The Habitable Planet

Unit 9 : Biodiversity Decline

Buttress roots of a canopy tree in the rainforest of northern Queensland, Australia. Courtesy William Laurance

Overview

Living species on Earth may number anywhere from 5 million to 50 million or more. Although we have yet to identify and describe most of these life forms, we know that many are endangered today by development, pollution, over-harvesting, and other threats. Earth has experienced mass extinctions in the past due to natural causes, but the factors reducing biodiversity today increasingly stem from human activities. In this unit we see how scientists measure biodiversity, how it benefits our species, and what trends might cause Earth's next mass extinction.

Sections:

1. Introduction

The term "biodiversity" was introduced in 1988 by evolutionary biologist E.O. Wilson, one of the leading experts in this field (footnote 1). Discussion of biodiversity has become commonplace in the past several decades. Although scientists are still trying to answer basic questions, including how many species there are on Earth, a broad trend is clear: extinctions are occurring today at an exceptionally high rate, and human activities are a major cause (footnote 2).

Is this a serious problem if millions of species remain? At times the question is posed this way—for example, when the fate of one seemingly obscure organism is at stake—but in fact there are important connections between biodiversity and the properties of ecosystems. For example, a tract of forest land can sustain more plants if it contains significant numbers of organisms that enhance soil quality, such as earthworms and microbes (Fig. 1). As we will see, a change in the status of one species can affect many others in ways that are not always predictable. Healthy ecosystems provide many important services to humans, although these functions are not always recognized or awarded economic value. If biodiversity erodes, we may lose some of these services permanently.

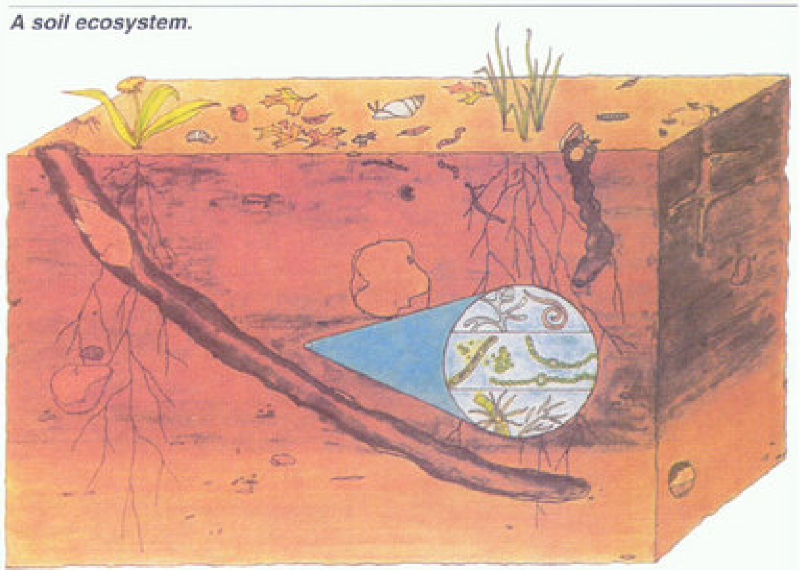

Figure 1. Roles played by small soil organisms

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There also is an aesthetic case for maintaining biodiversity. We take it for granted that nature is attractive, but much of the world's appeal is rooted in the contrast between many types of species, whether the setting is a coral reef filled with tropical fish or a forest filled with autumn colors.

This unit explores how scientists define and measure biodiversity, and how biodiversity is distributed around the globe and divided among the various types of organisms. It then discusses factors that are impacting biodiversity, including habitat loss, invasion by alien species, and over-harvesting. Emerging threats to biodiversity from global climate change are addressed in Unit 12, "Earth's Changing Climate," and Unit 13, "Looking Forward: Our Global Experiment."

2. Defining Biodiversity

The basic currency of biodiversity is species richness—the number of species in a given habitat, or worldwide. By analyzing fossilized life forms, which date back as far as 3.5 billion years, scientists can estimate how many species were present during past eras and compare those numbers to the present range of life. As we will see in Section 3, "Counting Species," species biodiversity is at a peak today compared to past levels, but at the same time many scientists believe that the current rate of extinction is also alarmingly high.

Another important biodiversity indicator is the level of genetic diversity within a species, which may influence the species' future trajectory (Fig. 2).

Figure 2. Color variation in the Oldfield mouse (Peromyscus polionotus)

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Species with low genetic diversity may be less likely to survive environmental stresses because they have fewer genetic options when problems arise. Conversely, populations with high levels of genetic diversity may be more likely to survive environmental and other stresses.

A historic example comes from Harvard Forest in Petersham, Massachusetts, where researchers have documented that an outbreak of an insect called the eastern hemlock looper caused an abrupt decline in the population of hemlock trees across the northeastern United States about 4,800 years ago. Hemlock numbers remained low for nearly 1,000 years after the blight struck but then recovered, possibly because the remaining individuals developed a resistance to the looper (footnote 3). If this theory is correct, it indicates that some hemlocks were genetically less susceptible to looper infestations than others and that natural selection slowly favored those trees in the years following the blight.

Ecosystem diversity is a third type of biodiversity. Life on Earth is distributed among many types of habitats, each of which provides a suitable living environment for specific kinds of organisms. These ecosystems range from tropical rainforests to hydrothermal vents on the ocean floor, where super-heated water bursts through cracks in the planet's crust (for more details, see Unit 4, "Ecosystems"). Many ecosystems are made up of species that have adapted to life under unusual conditions, such as Arctic sea ice communities (Box 1). The loss of these unique ecosystems can wipe out the many species that are highly specialized and unable to shift to other areas.

3. Counting Species

As discussed in Unit 1, "Many Planets, One Earth," life first appeared on Earth as early as 3.8 billion years ago. The earliest life forms were single-celled bacteria and archaea that harvested energy through chemical reactions before free oxygen began to accumulate in Earth's atmosphere. Early photosynthetic bacteria appeared about 3.5 billion years ago, but several billion years passed before multicellular organisms developed. This step took place around 600 million years ago, when Earth's atmosphere and oceans were accumulating increasing amounts of oxygen.

Early life forms were limited to the oceans until plants and animals evolved to live on land about 400 million years ago. Life on Earth became increasingly diverse as organisms adapted to environments on land, despite several waves of mass extinctions (Fig. 3).

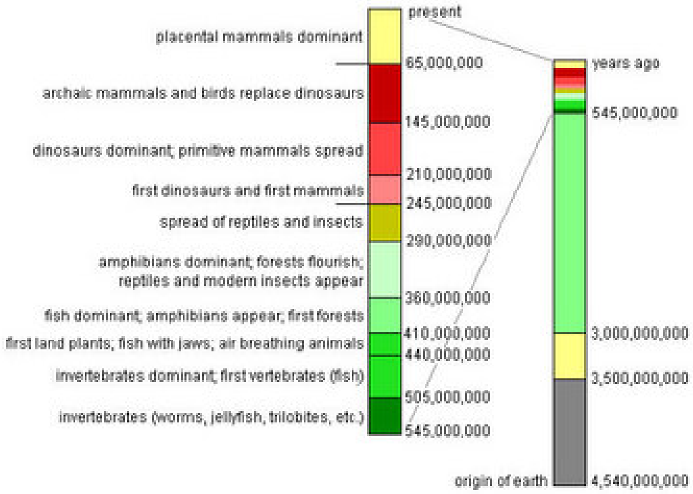

Figure 3. Time table of the evolution of complex life forms on earth

© Dennis O'Neil/anthro.palomar.edu.

