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Human Environmental Impact Through Time

The human evolutionary line began in Africa about 7 million years ago (Ma). It took some 5 or 6 million years (My) for protohumans to spread from Africa to Asia and then to Europe. These early humans, like other primates, made their living by seeking food and shelter from their environment, gathering plant foods, and hunting easy-to-kill prey. Sometimes, they also experienced threats from their environment, including accidents, droughts, vector-borne diseases, and attacks from predators. At this stage, with relatively low population densities and limited technologies, humans were not ecosystem engineers.

By some 50,000 years ago, however, humans had learned to use fire; developed complex tools, weapons, and language; and created art. On local scales, these modern humans were very much ecosystem engineers. Sometimes their enhanced abilities to make a living outstripped their local environment’s capacity to provide that living, and they caused local ecological disruptions. On several continents, for example, humans hunted large mammals to the point where many, such as the marsupial lion of Australia, went extinct. As humans became more efficient at exploiting their local environments, they spread farther. By 13,000 years ago, modern humans had spread to all continents and many islands across the globe. Then, about 10,000 years ago, people began to domesticate plants and animals. Instead of searching for food, they began to produce food.

Food production changed the course of human and environmental history. Domestication of plants and animals enabled people to adopt a sedentary lifestyle. As detailed by geographer and ecologist Diamond (1997, 2002), populations grew as agriculture developed, because larger sedentary populations both demanded and enabled more food production. Local ecological disruptions became more numerous and widespread and more intense. With animal domestication, contagious diseases of pets and livestock adapted to new human hosts. Diseases spread more quickly in crowded conditions; inadequate sanitation compounded the effects. From agriculture, civilization followed and with it, cities, writing, advanced technology, and political empires. In just 10,000 years, these developments led to nearly 7 billion people on Earth, industrial societies, and a global economy founded on complicated technologies and fossil fuels. Humans have emerged as ecosystem engineers on a global scale. The ecological disruptions we cause are no longer just...
local or regional but global, and we have become the principal threat to the environment.

Yet despite today's advanced technologies, humans are as dependent on their environments as other organisms are. History, not just ecology, has been very clear on this point. From the Old Kingdom of Egypt more than 4000 years ago to the culture that created the huge stone monoliths on Easter Island between 1000 and AD 1550 to the 1930s Dust Bowl of North America, civilizations or ways of life have prospered and failed by using and (mostly unwittingly) abusing natural resources.

In Old Kingdom Egypt, the resource was the valley of the Nile, richly fertilized with sediment at each flooding of the river, laced with canals and side streams, blessed with a luxuriant delta. Agriculture flourished and populations swelled, until unusually severe droughts brought on the civilization's collapse. On Easter Island, the resource was trees, which gave Polynesians colonizing the island the means to build shelter, canoes for fishing the open waters around the island, and log rollers for moving the ceremonial stone monuments for which the island is famous. Deforestation not only eliminated the humans' source of wood, but also further deprived the already poor soil of nutrients and made it impossible to sustain the agriculture that had sustained the island's civilization. On the dry Great Plains of North America, settlers were convinced that rain would follow the plow, and so they plowed homestead after homestead, only to watch their homesteads' soils literally blow away in the wind.

In these cases and many others, human civilizations damaged their environments, and their actions also worsened the effects on their civilizations of climatic or other natural cycles. Yet in each case, a human culture was operating precisely the way it had evolved to operate: The culture of Old Kingdom Egypt enabled its people to prosper on the Nile's natural bounty, but prolonged, unprecedented drought brought starvation and political disorder. Easter Islanders thrived and populated the island until its resources were exhausted. Dust Bowl farmers lived out their culture's view of dominating and exploiting the land for all it was worth. The inevitable outcome for all three cases was a catastrophe for the immediate environment and the people it supported—not only because the people were unprepared to cope with dramatic natural changes in their environments but because their own actions magnified the disastrous effects of those changes.

