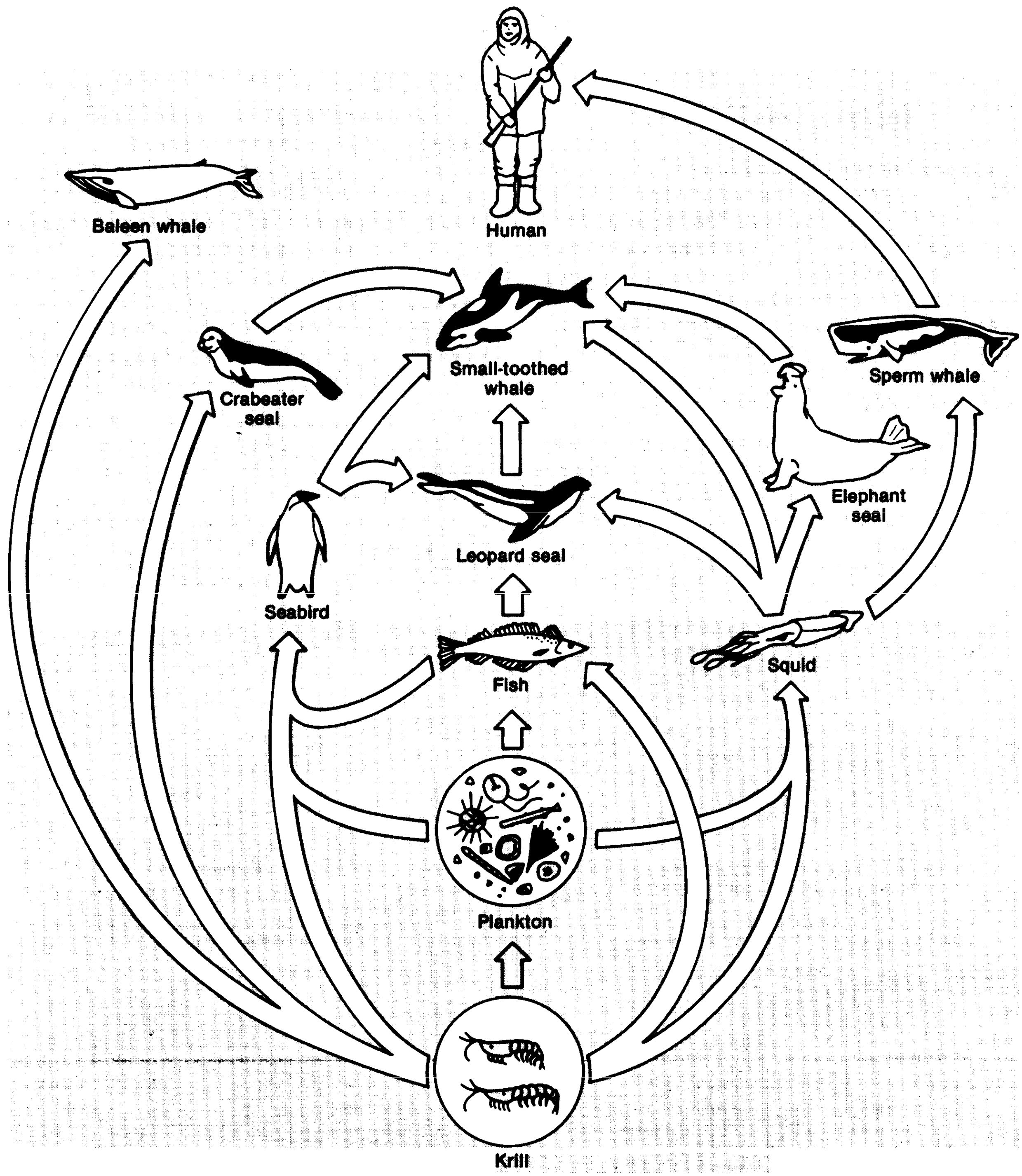
Certain species have a greater effect on productive processes than is indicated by their position in a food web (figure 2-1). Earthworms, for instance, improve the mixing of soil, increase the amount of mineralized nitrogen available for plant growth, aerate the soil, and improve its water-holding capacity (98). Ants also contribute to soil formation in temperate regions and the tropics. They contribute to the aeration, drainage, humidification, and enrichment of both forest and grassland soils (99).

In East Africa, species diversity increases the productivity of grasslands. For example, grazing by wildebeest promotes the lush regrowth eaten by gazelles (59,60). Similar interactions have been observed in North American grasslands between prairie dogs and bison. Although the standing crop of grass in prairie dog towns

Photo credit: National Park Service, Department of the Interior

Wind Cave National Park, South Dakota, contains a variety of wildlife including bison, elk, prairie dogs, prong horn. and deer Interactions between species such as prairie dogs and bison increase the productivity of grasslands,

Figure 2-1.—Krill: The Linchpin to the Antarctic Foodweb



Antarctic waters are among the most product ive in t he world. The main link in this food web is the small kri 11, shrimp-like creat ures that feed on plankton. Krill, in turn, support seabirds, fish, and squid, which are the mainstay of seals and whales.

is half that of grass outside, protein levels and digestibility are significantly higher. In Wind Cave National Park, prairie dog towns occupy less than 5 percent of the area, but bison spend 65 percent of their time per unit area in the towns, mostly feeding (28).