How do scientists estimate past and current numbers of species? Fossil records are key sources. By looking carefully at fossil records, scientists can use plant and animal fossils to trace species' evolution over time, estimate rates of speciation (the formation of new biological species), and assess how various organisms responded to known environmental changes in the past (footnote 4). It is important to note that fossil records are imperfect: not all organisms leave recognizable, well-preserved skeletons, so some species are easier to count than others. As a result, it is very difficult to make precise estimates of the number of species on earth at specific points in time, but the records do indicate trends in biodiversity levels.

Based on analyses of fossils, scientists estimate that marine biodiversity today is about twice the average level that existed over the past 600 million years, and that biodiversity among terrestrial organisms is about twice the average since life adapted to land about 440 million years ago. Fossil records also indicate that on average species exist for about 5 to 10 million years, which corresponds to an extinction rate of 0.1 to 1 species per million species-years (footnote 5).

Molecular phylogenetics is a newer tool for studying biodiversity. By measuring the degree of similarity between DNA, RNA, and proteins in the cells of closely related organisms, scientists can reconstruct these organisms' evolutionary histories and see how species are formed. For example, although it was long believed that fungi were closely related to plants, genetic analyses led by Mitchell Sogin of the Marine Biological Laboratory in Woods Hole, Massachusetts, have shown that fungi are more directly related to animals (footnote 6).

Our current understanding of biodiversity is uneven: for example, we know more about animals than we do about protists. As discussed in Unit 1, "Many Planets, One Earth," biologists classify life on Earth into three broad domains: Eukarya, Bacteria, and Archaea. The first group includes all animals and plants, as well as fungi and protists, while the latter two groups comprise different types of microbes (Fig. 4). None of these groups are descended from the others, and all have unique features.

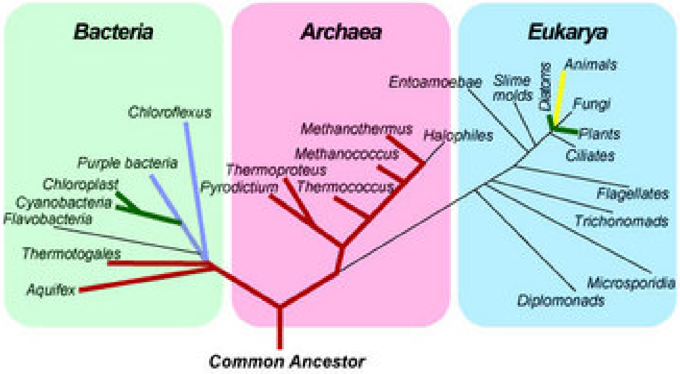

Figure 4. Three domains of life

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The biodiversity of Bacteria and Archaea is poorly understood for several reasons. Scientists do not agree on how to define a species of bacterium and do not have accurate estimates of the total number of bacterial individuals. From a practical standpoint, counting species of bacteria and other microbes is harder than counting bird species because birds have more defining features, including color, songs, and shapes. Visual and behavioral differences are clearer to the human observer. And many microbes are found in extremely challenging habitats, such as vents in the ocean floor.

Finally, humans tend to see animal and plant species as more interesting and important than other, smaller life forms. A discovery of a new monkey species is apt to become major science news, but new species of fungi are routinely reported in specialized journals without attracting serious popular interest. And the scientific literature focuses heavily on mammals and birds at the expense of other groups such as invertebrates and insects (footnote 7).

Based on fossil records and the opinions of experts who study various groups of living organisms, biodiversity on Earth appears to be at a historical peak today. Some 1.5 million species have been identified and described, but estimates suggest that at least another 5 to 15 million species remain to be catalogued (footnote 8). Insects and microorganisms are thought to account for large shares of these uncounted species. In July 2006, scientists involved in the Census of Marine Life (a ten-year project to measure ocean biodiversity) stated that there could be as many as five to ten million different types of bacteria in the oceans, some 10 to 100 times more than previously estimated. Many of these species may exist in relatively low numbers, but could have important ecological functions (footnote 9).

> *"Just as scientists have discovered through ever more powerful telescopes that stars number in the billions, we are learning through DNA technologies that the number of marine organisms invisible to the eye exceeds all expectations and their diversity is much greater than we could have imagined."*
>
> Mitchell L. Sogin, Marine Biological Laboratory (Woods Hole, MA)

4. Biodiversity Hotspots

Some areas of the globe are richer in species than others. As discussed in Unit 4, "Ecosystems," a latitudinal biodiversity gradient exists for animals and plants, with more species found in tropical than in temperate or polar regions. Recent work suggests that microbial communities are more diverse in temperate zones (footnote 10).

Conservationists refer to areas especially rich in biodiversity as hotspots. Based on work by British ecologist Norman Myers, who first proposed the concept, the nonprofit group Conservation International defines hotspots as regions that have at least 1,500 species of vascular plants that are endemic (found only in that area) and that have lost at least 70 percent of their original habitat. Drawing the exact borders of hotspots can be difficult, but Myers and others define a hotspot as "a separate biota or community of species that fits together as a biogeographic unit"—in other words, a community of organisms that live in a geographically unified zone and interact with each other (footnote 11).

Conservation International identifies 34 such hotspots in tropical and temperate regions around the globe (Fig. 5). There are three hotspots on U.S. territory: the California Floristic Province, a Mediterranean climate zone that covers the state's west coast and much of its central region; the Caribbean islands, including the U.S. Virgin Islands and Puerto Rico; and small patches of the Madrean-Pine Oak Woodlands, mountainous forests extending from Mexico into southern New Mexico and Arizona (footnote 12).

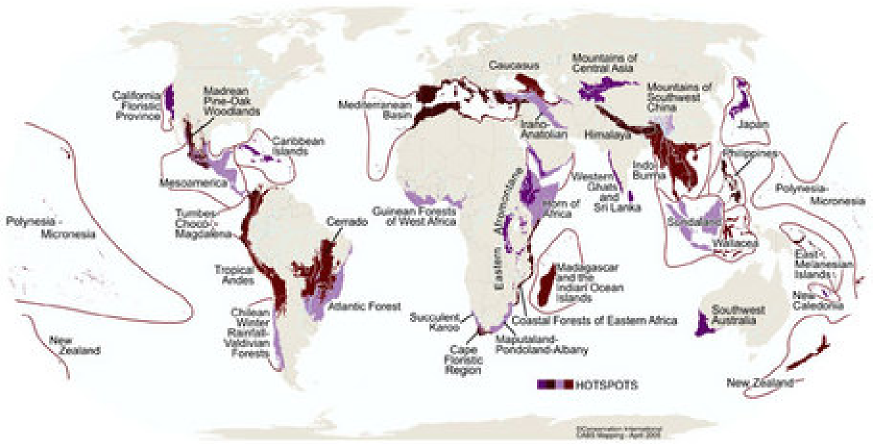

Figure 5. Biodiversity hotspots

Hotspots are a tool for setting conservation priorities. Because endemic species are found only in one place, protecting them requires preserving the areas in which they live. The 34 hotspots identified by Conservation International represent 2.3 percent of Earth's land surface but are home to at least 150,000 endemic plant species (50 percent of the world's total number of plant species) and nearly 12,000 terrestrial vertebrates (42 percent of the world's total number of terrestrial vertebrates).