Quoting an apt bit of cynical graffiti, historical philosopher Wright (2004, p. 107) sums up what he calls the hazards of human progress this way: “Each time history repeats itself, the price goes up.” Indeed, as the second decade of the 21st century begins, humans are ecosystem engineers on a planetary scale, and our global civilization threatens the life-sustaining capacity of all of Earth’s environmental “spheres”:

- **Geosphere (lithosphere):** Earth’s crust and upper mantle, containing nonrenewable fossil fuels, minerals, and nutrients that plants require. The activities of plants, animals, and microorganisms weather mineral soils and rocks, create organic soils, and alter erosion and sedimentation rates. Humans mine minerals, metals, and gems; extract fossil fuels including coal, oil, and natural gas; and increase erosion and sedimentation by removing or altering natural plant cover through agriculture, logging, and urbanization.

- **Atmosphere:** the thin envelope of gases encircling the planet. Living systems modify the atmosphere, its temperature, and the amount of water it contains by continually generating oxygen and consuming carbon dioxide through photosynthesis and affecting the amount and forms of other gases. Humans release toxic chemicals into the air and alter the climate by raising the atmospheric concentration of greenhouse gases, such as carbon dioxide and methane, through the burning of fossil fuels in motor vehicles, ships, airplanes, and power plants.

- **Hydrosphere:** Earth’s liquid surface and underground water; its polar ice caps, oceanic icebergs, and terrestrial permafrost; and its atmospheric water vapor. Living systems alter the water cycle by modifying the Earth’s temperature and the amount of water plants send into the atmosphere through a process called evapotranspiration. Humans build dams, irrigation canals, drinking-water delivery systems, and wastewater treatment plants. They use water to generate electricity; they mine groundwater from dwindling underground aquifers for farming as well as drinking; they alter the flows of surface waters for everything from transportation to the mining of gold; they drain wetlands to gain land area and abate waterborne diseases. Modern human interference in global climate is likely to disrupt the entire planetary water cycle.

- **Biosphere:** the totality of Earth’s living systems, that part of the Earth inhabited by living organisms. Life on Earth emerged 3.9 billion years ago and has sustained itself through changes in form, diversity, and detail since then. No planet yet discovered supports complex life as we know it on Earth. As predators, humans have decimated or eliminated wild animal populations worldwide. As domesticators of animals and plants, humans have massively reshaped landscapes by cutting forests, burning and plowing grasslands, building cities, desertifying vast areas, and overharvesting fish and shellfish. Human actions have precipitated a spasm of extinctions that today rivals five previous mass extinctions caused by astronomical or geological forces, each of which eliminated more than 70% of species then existing.

Humans themselves may be thought of as a sphere within the greater biosphere: the *ethnosphere*, or the sum total of all thoughts and intuitions, myths and beliefs, ideas and inspirations brought into being by the human imagination since the dawn of consciousness. In the words of anthropologist Davis (2009, p. 2), who coined and defined the term in 2002, “The ethnosphere is humanity’s greatest legacy. It is the product of our dreams, the embodiment of our hopes, the symbol of all we are and all that we, as a wildly inquisitive and astonishingly adaptive species, have created.” But, Davis notes, just as the biosphere is being severely eroded, so too is the ethnosphere, but at a much faster pace.

Today, the scientific consensus is that *H. sapiens* – a single species – rivals astronomical and geological forces in its impact on life on Earth.

### Biotic Impoverishment

The first step in dealing with the present impact of human activity is to correctly identify the nature of humanity's
relationship with the environment and how human actions affect that relationship. Many people still see the environment as something people must overcome, or they regard environmental needs as something that ought to be balanced against human needs (for example, jobs vs. the environment). Most people still regard the environment as a provider of commodities or a receptacle for waste.

When asked to name humanity’s primary environmental challenges, people typically think of running out of non-renewable raw materials and energy or about water and air pollution. Environmental research and development institutions focus on ways technology can help solve each problem, such as fuel cells to provide clean, potentially renewable energy or scrubbers to curb smokestack pollution. Even when people worry about biodiversity loss, they are concerned primarily with stopping the extinction of species, rather than with understanding the underlying losses leading up to species extinctions or the broader biological crisis that extinctions signal.