Some species have an unusually prominent position in food webs, being major predators of species on lower levels of the food chain and major prey of species on higher levels. Arctic cod, for example, feed on herbivorous and carnivorous zooplankton (amphipods, copepods, and decapods). Cod, in turn, is an important food of many bird and marine mammal species including gulls, narwhals, belugas, and harp seals (25),

Genetic Diversity

Intraspecific genetic diversity allows species to adapt to changing conditions, thus sustaining ecosystem and species diversity; it also helps produce plants and animals that will support more productive agriculture and forestry, Genetic diversity is distributed unevenly among and within species. Some groups of species appear to be more variable than others: reptile, bird, and mammal species have less than half the genetic variation found in invertebrate species and less than a quarter of that found in many insects and marine invertebrates (34),

The greater the amount of genetic variation in a population, the faster its potential rate of evolution (7). Certain genes are directly important for survival (e. g., genes conferring disease resistance), In addition, genetic diversity enables species to adapt to a wide range of physical, climatic, and soil conditions and to changes in those conditions. Genetic diversity is positively correlated with fitness, vigor, and reproductive success (7,85).

Among marine animals, and probably among terrestrial animals as well, high genetic variability is associated with high species diversity, which in turn is associated with a number of spatially different microhabitats (e. g., tropical and deep sea environments). It seems likely that the high genetic variability y provides the flexibility to make finely tuned adjustments to microhabitats.

BENEFITS TO RESEARCH

Research may hold answers to many of the questions facing this complex world. The results of research on the patterns and processes of temperate forests have provided methods for sustainable management of those ecosystems, Knowledge of tropical rain forests will result in similar strategies. Without diversity of species, researchers would not have the needed plant material to develop many vaccines, intravenous fluid, or other medicines, The potential for further advancement has not been fully realized, yet a loss of species diversity will adversely affect future research. Protection of genetic diversity is equally essential, because materials from plants and animals have provided *valuable* knowledge on viruses, immunology, and disease resistance.

Ecosystem Diversity

Many contributions of ecosystem diversity to global ecological processes, e.g., the role of wetlands in the Earth's oxygen balance, have yet to be demonstrated quantitatively, But the research required to develop and test these hypotheses depends on the full range of diversity. By studying natural ecosystems, scientists are better able to understand how the Earth works.

Knowledge of the role of ecosystem diversity in ecological processes is substantial and growing, largely because of the availability of natural research areas such as the Olympic National Park and the H.J, Andrews Experimental Ecological Reserve in Willamette National Forest (42,81). Relatively undisturbed grasslands in the

Serengeti National Park (Tanzania) and Wind Cave National Park (South Dakota) provide research significant for range management. Research includes, for example, studies of the extent to which grazing intensity increases primary production and the protein content and digestibility of grasses (28). Research on species and natural gene pools also requires ecosystem maintenance.

Representative examples of major ecosystems are used as reference sites for baseline monitoring on productivity, regeneration, and adaptation to environmental change. In addition, evaluation of development projects to ensure they are both economical and sustainable calls for assessment of, among other things, their environmental effects measured against unaltered sites with similar vegetation, soils, and climate.

The Zambezi Teak Forest ecosystem, for example, which yields Zambia's most valuable timber, is declining rapidly, due to excessive logging, fire, and shifting cultivation. If present trends continue, this forest would effectively disappear in 50 years. Attempts at artificial regeneration have met with little success. To improve understanding of natural regeneration, an undisturbed tract of the forest in Kafue National Park is being studied. Continued monitoring of the Kafue tract will provide data needed for assessing costs and benefits of any silviculture system for the Zambezi Teak Forest (72,74).

Ecosystems are also living classrooms. The University of California's Natural Land and Water Reserves System includes 26 reserves representing 106 of the 178 habitat types identified for the State. The reserves are used for instruction and research in botany, geology, ecology, archeology, ethology, paleontology, wildlife management, genetics, zoology, population biology, and entomology (52). Enabling children and adults to experience different ecosystems is an effective way to teach ecological processes, genetic variation, community composition and dynamics, and human relations with the natural world.

Species Diversity

Species diversity is the basis for many fields of scientific research and education. The array of invertebrates used in research illustrates the importance of diversity to the advancement of science. The 100 or so species of Hawaiian picture-winged fruit flies are the organisms of choice for basic research on genetics, evolutionary biology, and medicine. Tree snails of Hawaii and the Society Islands provide ideal material for research on evolution and genetic variation and differentiation (57).