What makes hotspots such rich biodiversity nodes? Many are located in moist tropical forests, the most diverse of Earth's major biomes. A number are islands or are physically bounded by deserts or mountain ranges, which has facilitated the evolution of endemic species by keeping populations in relative isolation and minimizing hybridization with other species. Most hotspots have widely varied topography, from lowlands to mountains, which produces a broad range of climatic conditions.

Advocates contend that hotspots should be protected because their loss could greatly accelerate what many scientists believe is an ongoing mass extinction (see Section 6, "A Sixth Mass Extinction?," below). Conversely, protecting them could save many of Earth's most threatened species. By definition, world hotspots have already lost at least 70 percent of their land area; many scientists warn that fragmenting them further will accelerate species loss because populations of endemic species will become smaller and more extinction-prone. This view is based on the theory of island biogeography, which is discussed further below in Section 7 ("Habitat Loss: Causes and Consequences").

About 10 percent of the original area of world biodiversity hotspots is currently protected as parks or reserves. Conservation International calls many of these areas "paper parks," where protection requirements are not enforced or where the covered zones have low biodiversity value (footnote 13). A 2004 study of how well the global network of protected areas preserved biodiversity found that many species were not covered by any habitat protections. "Global conservation strategies based on the recommendation that 10% (or other similar targets) of each country or biome be protected will not be effective because they are blind to the fact that biodiversity is not evenly distributed across the planet; by the same token, neither should protected areas be," wrote the authors (footnote 14).

5. Categories of Concern: Critically Endangered, Endangered, Vulnerable

What are the criteria for determining whether a species is in danger of extinction? To advise national governments, the multinational World Conservation Union (abbreviated IUCN for its formal title, the International Union for the Conservation of Nature) maintains a database of threatened species and subgroups and publishes the Red List, which catalogues species most at risk. For species in the highest risk groups—Critically Endangered, Endangered, and Vulnerable—IUCN weighs criteria including population size, geographic range, and how individuals are distributed, especially if the population is very small.

IUCN is working to improve its data on species, which currently is biased toward forests and other land ecosystems, emphasizes animals more strongly than plants, and does not cover microbes. Priority areas for the Union include better data on marine species and on arid and semi-arid ecosystems, which are expanding as a result of global climate change. Table 1 summarizes some estimates of threatened species (Critically Endangered, Endangered, and Vulnerable) from the 2006 Red List.

Table 1. Species classified as threatened by IUCN, 2006.

	Number of described species in IUCN database	Number of threatened species in 2006	Number threatened as % of described species
Vertebrates			
Mammals	5,416	1,093	20%
Birds	9,934	1,206	12%
Reptiles	8,240	341	4%
Amphibians	5,918	1,811	31%
Fishes	29,300	1,173	4%
Subtotal	**58,808**	**5,624**	**10%**

	Number of described species in IUCN database	Number of threatened species in 2006	Number threatened as % of described species
Invertebrates			
Insects	950,000	623	0.07%
Mollusks	70,000	975	1.39%
Crustaceans	40,000	459	1.15%
Others	130,200	44	0.03%
Subtotal	**1,190,200**	**2,101**	**0.18%**
Plants			
Mosses	15,000	80	0.53%
Ferns and allies	13,025	139	1.0%
Gymnosperms	980	306	31%
Dicotyledons	199,350	7,086	4%
Monocotyledons	59,300	779	1%
Subtotal	**287,655**	**8,390**	**3%**
Others			
Lichens	10,000	2	0.02%
Mushrooms	16,000	1	0.01%
Subtotal	**26,000**	**3**	**0.01%**

Other biological inventories cover different sets of organisms and offer different perspectives on which species are most highly threatened. For example, NatureServe (www.natureserve.org) pools data from a network of natural heritage programs and estimates the number of threatened species in the United States to be far greater than the IUCN’s estimates. "There is no single authoritative list of the world's endangered species, because we have yet to count and describe many living species," says Harvard University biologist Anne Pringle.

Scientific evidence is central to identifying endangered species. To determine whether a species is endangered or might become so, scientists collect data to answer questions including:

- Is the population growing, shrinking, or at a steady state, and why? How completely does it occupy its habitat? How is it being affected by competitors, parasites, harvesting, and hybridization with other species?

- Is the species' geographic range expanding or contracting? Is it fragmented into small areas? How many mature (breeding) individuals exist, and where are they located? How are external impacts on its habitat, such as pollution and development, expected to affect the species' range? How much habitat is needed to support a target population level?
- If the population is very small, is it expected to grow or contract? Will the number of mature individuals remain steady or fluctuate? Can they reach each other to breed?
- How biologically distinct is the species from other closely related organisms? Does the target group consist of one single species, or should it be reclassified as several distinct species?
- If a species is recovering from endangered status, what population size and distribution indicate that it no longer needs special protection?

These assessments draw on scientific fields including conservation biology, population ecology, biogeography, and genetics. Captive breeding programs have helped to preserve and reintroduce some species that were extinct in the wild, such as California condors. Recently scientists have successfully cloned several endangered varieties of cows and sheep, and some biologists advocate creating DNA libraries of genetic material from other endangered species. Others counter that cloning fails to address the root causes of the problem, including habitat loss and over-harvesting.

6. A Sixth Mass Extinction?

Species have appeared and disappeared continually throughout Earth's history, with extinctions occurring on average at a rate of 0.1 to 1 species per million species-years. At several points, however, this rate has risen sharply, producing five "mass extinction" events (Fig. 6). The most famous of these events, the Cretaceous-Tertiary (K-T) extinction 65 million years ago, is thought to have been caused at least in part by a giant asteroid that struck Earth off the coast of Mexico, causing tidal waves and climate-altering dust clouds. Dinosaurs, along with two-thirds of the other species on Earth, were killed off by the K-T extinction.

