Biodiversity

What it Means, How it Works, and What the Current Issues Are

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Biological diversity, or biodiversity, denotes the wealth and variety of all living things. Although naturalists have a long history of examining and classifying animals, plants, fungi, and other organisms, the term biodiversity, meaning the total variability of life, dates only from the 1980s. Biodiversity's importance was quickly recognized, and by the early 1990s, it became the subject of international agreements like the Convention on Biological Diversity adopted in Rio de Janeiro in 1992. Now, almost 20 years later, mounting evidence of the potential effects of global warming on different species and ecosystems only heightens the need to integrate biodiversity into the complex policy decisions that lie ahead.

Biodiversity typically is considered at three levels: species diversity, genetic diversity, and ecosystem diversity. The first category refers to the variety and abundance of species in a geographical area; the number of species is the simplest and most commonly used measure of biodiversity. Despite the tendency to focus on species, relying on species and their numbers alone does not go far enough: each species consists of subspecies, populations, and individuals. In fact, many practical conservation decisions target subspecies and populations rather than species.

The second and third categories of biodiversity, genetic and ecosystem diversity, have not garnered as much media coverage. Genetic diversity refers to variation between and within species, both among populations and among individuals within a population. Variations arise from mutations in genes, and natural selection of these characteristics is the primary mechanism of biological evolution. Ecosystem or systems diversity refers to the variation between communities and their associations with the physical environment.

Species have different functions within their communities; some can be substituted while others (keystone species) play determinant roles in the food web and cannot be removed without fundamentally altering the community itself. An example of a keystone species is the grey wolf. The cascading effects of the reintroduction of the grey wolf to Yellowstone demonstrate its disproportionate role in shaping the ecosystem. When wolves were absent, deer foraged in large numbers in riparian areas, removing vegetation and keeping areas open. The wolves' new presence has caused deer to avoid those areas where the risk of being preyed upon is greatest. Consequently, with the re-growth of vegetation, riparian habitat for birds and beavers has increased both in quality and extent. Several plants and trees that were previously overgrazed now flourish in spots that elk and deer avoid because of the presence of wolves. The new vegetation provides food for beaver and habitat for songbirds, and their populations have increased.

How Biodiversity Works

Ecologists generally consider species richness to increases ecosystem productivity, stability, and resiliency. Results from long-term field experiments indicate that although species richness and the resulting

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interspecies competition may cause fluctuations in individual species populations, diversity tends to increase the productive stability of an ecosystem as a whole. This concept is similar to the portfolio theory in economics, which illustrates how diversification of stock portfolios can effectively remove stock-specific risks on returns. Like stocks, the returns (that is, biomass in primary production) generated by different plant species are not perfectly correlated. Rather, changes in the biomass production by some species are associated with dissimilar changes in the biomass production by other species. In other words, a high number of species acts as a buffer against productivity reductions within any single species, and ecosystems with greater numbers of species experience fewer fluctuations in aggregate biomass production.

Diverse ecosystems also generally have relatively high rates of ecosystem processes and produce more biomass than less diverse systems. However, increases in the rates of ecosystem processes are not constant and seem to plateau at relatively low levels of species richness. Additionally, it is difficult to predict the magnitude, or even the direction, of the effects of removing or adding certain species. Experimental analyses also suggest that functional groups—sets of species serving different ecosystem functions such as decomposition, production, and nutrient recycling—are important to the role of biodiversity in ecosystems. Therefore, the distribution of species within and between functional groups also is an important determinant of ecosystem functions. Differential responses by various species and functional groups give rise to ecosystem stability.

Ecosystem resilience has two meanings in ecology. First, resilience can be defined as the magnitude of disturbance that can be absorbed by the ecosystem before it changes to another equilibrium state. Second, resilience is the rate at which the ecosystem returns to equilibrium after a disturbance. Species diversity may play important roles in the resiliency of ecosystems to disturbances. For example, recent research suggests that diverse communities may have a capacity to resist invasions by exotic, non-native species.

Several components of species diversity determine its effects within actual ecosystems. These include the number of species, their relative abundance, the particular species present, the interactions among species, and the spatial and temporal variations of these components. Current knowledge about the consequences of biodiversity loss in actual ecosystems is limited, particularly when considering large ecosystems and changes in biodiversity. Present information about how ecosystem functions relate to diversity comes primarily from simple ecosystems with few species, reflecting small variations in composition and relative abundance.