These perspectives miss a crucial point: the reason pollution, energy use, extinction, and dozens of other human impacts are important is their larger impact on the biosphere. Ecosystems, particularly their living components, have always provided the capital to fuel human economies. When populations were small, humans making a living from nature’s wealth caused no more disruption than other species. But with nearly 7 billion people occupying or using resources from every place on Earth, humans are overwhelming the ability of other life-forms to make a living and depleting the planet’s natural wealth. At this point in the planet’s history, one species is compromising Earth’s ability to support the living systems that evolved here over millions of years. The systematic reduction in Earth’s capacity to support life – which Woodwell (1990) termed ‘biotic impoverishment’ – is thus the most important human-caused environmental impact. At best, the ethics of this impact are questionable; at worst, it is jeopardizing our own survival.

The connection between biotic impoverishment and extinction is intuitively obvious. By overharvesting fish, overcutting forests, overgrazing grasslands, or paving over land for cities, we are clearly killing other organisms outright or eliminating their habitats, thereby driving species to extinction and impoverishing the diversity of life. But biotic impoverishment takes many forms besides extinction. It encompasses three categories of human impacts on the biosphere: (1) indirect depletion of living systems through alterations in physical and chemical systems, (2) direct depletion of nonhuman life, and (3) direct degradation of human life (Table 1).

### Table 1  The many faces of biotic impoverishment

| Indirect depletion of living systems through alterations in physical and chemical systems |
| 1. Degradation of water (redirected flows, depletion of surface and ground water, wetland drainage, organic enrichment, destruction, and alteration of aquatic biota) |
| 2. Soil depletion (destruction of soil structure, erosion, salinization, desertification, acidification, nutrient leaching, destruction, and alteration of soil biota) |
| 3. Chemical contamination (land, air, and water pollution from pesticides, herbicides, heavy metals, and toxic synthetic chemicals; atmospheric ozone depletion; ocean acidification; fish kills; extinctions; biotic homogenization, and biodiversity loss; bioaccumulation; hormone disruption; immunological deficiencies, reproductive and developmental anomalies; respiratory diseases; intergenerational effects) |
| 4. Altered biogeochemical cycles (alteration of the water cycle; nutrient enrichment; acid rain; fossil fuel combustion; particulate pollution; degradation of land and water biota; outbreaks of pests, pathogens, and red tides) |
| 5. Global climate change (rising greenhouse gas concentrations, altered precipitation and airflow patterns, rising temperatures, effects on individual and community health, shifts among and within global ecosystems) |

| Direct depletion of nonhuman life |
| 1. Overharvest of renewable resources such as fish and timber (depleted populations, extinctions, altered food webs) |
| 2. Habitat fragmentation and destruction (extinctions, biotic homogenization, emerging and reemerging pests and pathogens, loss of landscape mosaics and connectivity) |
| 3. Biotic homogenization (extinctions and invasions) |
| 4. Genetic engineering (homogenization of crops, antibiotic resistance, potential extinctions and invasions if genes escape, other unknown ecological effects) |

| Direct degradation of human life |
| 1. Emerging and reemerging diseases (occupational hazards, asthma and other respiratory ills, pandemics, Ebola, AIDS, hantavirus, tuberculosis, Lyme disease, West Nile fever, antibiotic resistance, diseases of overnutrition, higher death rates) |
| 2. Loss of cultural diversity (genocide, ethnic cleansing, loss of cultural and linguistic diversity, loss of knowledge) |
| 3. Reduced quality of life (malnutrition and starvation, failure to thrive, poverty, environmental refugees) |
| 4. Environmental injustice (environmental discrimination and racism; economic exploitation; growing gaps between rich and poor individuals, segments of society, and nations; gender inequities; trampling of the environmental and economic rights of future generations) |
| 5. Political instability (civil violence, especially under intransigent regimes; resource wars; international terrorism; increased number of environmental refugees) |
| 6. Cumulative effects (environmental surprises, increased frequency of catastrophic natural events, boom-and-bust cycles, interactions between disease and biodiversity, collapse of civilizations) |

### Degradation of Water

Humans probably spend more energy, money, and time trying to control the movement and availability of water than to manage any other natural resource. In the process, we contaminate water, move water across and out of natural basins, deplete surface and groundwater; modify the timing and amount of flow in rivers, straighten or build dikes to
constrain rivers, and alter natural flood patterns. We change the amount, timing, and chemistry of fresh water reaching coastal regions, and we dry up wetlands, lakes, and inland seas. Our demands are outrunning supplies of this non-renewable resource, and the scale of our transformations risks altering the planetary water cycle.