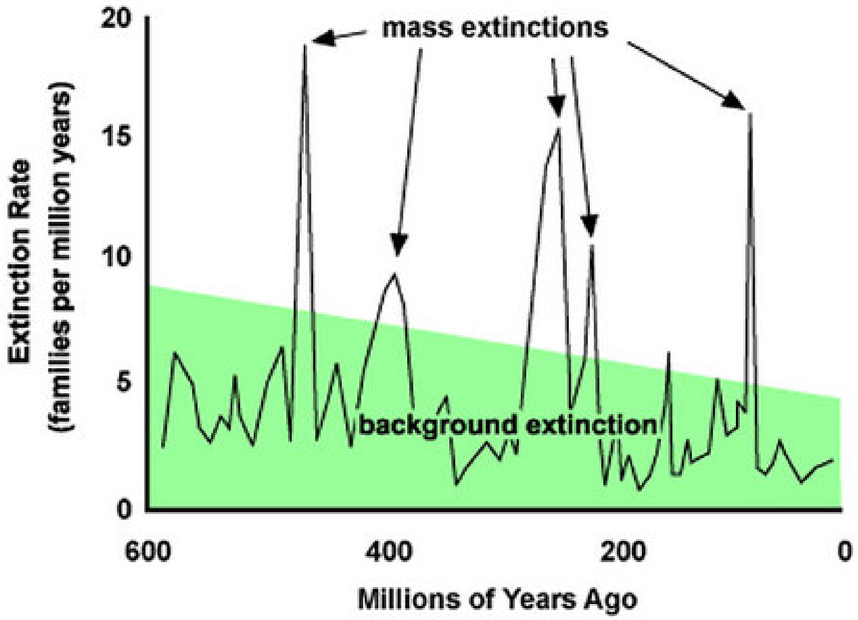

Figure 6. Earth's five mass extinctions

© University of California Museum of Paleontology's Understanding Evolution/ evolution.berkeley.edu.

Several lines of evidence suggest that Earth is experiencing a sixth mass extinction today. Estimates of extinction rates are imprecise for many reasons. In particular, they are extrapolated from a few well-known groups with relatively few species, such as birds and large mammals, to other groups for which there is little data—for example, fungi. However, there is wide agreement that current rates of extinction are at least several hundred times greater than historical background levels. Most scientific studies estimate that in the near term, extinction rates could rise by three to four orders of magnitude above past averages (footnote 15).

In addition to tracking extinction rates, scientists can look at population decline and habitat loss trends to estimate how quickly Earth's biodiversity levels are changing. To date, about 50 percent of the planet's natural habitats have been cleared for human use, and another 0.5 to 1.5 percent of nature is lost each year. Ongoing and current mass extinctions have been documented for many groups of organisms, including marine and freshwater fish, amphibians, and European farmland birds and macrofungi.

The current mass extinction is different from past events in several ways. First, it is happening much more quickly: each of the "Big Five" played out over thousands of years, but the current mass extinction is likely to be concentrated within 200 years. By the end of the 21st century, we may have lost two-thirds of the species on Earth (footnote 16). Second, past mass extinctions are thought to have been caused by natural phenomena such as the shifting of continents, comet or meteoroid impacts, or climate change independent of human influence, or some combination of these factors. In contrast, as we will see below, humans are causing the current mass extinction.

Despite concerns about a sixth mass extinction, new species are identified each year. For example, on a joint expedition to China and Nepal in early 2006, scientists from Conservation International and Disney's Animal Kingdom found new species that included a wingless grasshopper, a subspecies of vole, up to three new species of frogs, eight new species of insects, and ten new species of ants. These discoveries are evidence that we still know very little about Earth's biodiversity. In addition, new techniques for analyzing organisms' molecular structures have led scientists to reclassify some groups once viewed as single species into multiple species.

Sometimes it can be hard to determine the exact status of a rare species. In 2004, scientists from Cornell University and other institutions reported that they had seen and videotaped an ivory-billed woodpecker in Arkansas (Fig. 7). Ivory-bills had been presumed extinct since the 1930s, so this sighting caused great excitement but also spurred debate over whether the bird that was caught for a few seconds on film was in fact a more common type of woodpecker. Other researchers subsequently reported more than a dozen sightings and sound recordings of ivory-billed woodpeckers in Florida, but debate about whether ivory-bills still exist was ongoing as of late 2006. As the ivory-bill controversy shows, there is no definitive standard of proof for existence of a rare species, save perhaps a conclusive DNA sample—which may be impossible to get.

Figure 7. Watercolor painting of Ivory-billed Woodpeckers by John James Audubon

Courtesy National Audubon Society, Inc., 700 Broadway, New York, NY 10003, USA.

7. Habitat Loss: Causes and Consequences

Most endangered species are threatened by multiple factors, but habitat loss is generally viewed as the largest single cause of biodiversity loss worldwide. When humans convert wild areas for agriculture, forestry, urban development, or water projects (including dams, hydropower, and irrigation), they reduce or eliminate its usefulness as a habitat for the other species that live there.

As discussed in Unit 4, "Ecosystems," a species' ecological niche is the sum of all of the ranges of tolerance under which it can survive in a specific ecosystem, including temperatures, climate, type of shelter, food sources it needs, and many other factors. Generalist species can adapt to many different types of living conditions, but more specialized organisms may not be able to adjust when their habitat is changed or disappears as a result of land development.

All forms of development alter natural ecosystems. Commercial forestry involves road-cutting through forests and the harvesting of trees that are important as shelter or food for some species. Dams change river flow patterns, dissolved oxygen levels, and water temperatures and may prevent fish from swimming upstream to spawn. Farmers clear land, withdraw large quantities of water from local sources, and introduce pesticides and chemical fertilizers to the environment. Ranching impacts land physically through grazing and generates air and water emissions from animal wastes. Urban development clears land and paves it, which changes local water cycles by increasing surface runoff and reducing groundwater supplies. It also generates air and water pollution from industrial activities and transportation. (For more on these impacts, see Unit 7, "Agriculture," Unit 8, "Water Resources," and Unit 11, "Atmospheric Pollution.")

According to the Millennium Ecosystem Assessment (MA), a four-year, multinational analysis of the health of global ecosystems, cultivated land (including land used for livestock production and aquaculture) now covers one-quarter of Earth's terrestrial area. Mediterranean and temperate forests have been most heavily impacted by land conversion, but substantial conversion of tropical forests is also projected to occur by 2050 (Fig. 8). In contrast, boreal forests and tundra have experienced almost no conversion, although they are threatened by other forces, such as global climate change.

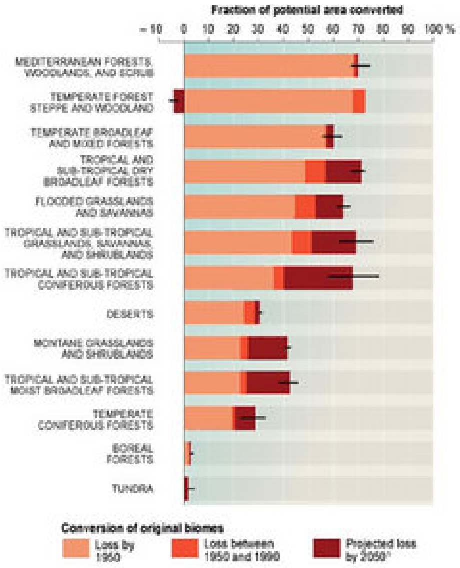

Figure 8. Terrestrial habitat transformation

© 2005. World Resources Institute. Millennium Ecosystem Assessment. Ecosystems and Human Well-Being: Synthesis, p.4 (Washington, DC: Island Press).