Where Do Things Stand?

The United States has a rich natural heritage to which the vast size of the nation and the extensive variation of climate, topography, and biota across different regions all contribute. Most species that live in the United States are well known and have been catalogued, especially macrobiotic ones. Around 140,000 U.S. species are currently described from the well-known taxonomic groups, including more than 96,000 insects, some 15,000 flowering plants, almost 10,000 crustaceans, over 1,100 fishes, over 500 birds, and over 400 mammals (*see Figure 1*).

Within the United States, species richness tends to be greater in southern areas and decreases gradually toward the north. A similar longitudinal gradient is observed in global biodiversity: species richness increases from the poles to the equator. Larger states with boundaries that encompass a diverse array of ecosystems tend to contain a greater number of species. For this reason, California, Texas, Arizona, New Mexico, and Alabama are the five states with the greatest species richness (*see Figure 2 on page 16*). States with the fewest species are geographically small, such as Hawaii (1,418 species), or have relatively uniform ecosystems, such as North Dakota (1,889 species). Despite its vast landmass, Alaska has fewer than 2,000 known species.

Endemic species are those that exist only within a limited region or location. Generally, states with distinct geographical features that are sufficiently isolated from surrounding areas are likely to have many endemic species. The small but geographically isolated Hawaiian Islands have an exceptional number of endemic species; more than 1,000 of Hawaii's 1,418 known species don't exist anywhere else.

Globally, many basic questions related to the current status of biodiversity remain unanswered. For example, fewer than two million species in the world are actually recognized and described. However, they constitute only some fraction of the number of total species in the world, which is unknown and must be estimated. Estimates vary from a few million to more than 100 million species, with current consensus around 14 million species. Species counts and their precision vary considerably across different taxonomic groups, and only the best-known—plants and animals—have species counts with narrow bounds of agreement. For all other groups of organisms, the precision of the estimated species counts is generally considered poor to moderate.

What Is Being Lost?

Species extinction is the most concrete example of biodiversity loss. By definition, a species becomes extinct when its last member dies. When only a few individuals of a species exist, that species may become functionally extinct, meaning that the reproduction and the long-term survival of that species become impossible. A species becomes extinct in the wild when the only living individuals belonging to that species are maintained in unnatural environments, such as zoos.

Ecological theory suggests that several factors contribute to the vulnerability of certain species to extinction. Species that are most susceptible to extinctions include large organisms; species high on the food web; species with small population ranges or population sizes; species that have evolved in isolation; species with little evolutionary experience of disturbances; species with poor dispersal or colonization abilities; migratory species; and species nesting or reproducing in colonies. Many island and locally endemic species share several of the above characteristics.

How common are extinctions in the United States? According to records of known species extinctions, approximately 0.2 to 0.4 percent of all described U.S. species have gone extinct. Within certain

***Figure 1*. Extinctions and species endangerment in the United States, by the International Union for the Conservation of Nature (IUCN) Classification**

Taxonomic group	Extinct, extinct in the wild	Critically endangered, endangered, vulnerable	Known species
Vertebrates, total	51	342	2,680
Mammals	4	40	428
Birds	27	71	508
Reptiles	1	27	360
Amphibians	3	50	283
Fishes	17	154	1,101
Invertebrates, total [a]	185	561	118,595
Molluscs and snails	134	261	7,500
Other invertebrates	51	300	>111,000
Plants and varieties [b]	30	240	17,680
Total	**267**	**1,143**	**>138,955**