Bristlecone pines, the oldest known living organisms and found only in the U.S. Southwest, are used to calibrate radiocarbon dates and hence, are important for archeology, prehistory, and climatology (62). Contributions of plant and animal species to biomedical research and drug synthesis abound (63,71). Examples include:

- Desert pupfishes, found only in the Southwest, tolerate salinity twice that of saltwater and are valuable models for research on human kidney disease (63).
- Sea urchin eggs are used extensively in experimental embryology, in studies of cell structure and fertilization, and in tests on the teratological effects of drugs (98).
- Medicinal leeches are important in neurophysiology and research on blood clotting (98).
- An extract of horseshoe crabs provides the quickest and most sensitive test of vaccines and intravenous fluids for contamination with bacterial endotoxins (98).
- Butterfly species are used in research on cancers, anemias, and viral diseases (82).
- The study of sponges is making substantial contributions to structural chemistry, pharmaceutical chemistry, and developmental biology and has also resulted in the discovery of novel chemical compounds and activities. D-arabinosyl cytosine, an important synthetic antiviral agent, owes its development to the discovery of spongouridine, which was isolated from a Jamaican

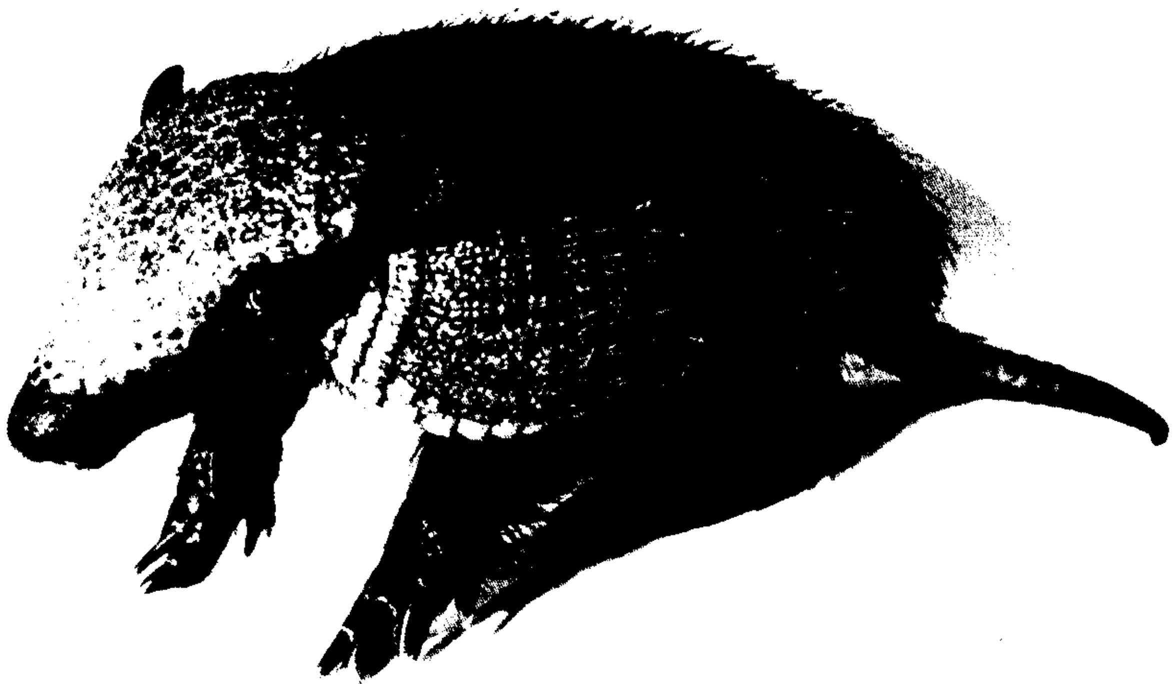


Photo credit J Cohen National Zoo

The armadillo is one of only two animal species known to contract leprosy.
These animals now serve as research models to find a cure.

sponge. Three derivatives of this compound have been patented as antiviral and anticancer drugs (10).

Genetic Diversity

Genetic variability is one of the characteristics of fruit flies, tree snails, and butterflies that makes them so useful for research. The unusual range of diversity among the races, varieties, and lines of corn contributes to its enormous value for basic biological research. One example is the discovery and analysis of regulatory systems that control gene expression, which added a new dimension to the study of inheritance (21).

The genus Nicotiana has also been used widely in genetic and botanical research largely because of the great variation among its species (84). The varied reactions to specific viruses characteristic of many *Nicotiana* species provide a potential tool for separating and identifying viruses, *Nicotiana* species have been involved in numerous discoveries of virus research (e. g., virus transmissibility, purification, and mutability) (35),

Special genetic stocks are essential research tools. For example, inbred lines of chickens developed at the University of California at Davis are used worldwide for research on immunology and disease resistance of chickens. Mutant stocks of chickens also serve as genetic models for scoliosis (lateral curvature of the spine) and muscular dystrophy in humans (58).

BENEFITS TO CULTURAL HERITA6E

Throughout history, societies have put great value on physical features of their environment. In developed and developing countries, a diversity of ecosystems is a source of esthetic, historic, religious, and ritualistic values. Species diversity assures people of national and state symbols, and many such symbols are protected. Genetic diversity continues in part because of the cultural value of plants and animals. Gardeners around the world share seed material ensuring genetic survival.