Land can become less suitable as habitat even if it is not directly converted to other uses. When actions such as suburban development and road-building carve large sectors of land into fragments, the undeveloped parcels may be too small or isolated to support viable populations of species that thrived in the larger ecosystems. This process, which is called habitat fragmentation, reduces biodiversity by:

- Splitting populations into smaller groups, which may be less viable because it is harder for the isolated individuals within the groups to defend themselves or find mates

- Increasing crowding and competition within the fragments

- Reducing species' foraging ranges and access to prey and water sources

- Increasing friction between animals and humans as animals range into developed areas

Fragmentation of natural ecosystems intensifies edge effects, impacts that stem from the juxtaposition of two different ecosystems—for example, a meadow and a paved street. The edges of natural ecosystems are more susceptible to light, wind, and weather than interior areas, so they are less suitable habitat for species that live in sheltered areas. Edges also are vulnerable to invasive species.

"We're seeing mortality rates [of old-growth rainforest tree species] go through the ceiling as a consequence of edge effects. It's obvious that the ecology of the rain forest is being altered in a profound way by fragmentation," says Bill Laurence of the Smithsonian Tropical Research Institute, who studies edge effects in Panamanian rain forests.

The theory of island biogeography, developed by ecologists Robert MacArthur and E.O. Wilson to explain the uneven distribution of species among various islands, offers some insights into how habitat fragmentation affects local species. According to the theory, the number of species on an island is a balance between the rate of colonization by new species and the rate of extinction of existing species. An island's population will approach an equilibrium level where the two trends are balanced and the number of species remains stable. Large islands typically have more resources, so they can be expected to support larger equilibrium numbers of species. Accordingly, extinction rates should increase with habitat fragmentation because smaller habitat fragments support fewer species.

Island biogeography also suggests that habitat fragmentation will reduce the rate at which species colonize new areas because they have trouble crossing gaps in between the smaller sections of remaining habitat. For example, as illustrated in Figure 9, many animals are killed crossing highways that divide their ranges (and are at risk of losing genetic diversity if they cannot reach other local populations to breed).

Figure 9. Habitat fragmentation and species mobility

© United States Department of Transportation, Federal Highway Administration.

One solution that is attracting increasing interest is to create corridors of land linking separate habitat zones, making it easier for wildlife to move from one sector to another without injury or interference. Research has shown that these corridors increase wildlife movement between habitat zones, although it can be difficult to maintain access for animals when the corridors cross human structure such as highways and railroad tracks (footnote 17).

8. Invasion by Exotic Species

Throughout the history of commerce, humans have transported animals, plants, and other live organisms around the globe. In many cases these species were deliberately brought, either as food supplies for the journey or to create new crops and animal colonies on arrival. Some live cargo has come along uninvited—for example, termites embedded in the wood slats of shipping crates, or fingernail-sized zebra mussels that ships suck up in ballast water. Thousands of exotic species have been introduced to new habitats worldwide as a result of human trade and travel, but they all have something in common: the potential to thrive and multiply beyond all expectations in their new environments.

When species are moved to new locations that offers conditions for life similar to their native habitats, they may exploit vacant ecological niches and grow quickly, especially if they have no natural predators in their new settings. Figure 10 shows a shopping cart that was pulled from Great Lakes waters infested with exotic zebra mussels, which have covered nearly every inch of the cart's surface.

Figure 10. Colonization by zebra mussels, Great Lakes

© United States Environmental Protection Agency.

These invasive species are major threats to biodiversity because local species are not adapted to compete with them. One extreme case, the brown tree snake, was introduced to Guam after World War II (probably as a stowaway on military cargo planes) from its native range in the eastern Pacific. The snake has killed off nine of Guam's twelve forest bird species, half of its lizards, and possibly some of its bat species, and caused major damage to the island's poultry industry. In 2004, the U.S. Congress authorized up to $75 million over five years to prevent brown tree snakes, which have traveled as far as Texas in cargo shipments, from becoming established in Hawaii and the U.S. mainland and to control their presence in Guam.

Plants can also become invasive. Spotted knapweed, a perennial that probably came to the United States from Eastern Europe or Asia a century ago in imported hay or alfalfa seed, has become established across Montana. The plants, each of which can produce up to 18,000 seeds annually, compete for water and nutrients with native bunch grasses and produce a toxin that damages other plants. This technique, in which plants compete by poisoning other species, is called allelopathy. For example, garlic mustard, a weed found across 30 states and Canada, suppresses the growth of native trees by killing the fungi that help the trees take up nutrients from soil.

Invasive species flourish because they have left their normal predators behind, so one way to control them is to import those enemies. For example, biologists have introduced eight of spotted knapweed's natural insect predators to Montana with mixed success. This strategy assumes that the imported predator can survive in the new environment, and that it will not become invasive itself. Cane toads were imported to Australia in the 1930s to control beetles that fed on sugar cane, but although they had been used successfully for this purpose in Hawaii and the Caribbean, in Australia the toads did not breed at the right time of year to eat cane beetle larvae. However, they did spread across most of Australia, and have outcompeted many other local frog species. Because they produce toxins in their bodies, the toads are also poisonous to predators such as fish and snakes, although some Australian birds and rodents are learning to eat only the non-toxic parts of the toads (footnote 18).

Invasion by exotic species threatens nearly 50 percent of the endangered species in the United States (footnote 19). Scientists are using remote sensing and geographic information systems to detect and map land cover changes and the spread of exotic plants, and also use high-speed computation and modeling to project how populations will grow. The yellow areas in Figure 11 show invasive salt cedar along the Rio Grande River.

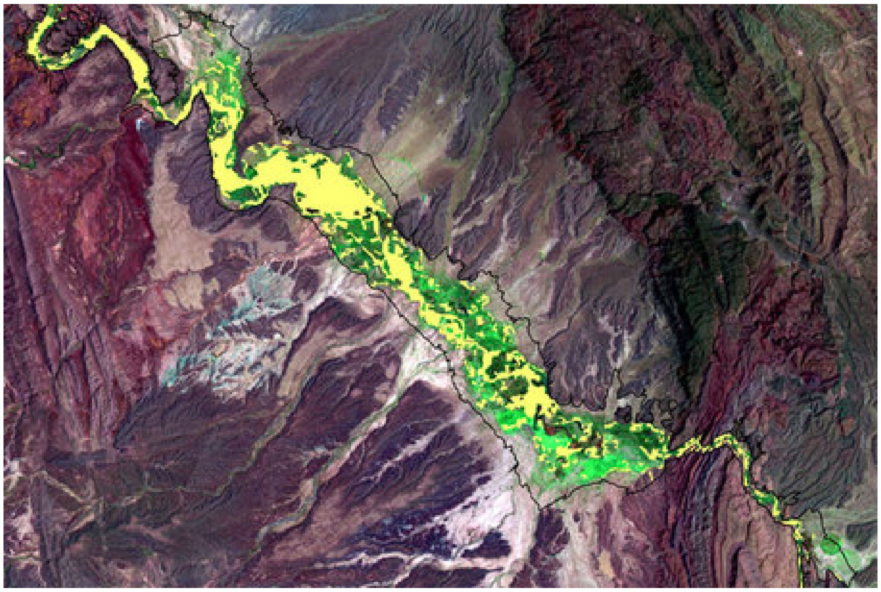

Figure 11. Landsat image of invasive salt cedar, 2002

© Center for Space Research, University of Texas.