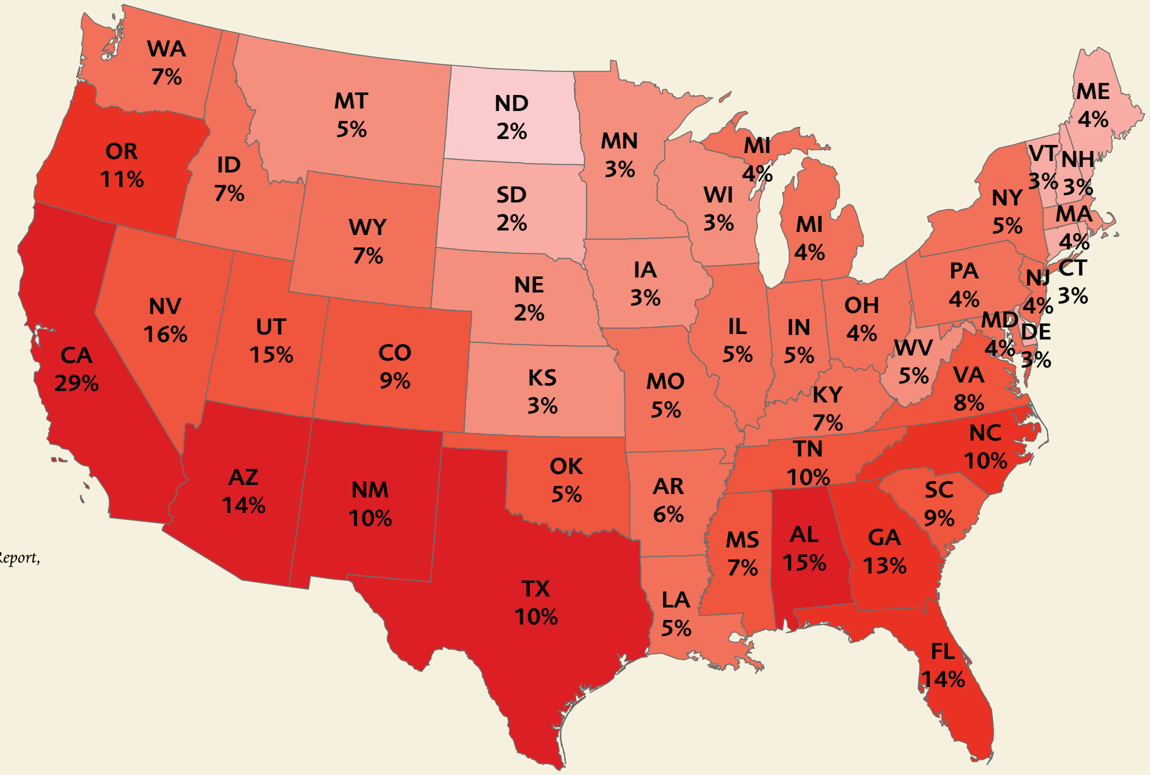
[a] Includes only the following five groups: snails, bivalves, crustaceans, insects, and arachnids. [b] Includes only the following four groups: flowering plants, conifers and cycads, ferns and allies, and lichens.
Compiled from the IUCN database, accessed Nov. 10, 2005.
Note: This figure excludes bacteria and protists (algae, protozoa, etc.) because of the inherent difficulty in finding and describing microscopic species.

Figure 2.
Species Richness and Percent Endangered by State.

Total number of species per state

- 1418–2000
- 2001–2500
- 2501–3000
- 3001–3500
- 3501–4000
- 4001–4500
- 4501–6717

Source: States of the Union: Ranking America's Biodiversity, *a NatureServe Report, April 2002.*



taxonomic groups, such as vertebrates, extinction rates are considerably higher. For example, about five percent of all known bird species in the United States are now extinct. Overall, the Hawaiian Islands are the unambiguous hotbed of extinctions, though they have been recorded in every U.S. state. Hawaii comprises only a small fraction (less than 0.2 percent) of the total land area of the United States, but it accounts for about 30 percent of extinctions and 50 percent of possible extinctions.

The Human Factor

The principal cause of contemporary biodiversity decline is habitat destruction and degradation, driven by the expansion of human populations and activities. Habitat loss is the major cause of endangerment for 85 percent of the species listed under the Endangered Species Act (ESA), the primary federal statute governing the protection and management of biodiversity. It often results from urban development, pollution, or fragmentation by small-scale encroachment (urban sprawl).

Invasive species are the second leading cause of species endangerment. Introduction can be intentional—through importation of ornamental plants, livestock, and game species—or unintentional, introduced via ballast water, potted soil, or freight containers. Tolerance of a wide range of environmental conditions, high rates of reproduction and dispersal, and a lack of natural predators within the new community are characteristics that help nonnative species thrive in the new habitat.

Human activities also cause chemical pollution and contamination of natural systems. For example, urban, agricultural, and industrial sources often release large amounts of nitrates and phosphates into aquatic systems, where they cause algal blooms that choke oxygen and shade other species. However, regulation of toxic pollutants in the United States has lowered concentrations of many industrial pollutants from point sources to the lowest levels since measurements began.