Ecosystem Diversity

Natural ecosystems have great cultural (including religious, esthetic, and historic) importance for many people. Mountains are the focus of religious celebrations and rituals throughout the world: Mount Kenya, Mount Everest, Mount Fuji, Mount Taishan in China, and Black Mesa in Arizona. Forests also have great spiritual value: probably the only surviving examples of primary forest in southwestern India are sacred groves—ancient natural sanctuaries where all living creatures are protected by the deity to which the grove is dedicated. Removing even a twig from the grove is taboo (36).

People who lead subsistence-based lives identify closely with the ecosystems on which they depend. Two examples are the Guarao people in the mangrove swamps and savannas of Venezuela's Orinoco Delta (39) and the Inuit people in the tundra of the North American Arctic (9,24). The economic, social, and spiritual elements of the relationship between such peoples and the ecosystems that support them are inseparable.

Ecosystems define and symbolize relationships between human beings and the natural world and express cultural and national identity, In the United States, the landscapes protected in wilderness areas, national parks, monuments, and preserves are full of historical meaning and show the close ties between America the nation and America the land. Examples of these are pre-Columbian Indian habitations at Mesa Verde in Colorado; symbols of the opening of the Midwest and West at Voyageurs Park in Minnesota; and combinations of wilderness preservation and human occupation including current subsistence-use at Kobuk Valley in Alaska (66,94).

Species Diversity

> Whereas the Continenta] Congress in 1782 adopted the bald eagle as a national symbol; and
>
> Whereas the bald eagle thus became the symbolic representation of a new nation under a new government in a new world; and
>
> Whereas by that act of Congress and by tradition and custom during the life of this Nation, the bald eagle is no longer a mere bird of biological interest but a symbol of the American ideals of freedom . . .
>
> –Bald and Golden Eagle Protection Act of 1940

Photo credit: National Wildlife Federation

Cultural value of species is exemplified by the bald eagle, adopted by the Continental Congress as a symbol of the United States.

When Congress adopted the bald eagle as a national symbol, it was responding to an ancient human need to identify with other species, All over the world and throughout history, people have adopted animals and plants as emblems, icons, symbols, and totems and invested them with ideals and values, adopted them as representations of particular characteristics of their culture and society, sought the power and authority they stand for, or venerated them as embodiments of fruitfulness and life itself.

The endangered bowhead whale plays a pivotal cultural role in several Yupik and Inupiat Eskimo villages in northern Alaska, Bowhead whale hunting is the first and most important activity in the subsistence cycle. It is a major social unifier, providing community identity and continuity with the past, The division, distribution, and sharing of bowhead whale meat and skin involve the entire community, strengthening kinship and communal bonds. Important ceremonies, celebrations, and feasts accompany the harvest of a bowhead whale and the distribution and sharing of its meat (4,5).

Port Or ford Cedar *(Chamaecyparis lawsonilance),* prized for its cultural and economic values, has become the focus of a recent controversy. It grows only in a small area of southern Oregon and northern California, where it produces some of the area's highest priced timber. Top quality may cost as much as $3,000 per 1,000 board-feet. This price reflects demand from Japan, where it is used in homes and temples as a substitute for the no longer available Japanese Hinoki cypress. It also has great cultural importance for Native Americans of the Hupa, Yurok, and Karok tribes in northwestern California, who regard it as sacred and use the wood in homes and religious ceremonies, Management of remaining stands of the cedar has become controversial, because mature trees are in short supply and threatened by a tree-killing root-rot disease, spread partly by logging operations (22).

Native Americans seek to reserve all the Port Orford Cedar growing on formal tribal land–now administered by the U.S. Forest Service—for ceremonial purposes. Other citizens' groups seek a management plan that would control logging operations and restrict loggers' access to some areas to reduce the spread of the fungus. Scientists at the Forest Service and Oregon State University are exploring the genetic diversity of the species in an effort to develop strains resistant to the fungus (22),

In South and Southeast Asia, trees, Asian elephants, monkeys, cobras, and birds figure prominently in tribal religions and have been taken into the pantheons of Hinduism and Buddhism. Certain tree species, such as *Ficus religiosa,* are sacrosanct and may not be cut down (2,20); political authorities often invoke the sanction of animals to win popular support (61). Interspecific loyalties persist; the hornbill, central figure of the Gawai Kenya-lang or Hornbill Festival of the Iban people in Sarawak, Malaysia, is also the official emblem of the state (50).