It is important to note that many introduced species do not become invasive or have harmful impacts in their new settings. For example, major food crops and domestic animals have been traded worldwide and are rarely invasive. What makes a species likely to become invasive? The examples cited here point to several characteristics. Exotic species that reproduce quickly, can poison predators or competitors, and do not face natural predators in their new locales are well-positioned to spread and outcompete local species. As discussed in Unit 4, "Ecosystems," many r-adapted species have the capacity to become invasive pests because they flourish and reproduce quickly in unstable environments.

9. Other Drivers of Biodiversity Loss

Humans are harvesting many plants and animals at faster rates than the populations can maintain themselves (harvesting includes the use of animals and plants for food as well as other applications like medicines, trophies, and clothing). The declining yield from world fisheries shows how over-harvesting threatens biodiversity on a large scale.

According to the Food and Agriculture Organization (FAO), about half of ocean fish stocks are being exploited close to their maximum sustainable limits (i.e., close to levels of harvesting that will not reduce future yields). About one-fourth of global stocks are either overexploited, depleted, or recovering from depletion, and the remaining fourth are underexploited or moderately exploited. In several Atlantic and Pacific fisheries, traditional stocks have been depleted and fishermen are targeting other, less-valuable species (footnote 20).

In addition to depleting human food supplies, overfishing disrupts marine ecosystems and affects other species in the food chain. "Overfishing removes the most important and abundant consumers in a natural ecosystem," says Jeremy Jackson of the Smithsonian Tropical Research Institute. "Fish eat fish, but fish also eat seaweed. If they're not there, the seaweed grows 10 times or 100 times faster than corals, it grows over corals, smothers them, and kills them."

Hunting may also threaten animal and bird species. When North America was settled by European explorers, millions of passenger pigeons wintered in southern forests and migrated north to summer nesting grounds around the Great Lakes, darkening the skies as they flew. But large-scale hunting and forest clearing in the 19th century decimated pigeon numbers. The last known individual died in the Cincinnati Zoo in 1914 (Fig. 12).

Figure 12. Passenger pigeons, from John James Audubon's Birds of America

Courtesy National Audubon Society, Inc., 700 Broadway, New York, NY 10003, USA.

Today, major hunting and fishing organizations such as Ducks Unlimited and the Izaak Walton League take a more balanced approach and devote significant resources to protecting and conserving wildlife habitat. However, in developing countries where hunting is less strictly regulated, poaching and illegal trafficking threaten many wild species. International trade in wildlife generates billions of dollars annually and has depleted many species that are prized for uses including trophies, jewelry, food, exotic clothing, ingredients for medicine, and other uses. Many of these applications have encouraged wasteful and inhumane harvesting practices, such as cutting fins off of live sharks for use in shark-fin soup and throwing the maimed sharks back into the ocean to drown.

Pollution reduces biodiversity by either changing organisms' biological functions or altering the environmental conditions that they need to survive. For example, pesticides can affect the health and reproductive patterns of many species. Bald eagles, which declined to near-extinction in the early 1960s, are a well-known example. The chlorinated hydrocarbon pesticide DDT, which was used heavily in the 1940s and 1950s, bioaccumulated in eagles' fatty tissue and caused them to lay eggs with thin shells that broke before hatching. In 1963 there were 417 breeding pairs of bald eagles in the Lower 48 states; a federal ban on DDT and other protective measures helped increase this to more than 6,400 pairs by 2000. However, other chemicals currently in use may also act as endocrine disruptors in species including turtles, amphibians, and some fish.

Pollution is an important threat to aquatic ecosystems, where it can affect many environmental parameters. Agricultural runoff carries excess nutrients that cause algal blooms and deplete dissolved oxygen levels, while siltation from logging and construction reduces available light. Mining generates toxic chemical wastes that can poison local water supplies.

Global climate change threatens biodiversity worldwide because it is modifying average temperatures and rainfall patterns, and thereby shifting climate zones. Ecologists have documented changes in the geographic ranges and breeding cycles of many species. However, some organisms that are highly adapted to specific conditions—such as the Arctic sea ice communities described above in Box 1—may not be mobile enough to find new habitats as their local climate conditions change. As a result, many scientists believe that climate change could increase current extinction rates. (For more details, see Unit 12, "Earth's Changing Climate.")

10. Why Biodiversity Matters

There are both practical and moral arguments for preserving biodiversity. From a practical point of view, humans derive many kinds of food, medicine, and fuel from plant and animal sources. All food crops were originally domesticated from wild species. More recently, researchers have derived anticancer drugs from the bark of the Pacific yew tree and from the Madagascar periwinkle flower. Scientists are currently working to isolate enzymes from a diversity of microbes that can digest plants for human use as transportation fuels. Many existing species that we know little about—especially insects, fungi, and microbes—may yield similarly important products.

Natural resources also provide jobs and income to many communities. Roughly 40,000 jobs were lost in Newfoundland in the 1990s when North Atlantic cod stocks collapsed due to over-fishing. Protecting biodiversity helps to ensure that crops, fisheries, and animal stocks will have enough genetic variety to survive natural disasters and diseases. When new diseases strike common crops, genetic stocks derived from wild relatives can be used to identify traits for resistance to the new infestations. This is the rationale for protecting areas that harbor wild relatives of domesticated plants and for creating stock centers that maintain seeds from wild relatives. For example, the C.M. Rick Tomato Genetics Resource Center at the University of California at Davis is a repository for wild and mutant strains of tomato and provides seed samples for research worldwide (footnote 21).

Healthy ecosystems also provide many other important services to human communities. These functions are so basic that they can go unnoticed, until they disappear. The American Dust Bowl occurred in the 1930s because repeated plowing and cultivation across the Great Plains broke up the cover of prairie grasses (viewed as weeds by farmers) that held the soil in place. Several years of extreme drought left the plains vulnerable to wind erosion, which blew topsoil off millions of acres and displaced thousands of farming families (Fig. 13).

Figure 13. Buried machinery in barn lot, Dallas, South Dakota, 1936

© United States Department of Agriculture.

In the past several decades, societies have begun to recognize the economic value of ecosystem services. For example, New York City signed an agreement in 1997 with state and federal agencies and 80 upstate communities to buy and protect lands in the Catskill and Delaware watersheds, which supply about 90 percent of the city's drinking water. By spending $1.4 billion on land acquisition and related measures to reduce pollution in the target areas, New York avoided building a $6–8 billion filtration plant to purify water from these sources (footnote 22).

Concerns about global climate change have increased awareness of the role that ecosystems play in sequestering carbon from the atmosphere and are spurring investment in programs to preserve this service. The World Bank's Prototype Carbon Fund (PCF), which invests in projects that reduce greenhouse gas emissions and promote sustainable development, is supporting ecosystem protection initiatives including native forest restoration in Brazil, soil conservation in Moldova, and afforestation (planting new forests) on degraded agricultural land in Romania. Under procedures outlined in international climate change agreements, each of these projects will generate economic credits for reducing carbon dioxide emissions—a mechanism that effectively monetizes the benefit that the ecosystems provide by taking up atmospheric carbon dioxide in plants. By purchasing these credits, PCF will give local agencies a financial incentive to carry out the projects. The bank hopes to spur similar commitments from private investors that will help to create a market for carbon credits.