Global climate change, caused by the atmospheric accumulation of human-generated greenhouse gases, may also drive substantial biodiversity loss. Although many species have the capacity to adapt to environmental change, climate change likely will occur more rapidly than most previous, natural climate shifts. Shifts in temperature and precipitation could have numerous impacts on biodiversity, including shifts in migration and breeding patterns; expansions or contractions of natural species ranges; rise in sea level, water temperature, and acidity; increase in disease transmission and pest infestations; and unpredictable fluctuations in populations and habitat conditions.

The adaptive power of some species will likely be overwhelmed by these new pressures, especially when combined with fragmentation, decreased connectivity of habitats, and other stresses that already threaten many species and may create additional barriers to adjustment to changing conditions. The best known example of such species are polar bears, which were recently added to the endangered species list, and are seriously threatened by the predicted sea ice change associated with climate change.

Integrating Economics and Ecology to Help Preserve Biodiversity

One certainty in determining appropriate long-term biodiversity policy is that economic and ecological tradeoffs are unavoidable. Identifying successful strategies to preserve biodiversity requires integrating economics and ecology, For example, systematic conservation planning aims to identify the most cost-effective conservation strategies for achieving specific conservation goals such as protecting certain total amount of habitat, species, or populations, under budget constraints. Though cost-effectiveness analyses do not address the broader rationale for conservation—that is, how much societies should invest in conservation—they help improve practical conservation decisions.

Because most biodiversity occupies working landscapes rather than reserves, examining alternative management strategies for multiple-use areas also is centrally important. Understanding the drivers of land use change, as well as landowners' preferences and behaviors relative to alternative biodiversity conservation policies, is helpful in finding practical approaches to protecting biodiversity. For example, preserving biodiversity in working landscapes using easements may be achieved relatively inexpensively compared to full preservation through acquisitions or prohibitive regulation. Augmenting regulatory approaches to conservation with economic incentives to protect biodiversity may therefore prove both economically and ecologically more prudent than relying solely on regulatory approaches.

Valuation of biodiversity highlights its economic importance to societies. However, economic analysis can be controversial and, to some, even fundamentally objectionable. Disagreements are especially common when economic valuation and arguments are used to address species protection and, alternately, extinctions. But in many cases, economic values from biodiversity are related to our everyday life rather than species existence or extinction. For example, many commodities essential to human well-being—such as food, feed, fiber, wood, and pharmaceutical products—originate from and are continually supplemented by ecosystems and their biodiversity. Nature also provides genetic resources for breeding new plant varieties and organisms for the development of biological control and remediation methods. And ecosystems as a whole contribute valuable services through watershed protection, water filtration, carbon and nutrient storage and cycling, pollution breakdown and absorption, replenishment of soil fertility, erosion prevention, and climate stability.

Rather than taking for granted that biodiversity should or should not be preserved, economics provides a systematic framework to assess the various tradeoffs involved in decisions regarding biodiversity preservation. For example, it may be possible to estimate the level of conservation benefits achieved from allocating land for protection and then compare those results the benefits of using the same land for other purposes, such as agriculture or forestry. Depending on the relative benefits and costs, such analysis may suggest that all, none, or just a fraction of the land should be devoted to conservation. When all-or-nothing conservation is not the only option, it may be possible to connect current land uses with conservation goals at relatively low cost by providing landowners with economic incentives.

Assessments of biodiversity conservation options may vary greatly by location, depending on unique economic and natural characteristics. And they obviously are not definitive because of limited knowledge and imperfect methods in both economics and ecology. But these inquiries provide relevant information that, in the context of other considerations, can help decisionmakers identify practical conservation choices. ■

THE HARD NUMBERS

In addition to past extinctions, many species are currently endangered and dependent on conservation measures. According to the World Conservation Union (IUCN), widely recognized as the world's leading conservation network, 1,143 species in the United States—903 animals and 240 plants—are classified from vulnerable to critically endangered, meaning that these are under high to extreme high risks of extinction. In addition, IUCN lists another 292 animals and 27 plants that are either conservation dependent or near threatened. The 903 endangered animal species include 342 vertebrates: 40 mammals, 71 birds, 27 reptiles, 50 amphibians, and 154 fishes. Taking into account the known 51 extinct vertebrates, almost 15 percent of all known U.S. vertebrates, or 393 of 2,680 species, are either extinct or endangered.