In urban North America, species also express community identity. Inwood, Manitoba, proclaims itself the garter snake capital of the world (after the mass matings of red-sided garter snakes that occur nearby) (67], and Pacific Grove, California, dubs itself Butterfly Town, USA (after the spectacular colonies of Monarch butterflies that overwinter there) (98). These actions are partly commercial acumen—the phenomena are tourist attractions—but they also reflect civic pride and perhaps something deeper as well,

Genetic Diversity

Many crop varieties and livestock breeds persist because they are culturally valuable to different societies, This group includes plants and animals with religious and ceremonial significance—such as the festival rices of Nepal and Mithan cattle in northern Burma and northeastern India (40)—as well as varieties valued for their contribution to the traditional diet. Farmers in the Peruvian Andes commonly plant their potato fields with many varieties (often 30 or more), producing a mixture of colors, shapes, textures, and flavors to enhance the diet (14), In northwestern Spain, a mosaic

Photo credit. G. Nabhan

Hopi Indian garden of mixed crops illustrates ancient horticultural traditions that persist on this continent.

of local varieties of beans and other legumes is grown, each variety intended for a particular dish in the traditional cuisine (3).

A growing number of Americans value traditional cuhivars and breeds for their history and for their esthetic and culinary qualities. Native Americans, helped by grassroots organizations, continue to grow traditional varieties of corn, chiles, beans, and squash (91). Hispanic-American farmers in the Southwest prefer native corn for its texture, flavor, and color, even though its yield is only one-third to one-fourth of hybrid corn (64), The cultural value of rare livestock breeds is exemplified by Texas Longhorn cattle (which have a prominent place in American history) and Navaho sheep (whose fleece is important to Navaho weaving).

Gardeners have organized national and regional networks to conserve some plant varieties because they have better taste, have links with national, local, and ethnic history; are suitable for the home garden; and because of the abundance of colors and forms found among old and local varieties of potatoes, corn, beans, and other crops (33,43,47,64,91).

BENEFITS TO RECREATION AND TOURISM

Millions of people worldwide derive benefits from recreation and tourism provided by biological diversity. Without diverse ecosystems, countries would lose tremendous amounts of foreign exchange. Without wilderness areas, national parks, or national forests, city dwellers would have no place to “escape” the daily pressures. Species diversity is essential to the millions of wildlife photographers, bird lovers, and plant and animal watchers. And without genetic diversity, horticulturists, gardeners, animal breeders, and anglers would find little enjoyment in their avocations.

Ecosystem Diversity

State and National parks in the United States attract 700 to 800 million visitors per year (73,74), and National Forests receive some 200 million visitors per year (93). One reason for these visits—indeed, some surveys suggest the main reason—is to enjoy the variety of landscapes the parks and forests protect (83), Sightseeing accounts for more recreation-visitor days (52 million) in National Forests than any other recreation activity except camping (60 million) (93).

Ecosystem diversity is a significant recreational asset in developing countries as well. In Venezuela, the mangrove forests of Morrocoy National Park attract 250,000 to 500,000 visitors per year (39); in Nepal, mountain landscapes, rhododendron forests, and fauna bring in foreign exchange (55),

Species Diversity

About 95 million Americans a year participate in nonconsumptive recreational uses of wildlife (observing, feeding, or photographing wild plants and animals); each year 54 million Americans fish and 19 million Americans hunt for sport. In the process they spend $32.4 billion per year (95).

Surveys of American recreational uses of wildlife reveal that a number of different species interest people. Recreational hunters in North America pursue some 90 species (73,74). Millions of Americans take time to observe not only birds and mammals, but also amphibians, reptiles, butterflies, spiders, beetles, and other arthropods (95),

Little data exist on wildlife recreational use by people in developing countries, but for several nations wildlife-based tourism is big business. The spectacular wild animals of east and southern Africa are the resource base of a tourist industry that brings millions of dollars in foreign exchange. In 1985, Kenya netted about $300 million from almost 500,000 visitors, making wildlife tourism the country's biggest earner of foreign exchange (l).

Genetic Diversity

Millions of home gardeners and members of horticultural and animal breed associations derive recreational benefit from genetic diversity. So, too, do millions of anglers who take advantage of stocking and enhancement programs. Tourism associated with genetic diversity involves fewer people, although the Rare Breeds Survival Trust in the United Kingdom receives 100,000 visitors a year. In North America, at least 10 million people visit the some 200 living historical farms—open-air museums that recreate and interpret agricultural and other activities of a particular point in history (91).

BENEFITS TO AGRICULTURE AND HARVESTED RESOURCES

In agriculture, a diversity of ecosystems, species, and genetic material provides increased amounts and quality of yields. In a world where population is rapidly increasing, assuring a continued increase in harvested resources is essential. Diversity in an agroecosystem provides habitat for predators of crop pests and breeding sites for pollinators. Diversity of species can be a buffer against economic failure and can also play an important role in pest management. Further, the use of genetic materials by breeders has attributed to at least 50 percent of the increase in agriculture yields and quality.

Ecosystem Diversity

Both diversity and isolation affect the ability of pests to invade a crop. They also affect the supply of pests' enemies, Uncultivated habitats next to croplands contain wildflowers, which contain important nutrients for the adult stages of predatory and parasitic insects (37). Wildflowers also support essential alternate hosts for parasites, especially in seasons when pests they prey on are not present, In California, for instance, wild brambles (Rubus) provide an off-season reservoir of prey for wasps, which control a major grape pest, This arrangement saves grape growers $40 to $60 per acre in reduced pesticide costs (6,54).