If ecosystems provide such valuable services, why do many communities exploit and damage them? First, valuing ecosystem services is a relatively new concept, and there are many different approaches to estimating those values. Second, local communities often have more to gain from quick exploitation than from conservation unless they receive special incentives, such as premium prices for sustainably-produced products. Third, existing incentives may reward communities that develop ecosystems instead of conserving them. For example, many U.S. communities encourage commercial development because it generates property taxes, even though this development reduces open space and increases traffic and pollution (footnote 23). The development pictured in Fig. 14 threatens the habitat of the Douglas County pocket gopher, which is endemic to the area.

Figure 14. Suburban development in Douglas County, Colorado

© Center for Native Ecosystems.

Many advocates also make aesthetic and moral arguments for conserving biodiversity. Species richness adds to our enjoyment of nature, even at a simple level: most hikers would probably agree that a wild meadow, with its variety of plants, animals, and birds, is more interesting to visit than a cultivated field. Morally, the fact that speciation rates for many types of organisms are less than one per million years means that extinction is permanent, at least on human time scales: once a species is extinct, it will not be replaced for thousands or millions of years. In the words of biologists Rodolfo Dirzo and Peter Raven, "The loss of biodiversity is the only truly irreversible global environmental change the Earth faces today" (footnote 24).

11. Biodiversity in Your Back Yard

Biodiversity is not just an issue for scientists. Anyone who interacts with nature has a role to play in understanding and protecting biodiversity in her or his everyday environment. Observers contribute to many species monitoring projects—for example, the National Audubon Society's Christmas Bird Count (Fig. 15) and the annual Great Backyard Bird Count (GBBC), sponsored by Audubon and Cornell University on President's Day Weekend; Frogwatch USA, a frog and toad monitoring program sponsored by the National Wildlife Federation and the U.S. Geological Survey; and the Reef Environmental Education Foundation's fish and invertebrate monitoring programs (footnote 25).

Figure 15. Western Hemisphere locations for the Christmas Bird Count

© National Audubon Society. Cornell Lab of Ornithology.

Monitoring programs can help to protect biodiversity by increasing the amount of information that is available to scientists and policy makers. There are not enough trained scientists to monitor all species that are endangered or otherwise of interest, or the spread of invasive species, or the impacts of trends such as habitat fragmentation. In the United States, many agencies and organizations collect data on ecosystems, but often their data is not coordinated or integrated. In a 2006 report, the H. John Heinz Center identified ten key data gaps that impede effective reporting on the state of the nation's ecosystems. These gaps include:

- Reporting on species and communities at risk of extinction or loss
- Measuring the extent and impacts of non-native species
- Assessing the condition of plant and animal communities
- Assessing the condition of riparian areas and stream habitat

Monitoring programs that involve the public are not always subject to the same design criteria and quality controls as scientific field studies, but they can generate large data sets over broad geographic areas at a low cost. During the 2006 Great Backyard Bird Count, volunteers tallied 623 species and more than 7.5 million individual birds, both records for the decade-old event. And new species may be found anywhere, especially microbial species. For example, in 2003 researchers from the American Museum of Natural History found a new species of centipede in leaf litter in New York's Central Park, and in 2006 a graduate student discovered a new bacterium in a salt pond on Cape Cod (footnote 27).

12. Major Laws and Treaties

The main international agreement to protect biodiversity is the Convention on Biological Diversity, which was opened for signature at the United Nations Conference on Environment and Development in 1992 and currently has 188 members (the United States signed the convention in 1992 but has not ratified it). The Convention sets out three goals: conserving biodiversity, using its components sustainably, and sharing the benefits of genetic resources fairly. Because national governments set the rules that govern most uses of biodiversity, such as farming, forestry, and economic development, the Convention requires members to develop national strategies for measuring and conserving their biodiversity resources. Policies for protecting threatened species and restoring damaged ecosystems are also left to individual governments.

Threatened species are also protected by the Convention on International Trade in Endangered Species (CITES), which has 169 adherents. Under CITES, nations agree to set up licensing systems for all trade in species protected under the treaty and to apply specific restrictions outlined in the convention. CITES protects some 5,000 species of animals (mammals, birds, reptiles, amphibians, fish, and invertebrates) and 28,000 species of plants (Fig. 16).

Figure 16. Tomato frog (Dyscophus antongilii). Listed on CITES Appendix I (threatened with extinction)

© Franco Andreone.

Many nations have passed domestic laws that protect endangered species, using frameworks similar to the IUCN Red List and focusing on the most threatened species. However, the Red List is generally accepted as the most complete global data source, even taking into account its gaps.

The U.S. Endangered Species Act (ESA), passed in 1973, seeks to protect species that are endangered (threatened with extinction throughout all or a significant portion of their ranges) or threatened (likely to become endangered throughout all or a significant portion of their range) within the foreseeable future. It does so by barring the "take" of listed species (including actions such as killing, harvesting, harassing, pursuit, and habitat alterations that kill or hurt wildlife, such as destroying nesting grounds) and any trade in those species without a federal permit. Federal agencies are required to designate "critical habitat" for listed species when it is judged to be "prudent and feasible," and actions such as development that would adversely impact critical habitat areas are prohibited.

Protection under the ESA has helped dozens of endangered species to recover and establish self-sustaining populations, including the bald eagle and green sea turtle. Figure 17 shows population trends for the Atlantic piping plover, which was listed as endangered in 1985.

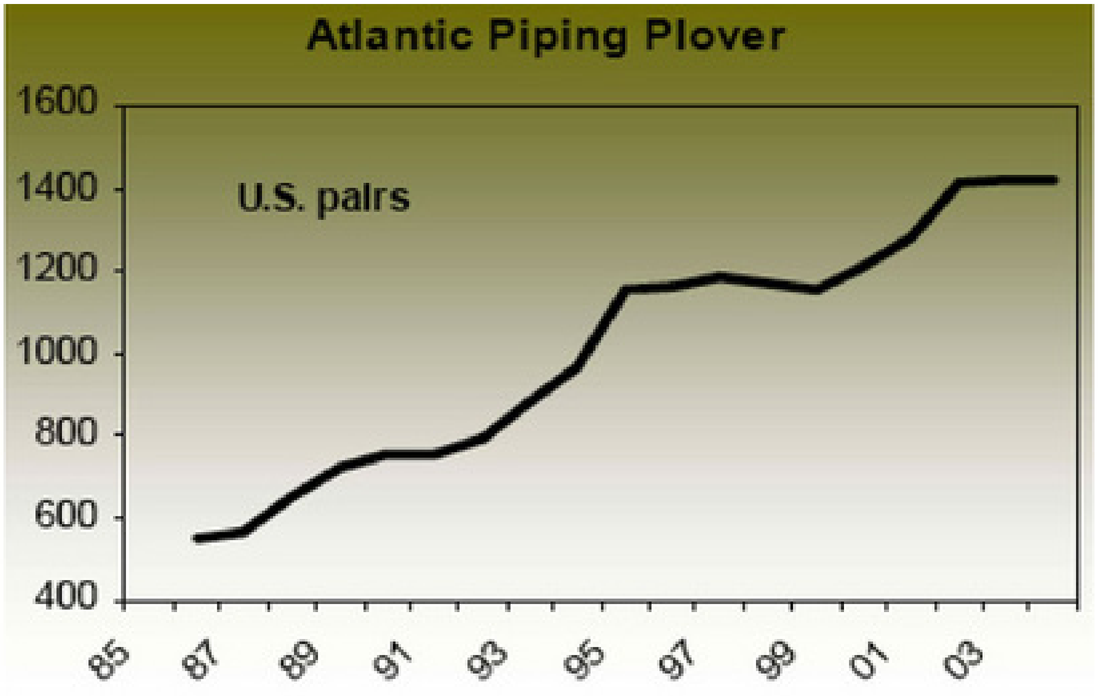

Figure 17. Atlantic piping plover recovery trends

Courtesy Kieran Suckling. © Center for Biological Diversity.