Physical alterations of the Earth’s waters, combined with massive industrial, agricultural, and residential pollution, have taken a heavy toll on nonhuman aquatic life. By 2005 as much as one-fifth of the world’s coral reefs had been destroyed, and only 30% remained healthy. Globally, the number of oceanic dead zones, where little or no dissolved oxygen exists, tripled during the last 30 years of the 20th century. The biota of freshwater systems has fared no better. A 4-year survey of the freshwater fishes inhabiting Malaysian rivers in the late 1980s found only 46% of 266 known Malaysian species. Some 40% of North America’s freshwater fishes are at risk of extinction; two-thirds of freshwater mussels and crayfishes and one-third of amphibians that depend on aquatic habitats in the United States are rare or imperiled.

Humans use at least 54% of the Earth’s accessible water runoff, a figure that is likely to grow to 70% by 2025. By then, more than a third of the world’s population could suffer shortages of fresh water for drinking and irrigation. Groundwater aquifers in many of the world’s most important crop-producing regions are being drained faster than they can be replenished: a study published in 2010 found that the rate of groundwater depletion worldwide had more than doubled from 1960 to 2000. Natural flood regimes, as in the Nile River basin, no longer spread nutrient-rich silt across floodplains to nourish agriculture; indeed, the High Dam at Aswan traps so much silt behind it that the Nile delta, essential to Egypt’s present-day economy, is slumping into the sea. Whole inland seas, such as the Aral Sea in Uzbekistan, are drying up because the streams feeding them contain so little water. In addition to eliminating habitat for resident organisms, the sea’s drying is bringing diseases to surrounding human populations. Indeed, diseases caused by waterborne pathogens are making a comeback even in industrialized nations.

In the past five or six decades, the number of large dams on the world’s rivers grew more than seven times, to more than 40,000 today. The mammoth Three Gorges Dam across China’s Yangtze River, completed in 2006, created a 660-km-long serpentine lake behind it. The dam displaced more than 1 million people and may force the relocation of another 4 million from the reservoir region, which, at 58,000 km², is larger than Switzerland. The dam has greatly altered ecosystems on the Yangtze’s middle reaches, compounding perils already faced by prized and endemic fish and aquatic mammals. The sheer weight of the water and silt behind the concrete dam raises the risk of landslides and strains the region’s geological structure, while water released from the dam eats away at downstream banks and scours the bottom. And by slowing the flow of the Yangtze and nearby tributaries, the dam drains the river’s ability to flush out and detoxify pollutants from upstream industries.

Soil Depletion

Not just dirt, soil is a living system that makes it possible for raw elements from air, water, and bedrock to be physically and chemically assembled, disassembled, and reassembled with the aid of living macro- and microorganisms into the green cloak of life above ground. Accumulated over thousands of years, soil cannot be renewed in any time frame useful to humans alive today, or even to their great-grandchildren.

Humans degrade soils when they compact it, erode it, disrupt its organic and inorganic structure, turn it too salty for life, and cause desertification. Urbanization, logging, mining, overgrazing, alterations in soil moisture, air pollution, fires, chemical pollution, and leaching out of minerals all damage or destroy soils. Thanks to removal of vegetative cover, mining, agriculture, and other activities, the world’s topsoils are eroded by wind and water ten to hundreds of times faster than they are renewed (at roughly 10 tons ha⁻¹ year⁻¹).

Soils constitute the foundation of human agriculture, yet agriculture, including livestock raising, is the worst culprit in degrading soils. Agricultural practices have eroded or degraded more than 40% of present cropland. Over the last half century, some 24,000 villages in northern and western China have been overrun by the drifting sands of desertification. Besides topsoil erosion, the damage includes salting and saturation of poorly managed irrigated lands; compaction by heavy machinery and the hooves of livestock; and pollution from excessive fertilizers, animal wastes, and pesticides.