A variety of wild habitats also provides food, cover, and breeding sites for pollinators. Wild pollinators (chiefly insects) make major contributions to the production of at least 34 crops grown or imported by the United States, with a combined annual average value of more than $1 billion. They are the main pollinating agents in the production of cranberry and cacao, the propagation of red clover, and the production and propagation of cashew and squash. They are also significant pollinators for such crops as coconut, apple, sunflower, and carrot. The abundance of wild pollinators is largely determined by the availability of ecosystem diversity (woods, scrub, bare ground, moist areas, patches of flowers) within flight range of the crops to be pollinated (73,74).

permanent pastures and rangelands occupy one-fourth of the Earth's land surface (31). Because they support most of the world's 3 billion head of domesticated grazing animals (45), rangelands can be considered harvested ecosystems, where the nutrients and solar energy of marginal lands are converted into meat, milk, wood, and other goods,

In the United States, 34 rangelands are involved and include plains, prairie, mountain grassland, and Texas savanna (93). Pastoral nomadism and migrations by wild herbivores are traditional ways of using these resources. Modern ways include hauling sheep between summer and winter ranges, which may be 300 to 400 kilometers apart in the intermountain region (12).

Species Diversity

Diversity of harvestable species acts as a buffer that allows people in fluctuating environments to cope with extremes. For instance, in Botswana, five wild plant species are extensively used by pastoralists and river people, but an additional 50 or more species are resorted to in times of drought (17).

Harvested species provide much of the subsistence of indigenous peoples and rural communities throughout the world. Wild bearded pig and deer contribute about 36,000 tons of meat a year to rural diets in Sarawak, Malaysia. This amount of meat from domestic animals would cost about $138 million. (15). Per capita consumption of harvested food by Inuit in the North American Arctic averages annually from 229 kg (504 lb) to 346 kg (761 lb). The per capita cost of buying substitute food (usually of lower nutritional and cultural value) was estimated to be $2,1OO per year (1981 figures) (4,101).

The commercial timber, fishery, and fur industries obtain most of their resources by harvesting wild species, Harvested resources are also major contributors to the pharmaceutical industry, and to many other industries as well. The average annual value of the wild resources produced and imported by the United States between 1976 and 1980 was about $27,4 billion, of which $23 billion was timber (73,74).

Many species are involved, but most of them are economically significant only to the tradesmen involved. Even so, the number of harvested species might run up to more than a hundred. For example, it takes on average 70 species to make up 90 percent of the annual value of U.S. commercial fishery landings (74).

In agriculture, two types of diversity are useful in pest management programs: crop diversity and pest enemy diversity, Crop diversity (multiple cropping) can promote the activity of beneficial insects. For example, to attract Lycosa wolf spiders, the main predators of corn borers in Indonesia, farmers interplant the corn with peanuts (46). In California, lygus bugs, one of the main pests of cotton, are controlled somewhat by strip-planting alfalfa, which the bugs prefer to cotton (11). Pest enemy diversity includes introduced as well as native enemies. The Florida citrus industry saves $35 million per year by using three parasitic insect species that were imported and established at a cost of $35,000. Some 200 foreign insect pests in the United States are controlled by introduced parasites and predators (63).

A long-standing use of wild species diversity is as a source of new domesticates. In the United States, the combined farm sales and import value of domesticated wild species is well over $1 billion per year. The domestication of two major groups of resources—timber trees and aquatic animals—has only begun and is at about the same stage that agricultural domestications were some 5,000 years ago. But agricultural and horticultural domestications are still occurring.

Among the successful new food crops developed this century are kiwifruit, highbush blueberry, and wild rice (most of the wild rice

Photo credit: M.A. Altieri

Two intercropping systems —fava beans and brussels sprouts, and wild mustard and brussels sprouts—demonstrate the benefits of diversity to agriculture. Both systems benefit the brussels sprouts crop: wild mustard acts as a trap crop of flea beetles, and fava beans fix nitrogen with possible benefits to brussels sprouts yields.

produced in the United States is domesticated). New and incipient forage crops include Bahia grass, desmodium, and several of the wheatgrasses, Red deer and aquiculture species such as catfish, hardshell clam, and the giant freshwater prawn, are among the newly domesticated livestock. Loblolly pine, slash pine, parana pine, and balsa are some of the new timber domesticates (73,74).

Domestication of wild species increases the economic benefits of wild species by improving product quality and by raising yields. It can also make a valuable contribution to rural development in areas that are marginal for conventional crops and livestock. Nepal's Department of Medicinal Plants has organized the farming of two native species IRauvolfia *serpentine* and *VaZeriana wallichii)* for example, and it is investigating propagation of several other wild species that are sources of drugs, perfumes, and flavors for export, Scientists in Zambia and Botswana are working on the domestication of mungongo tree, whose fruits are used for food and oil and whose wood is valued for carvings (74),

Genetic Diversity

Health and long-term productivity of wild resource species—from game animals to timber trees to food and sport fish—depend on genetic diversity within and among the harvested populations, If the best individuals (biggest animals, tallest trees) are harvested before they repro-

Photo credit M Plotkin

Medicine from nature: *Croton* sp., known as "sangre de grade" in the Peruvian Amazon. This tree produces a sap used for a variety of medicinal purposes.

duce, then the productivity and adaptability of the population will progressively decline.