Decisions taken under the ESA about whether to list or delist a species and how to define critical habitat often become highly controversial, with debate centering on two issues: the quality of the scientific analysis that provides a foundation for these actions and the economic tradeoffs involved in restricting development to protect species that may be present in very low numbers. These controversies underline the fact that the greatest current threat to biodiversity is human development.

In July 2006, 19 leading biodiversity experts from 13 nations issued a statement warning that the world is "on the verge of a major biodiversity crisis" and that governments and private actors needed to take the issue more seriously. Part of the problem, they stated, is that biodiversity is even more scientifically complex than issues such as stratospheric ozone depletion or climate change: "By definition, biodiversity is diverse: it spans several levels of biological organization (genes, species, ecosystems); it cannot be measured by simple universal indicators such as temperature and atmospheric CO_2 concentration; and its distribution and management are more local in nature" (footnote 28).

Accordingly, they argued, a need exists for an expert body to provide organized, coordinated, and internationally validated scientific advice on biodiversity issues, as the Intergovernmental Panel on Climate Change does for global climate change (for more details, see Unit 12, "Earth's Changing Climate"). France is sponsoring a consultation process aimed at designing such a panel.

13. Further Reading

Annenberg Media, Rediscovering Biology: Molecular to Global Perspectives, Units 4 ("Microbial Diversity") and 12 ("Biodiversity"), http://www.learner.org/channel/courses/biology/index.html. Two units from a professional development course for high school biology teachers, including video, online text, and supporting materials.

Center for Biological Diversity, "The Road to Recovery: 100 Success Stories for Endangered Species Day 2006," http://www.esasuccess.org/reports/. Profiles of species that have increased their populations under the U.S. Endangered Species Act.

Cornell Laboratory of Ornithology, **The Search for the Ivory-Billed Woodpecker**, http://www.birds.cornell.edu/ivory. News, evidence, and updates from the researchers who claimed to have found an ivory-bill in 2004.

Rolf Gradinger, "Arctic Sea Ice: Channels of Life," NOAA Ocean Explorer, http://oceanexplorer.noaa.gov/explorations/02arctic/background/sea_ice/sea_ice.html. Explore the unique environment of Arctic sea ice communities.

University of California Museum of Paleontology, "The Phylogeny of Life," http://www.ucmp.berkeley.edu/alllife/threedomains.html. Detailed information on the structure, ecology, and fossil records of major subgroups in the three domains of life.

http://www.discoverlife.org. An online guide to the world's flora and fauna, with information on each group's taxonomy, natural history, abundance, distribution, and ecology.

Footnotes

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4. For examples, see Field Museum, "Meet the Scientist," http://www.fieldmuseum.org/biodiversity/scientist_department5.html.

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10. Noah Fierer and Robert B. Jackson, "The Diversity and Biogeography of Soil Bacterial Communities," **Proceedings of the National Academy of Sciences**, vol. 103 (2006), pp. 626–31.

11. Norman Myers et al., "Biodiversity Hotspots for Conservation Priorities," **Nature**, vol. 403, February 24, 2000, p. 853.

12. For an interactive map with detailed descriptions of all 34 global hotspots, see Conservation International, http://www.biodiversityhotspots.org/xp/Hotspots/hotspots_by_region/.

13. Conservation International, "Protected Area Coverage in the Hotspots," http://www.biodiversityhotspots.org/xp/Hotspots/hotspotsScience/conservation_responses/protected_area_coverage.xml.

14. Ana S. L. Rodrigues et al., "Effectiveness of the Global Protected Area Network in Representing Species Diversity," **Nature**, vol. 428, April 8, 2004, p. 642.

15. Andrew Balmford, Rhys E. Green, and Martin Jenkins, "Measuring the Changing State of Nature," **TRENDS in Ecology and Evolution**, vol. 18, no. 7, July 2003, p. 327.

16. Dirzo and Raven, p. 164.

17. Douglas J. Levey et al., "Effects of Landscape Corridors on Seed Dispersal by Birds," **Science**, vol. 309, July 1, 2005, pp. 146–48; Cornelia Dean, "Home on the Range: A Corridor for Wildlife," **New York Times**, May 23, 2006, p. F1.

18. "The Unwanted Amphibian," Frog Decline Reversal Project, Inc., http://www.fdrproject.org/pages/toads.htm.

19. David S. Wilcove et al., "Quantifying Threats to Imperiled Species in the United States," **Bioscience**, vol. 48, no. 8, August 1, 1998.

20. Food and Agriculture Organization, **The State of World Fisheries and Aquaculture 2004**, http://www.fao.org/DOCREP/007/y5600e/y5600e00.htm, p. 32.

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26. **Filling the Gaps: Priority Data Needs and Key Management Challenges for National Reporting on Ecosystem Condition** (Washington, DC: H. John Heinz Center, May 2006), p. 3.

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Glossary

biomes : Broad regional areas characterized by a distinctive climate, soil type, and biological community.

ecosystem : A level of organization within the living world that includes both the total array of biological organisms present in a defined area and the chemical-physical factors that influence the plants and animals in it.

edge effect : The observed increase in the number of different species along the margins of two contrasting environments in an ecosystem. This term is commonly used in conjunction with the boundary between natural habitats, especially forests, and disturbed or developed land.

endemic : Describing a disease or characteristic commonly found in a particular region or group of people; a disease constantly present at low levels in an area.

habitat fragmentation : A process of environmental change important in evolution and conservation biology. It can be caused by geological processes that slowly alter the layout of the physical environment or by human activity, such as land conversion, that can alter the environment on a much faster time scale.

hotspots : An informal expression designating specific areas as being contaminated with radioactive substances, having a relatively high concentration of air pollutant(s), or experiencing an abnormal disease or death rate.

invasive species : Refers to a subset of introduced species or non-indigenous species that are rapidly expanding outside of their native range.

speciation : The formation of two or more genetically distinct groups of organisms after a division within a single group or species. A group of organisms capable of interbreeding is segregated into two or more populations, which gradually develop barriers to reproduction.

species richness : A type of approach to assessing biodiversity that examines the distribution of all resident terrestrial vertebrates: amphibians, reptiles, birds, and mammals.

species-years : A way to measure extinction rate. There is approximately one extinction estimated per million species-years. This means that if there are a million species on Earth, one would go extinct every year, while if there was only one species, it would go extinct in one million years.