Living, dead, and decomposing organic matter is the key to soil structure and fertility. Soil depleted of organic matter is less permeable to water and air and thus less able to support either aboveground plants or soil organisms. The linkages between soil’s inorganic components and the soil biota – naturalist Wilson’s (1987) “little things that run the world” – are what give soil its life-sustaining capacity. A clear-cut forest patch whose soil biota has been damaged beyond recovery can no longer sustain trees, no matter how many are planted; another clear-cut patch whose soil community is intact – especially the close associations among fungi and tree roots – will support new tree growth. Destroying soil biota unleashes a whole series of impoverishing biotic effects both below and above ground.

Chemical Contamination

In 1962, Rachel Carson’s landmark book, Silent Spring, alerted the world to the pervasiveness of synthetic chemicals produced since World War II. As many as 100,000 synthetic chemicals are in use today. True to one company’s slogan, many of these have brought ‘better living through chemistry,’ providing new fabrics and lighter manufacturing materials, antibiotics, and life-saving drugs.

But industrial nations have carelessly pumped chemicals into every medium. Chemicals – as varied as prescription drugs flowing out of sewage plants, pesticides, heavy metals, and cancer-causing by-products of countless manufacturing processes – now lace the world’s water, soil, and air and the bodies of all living things, including humans. Chemicals directly poison organisms; they accumulate in physical surroundings and are passed through and, in many cases, concentrated within portions of the food web. Chemicals cause cancer, interfere with hormonal systems, provoke asthma, and impair the functioning of immune systems. They have intergenerational effects, such as intellectual impairment in children whose mothers have eaten contaminated fish.
What’s more, over half a century of pesticide and antibiotic overuse has bred resistance to these chemicals among insects, plants, and microbes, giving rise to new and reemerging scourges.

Many chemicals travel oceanic and atmospheric currents to sites far from their source. Sulfur emissions from the US Midwest, for example, fall to earth again as acid rain in Europe, killing forests and so acidifying streams and lakes that they, too, effectively die. China’s burning of soft coal sends air pollution all the way to northwestern North America; the heavy haze hanging over China’s chief farming regions may be cutting agricultural production by a third. Chlorofluorocarbons (CFCs), once widely used as refrigerants, have damaged the atmospheric ozone layer, which moderates how much ultraviolet radiation reaches the Earth, and opened ozone holes over the Arctic and Antarctic.

But even more alarming is an unprecedented acidification of the oceans that has only recently attracted the attention of major scientific research consortiums. Acid added to the world ocean by human activity has lowered the ocean’s pH; it is lower now than it has been in 20 My, which translates into a 30% increase in sea-surface acidity since industrialization began. The future of marine life in an ocean acidifying at this speed and intensity looks bleak. As the concentration of hydrogen ions rises, the calcium carbonate in the shells or skeletons of organisms such as tropical corals, microscopic foraminifera, and mollusks begins to dissolve; further, more hydrogen ions combine with the calcium carbonate building blocks the organisms need, making it harder for them to extract this compound from the water and build their shells in the first place.

Although many of the most obviously deadly chemicals were banned in the 1970s, they continue to impoverish the biosphere. Polychlorinated biphenyls – stable, nonflammable compounds once used in electrical transformers and many other industrial and household applications – remain in the environment for long periods, cycling among air, water, and soils and persisting in the food web. They are found in polar bears and arctic villagers; they are implicated in reproductive disorders, particularly in such animals as marine mammals, whose long lives, thick fat layers where chemicals concentrate, and position as top predators make them especially vulnerable.

The agricultural pesticide DDT, sprayed with abandon in the 1940s and 1950s, even directly on children, had severely thinned wild birds’ eggshells by the time it was banned in the United States. Populations of birds such as the brown pelican and bald eagle had dropped precipitously by the 1970s, although they have recovered enough for the species to be taken off the US endangered species list, the bald eagle in 2007 and the brown pelican in 2009. Reproduction of central California populations of the California condor, in contrast, continues to be threatened by DDT breakdown products, which, 40 years after the pesticide was banned, are still found in the sea lion carcasses the birds sometimes feed on.