In addition, certain populations are better adapted to particular locations than others. For example, chinook, coho, and sockeye salmon from different rivers are genetically distinct; these distinctions reflect differences in the physical and chemical characteristics of the streams in which they originated (69,70). Diversity needs to be maintained so that any restocking to compensate for overharvesting or habitat degradation can use populations that are adapted to the specific environmental conditions.

In agriculture, genetic diversity in the form of readily available genes reduces a crop's vulnerability to pests and pathogens. Resistance genes can be introduced as long as a high degree of genetic diversity is maintained in offsite collections, onsite reserves, and agroecosystems. U.S. plant breeders keep a substantial supply of diversity in cultivars, parental lines, synthetic populations, and other breeders' stocks ready for use (13,26),

The genetic variation in domesticated plants and animals and in their wild relatives is the raw material with which breeders increase yields and improve the quality of crops and livestock. Use of genetic resources during this century has revolutionized agricultural productivity. In the United States from 1930 to 1980, yields per unit area of rice, barley, and soybeans doubled; wheat, cotton, and sugarcane yields more than doubled; fresh-market tomato yields tripled; corn, sorghum, and potato yields more than quadrupled; and processing-tomato yields quintupled (65,92).

At least half of these increases have been attributed to plant breeders' use of genetic diversity. The gain due to breeding is estimated to be 1 percent per year for corn, sorghum, wheat, and soybeans, due mainly to improvements in grain-to-straw ratio, standability, drought resistance, tolerance of environmenta1 stress, and

Photo credit: United Nat/ens—/d Tzovaras

Plant breeders' use of genetic diversity has significantly increased the productivity of crops such as wheat.

pest and disease resistance (18,27,79). Similarly, the average milk yield of cows in the United States has more than doubled during the past 30 years; about one-fourth of this increase is due to genetic improvement (89).

Developing countries have also achieved increased production of major crops. The Green Revolution that has transformed heavily populated Asian countries is founded on use of particular genes. High-yielding varieties of rice, for example, rely on a gene from a traditional variety for the "dwarf" stature that enables the plant to channel nutrients from fertilizers into grain production without getting top-heavy and falling over before harvest time. Although the dwarfing trait is effective in many locations, the high-yielding varieties need other genetic characteristics from many different varieties, The rice variety IR36, used in many countries to sustain yield gains, was derived by crossbreeding 13 parents from 6 countries (19,87).

progress in tomato improvement in the United States has followed the use of exotic germplasm (traditional cultivars, wild forms of the domesticated species, and exclusively wild species). Fruit quality (color, sugar content, solids content); adaptations for mechanized harvesting; and resistance to 15 serious diseases have been transferred to the tomato from its wild relatives. One researcher noted:

> Resistance to some of these diseases is mandatory for economic production of the crop in California, and it is doubtful whether the State's tomato industry would exist without these and other desired traits derived from exotics (77).

Rice and tomato illustrate the importance of maintaining as much of the genetic variation remaining within the domesticates and their wild relatives as possible, because both crops have benefited from genes occurring in a single population and nowhere else, Asian rice cultivars get their resistance to grassy stunt virus, a disease that in one year destroyed 116,000 hectares (287,000 acres), from one collection of Oryza *nivara (53).* The gene for a jointless fruit-stalk (a trait that assists mechanized harvesting and is worth millions of dollars per year) in tomato is found in a single population of a wild relative *(Lycopersicon cheesmanii)* unique to the Galapagos Islands (78),

A variety of genetic resources is being used in the breeding of livestock, particularly cattle and sheep. Crossbreeding Brahman cattle with Hereford, Angus, Charolais, and Shorthorn breeds has had a major impact on commercial beef production in North America (30). A number of African cattle breeds are notable sources of disease and pest resistance (West African Shorthorn to trypanosomiasis, N'dama and Baole to dermatitis, Zebu to ticks) (34), The Finnish landrace of sheep was almost lost before its high level of reproductive efficiency was discovered, It has now been incorporated into commercial mating lines in the United Kingdom and North America (30).

Yield and quality improvements can continue to be made and defended against pests and pathogens, provided plant and animal breeding continues to be supported and the genetic diversity that breeders draw on is maintained, Indeed, there is no option but to go on improving crops and livestock if world agriculture is to respond successfully to economic and environmental changes and to the new strains of pests and diseases that evolve to overcome existing resistance.

VALUES AND EVALUATION OF BIOLOGICAL DIVERSITY

Biological diversity benefits everyone, is valued by many (in a variety of ways), but is owned by no one. Thus, its evaluation is fraught with complexity. There are two broad classes of value: economic and intrinsic.

Economic Value

Economic evaluation potentially *covers all* functional benefits described in this chapter, ranging from tangible benefits from harvested resources and breeding materials to spiritual and other cultural benefits. The ability to calculate these values varies, however. In the cases where markets exist, calculations are easily determined (at least $27,4 billion per year in the United States for commercially harvested wild species, as noted earlier). In other cases, values are more difficult to calculate, and “shadow prices” may be used to approximate values for such benefits as ecological processes and recreation, For cultural and esthetic values, economic valuation may be impossible,

If humans interacted in a system with limited resources, then markets would allow equilibrium prices to emerge for all commodities, services, amenities and resources. These prices would reflect the relative values (including social values) of each item. The essential premises for economic valuation are utility and scarcity (75).

But for most benefits of biological diversity, free market principles do not apply. Maintenance of biological diversity is a “nonrival” good (it benefits everybody), and it is a “nonexclusive” good (no person can be excluded from the satisfaction of knowing a species exists), as are many of its benefits (research and education, cultural heritage, nonconsumptive recreation, use of genetic resources). And it is not clear that market-oriented logic is adequate to deal with two cardinal features of biological diversity: its potential for indefinite renewability (long-time horizon) and for extinction (irreversibility) (75).

Intrinsic Value

Intrinsic evaluation acknowledges that other creatures have value independent of human recognition and estimation of their worth. The concept is both ancient and universal. A spokesperson of the San people of Botswana put it this way:

> Once upon a time, humans, animals, plants, and the wind, sun, and stars were all able to talk together. God changed this, but we are still a part of a wider community. we have the right to live, as do the plants, animals, wind, sun, and stars; but we have no right to jeopardize their existence (16).

This preceding statement might be supported by Americans who believe in “existence values” —values that are defined independently of human uses (68). This belief implies a human obligation not to eradicate species or habitats, even if doing so harms no human. A 3-year study of American attitudes toward wildlife found that the majority seemed willing to make substantial social and economic sacrifices to protect wildlife and its habitats (51). Advocates of wildlife protection maintain that “it makes me feel better to know there are bears in the area, even though I’d just as soon never run into one” (76). Proponents of biological diversity argue that even if diversity is functionally redundant or has no utilitarian worth, it should be maintained just “because it is there. ”

CONSTITUENCIES OF DIVERSITY

Biological diversity benefits a variety of interest groups, so its constituency is enormous but fragmented by the interests of particular groups. Each group may appear small compared with the Nation as a whole. Collectively, however, these groups and their combined concern amount to the national interest in maintaining biological diversity.

Public Awareness

A major obstacle to promoting effective and long-term maintenance of biological diversity is the lack of awareness on the part of the general public of the importance of diversity (in the broader sense). It is easy to understand why the loss of biological diversity has difficulty capturing public attention. First, the concept is complex to grasp. For this reason, efforts to solicit support have appealed to emotionalism associated with the loss of particularly appealing species or spectacular habitats (86), Although effective in many cases, this approach has the effect of limiting the constituency and the boundaries of the problem. A second reason is that the more pervasive threats to diversity, such as habitat loss or narrowing of agricultural crop genetic bases, are not dramatic events that occur quickly. The difficulty is one of responding to a potentially critical problem that, for the average person, seems to lack immediacy.

Finally, promoting the case for biological diversity maintenance is also difficult because of the proliferation of environmental problems brought to public attention in the last decade or two, including acid rain, ozone depletion, the greenhouse effect, and loss of topsoil. "All these environmental problems have the apocalyptic potential to destroy, yet in every case the cause, imminence, and scope of that power are subject to polarizing (and eventually paralyzing) interpretation" (29).

Notwithstanding these difficulties, the environmental movement of the 1970s elevated environmental quality to a major public policy concern. Although the momentum of public attention may have slowed in the 1980s, it is clear that concern for the environment remains firmly entrenched in the collective consciousness of the American public. A 1985 Harris poll, for example, indicated that 63 percent of Americans place greater priority on environmental cleanup than on economic growth (41).

Balancing Interests and Perspectives

In assessing the level of public resources to be directed toward maintaining biological diversity, it is important to maintain a frame of reference of how, when, and for whom biological diversity is important. Such a perspective should consider:

1. varying perceptions on the value of biological diversity and threats to it;
2. an awareness that only some diversity can be or probably will be saved; and
3. a recognition that resources available to address efforts are limited.

As mentioned earlier, biological diversity is not at present a pervasive concern for many people, or at least there is no consensus that as much diversity must be conserved as possible. While earlier sections of this chapter identified large constituencies that value biological diversity, some elements of society remain apathetic to the issue, and others support efforts to eliminate various components of diversity. For example, considerable resources are directed to reducing populations or even eliminating entire species of pests, pathogens, or predators that threaten agriculture and human health. In terms of public policy, such efforts imply a need to recognize that in some cases diversity maintenance and other human interests can conflict. It should be noted, however, that conflicts stem less from the existence of diversity than from the altered abundance of particular species.

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