Carson’s book revealed the real danger of chemical pollutants: they have not simply perturbed the chemistry of water, soil, and air but harmed the biosphere as well. The list of chemicals’ effects on living things is so long that chemical pollution equals humans’ environmental impact in most people’s minds, yet it is just one form of biotic impoverishment.

**Altered Biogeochemical Cycles**

All the substances found in living things – such as water, carbon, nitrogen, phosphorus, and sulfur – cycle through ecosystems in biogeochemical cycles. Human activities modify or have the potential to modify all these cycles. Sometimes the results stem from changing the amount or the precise chemistry of the cycled substance; in other cases, humans change biogeochemical cycles by changing the biota itself.

Freshwater use, dams, and other engineering ventures affect the amount and rate of river flow to the oceans and increase evaporation rates, directly affecting the water cycle and indirectly impoverishing aquatic life. Direct human modifications of living systems also alter the water cycle. In South Africa, European settlers supplemented the treeless native scrub, or fynbos, with such trees as pines and Australian acacias from similar Mediterranean climates. But because these trees are larger and thirstier than the native scrub, regional water tables have fallen sharply.

Human activity has disrupted the global nitrogen cycle by greatly increasing the amount of nitrogen fixed from the atmosphere (combined into compounds usable by living things). The increase comes mostly from deliberate addition of nitrogen to soils as fertilizer but also as a by-product of the burning of fossil fuels. Agriculture, livestock raising, and residential yard maintenance chronically add tons of excess nutrients, including nitrogen and phosphorus, to soils and water.

The additions are often invisible; their biological impacts are often dramatic. Increased nutrients in coastal waters, for example, trigger blooms of toxic dinoflagellates – the algae that cause red tides, fish kills, and tumors and other diseases in varied sea creatures. When huge blooms of algae die, they fall to the seafloor, where their decomposition so robs the water of oxygen that fish and other marine organisms can no longer live there. With nitrogen concentrations in the Mississippi River two to three times as high as they were 50 years ago, a gigantic dead zone forms in the Gulf of Mexico every summer; in summer 2010 this dead zone covered 20,000 km².

The burning of fossil fuels is transforming the carbon cycle, primarily by raising the atmospheric concentration of carbon dioxide. With other greenhouse gases, such as methane and oxides of nitrogen, carbon dioxide helps keep Earth’s surface at a livable temperature and drives plant photosynthesis, but since the Industrial Revolution, atmospheric carbon dioxide concentrations have risen nearly 40% and are now widely thought to be disrupting the planet’s climate. In addition, the effects of catastrophic oil spills like the one that followed the April 2010 explosion of the Deepwater Horizon drilling rig in the Gulf of Mexico – and the effects of the chemicals used to disperse the resulting plumes of oil – may reverberate for decades.

**Global Climate Change**

In its 2007 report, written and reviewed by more than 3500 scientists, the Intergovernmental Panel on Climate Change (IPCC) concluded that climate warming was “unequivocal” (p. 2), that most of the average global warming over the previous 50 years was “very likely due to anthropogenic GHG emissions.”
Quammen (1996) likens our actions to starting with a greenhouse gas] increases” (p. 5), and that this warming has likely had “a discernible influence at the global scale on observed changes in many physical and biological systems” (p. 6).

The concentrations of heat-trapping gases in the atmosphere are at their highest level in more than 200,000 years. The 20th century in the Northern Hemisphere was the warmest of the past millennium; the first decade of the 21st century, and the first 7 months of 2010, were the warmest on record.

Higher global temperatures set in motion a whole series of effects, making the study of climate change, and of humans’ role in it, complex and controversial. Spring arrives at least 1 week earlier in the Northern Hemisphere. Polar glaciers and ice sheets are receding. The Arctic is warming twice as fast as the rest of the planet, and arctic sea ice melted at a near-record pace in 2010. With the sun heating the newly open water, winter refreezing will take longer, and the resulting thinner ice will melt more easily the following summer.

The large-scale circulation of global air masses is changing and, with them, the large-scale cycles in ocean currents, including the periodic warming and cooling in the tropical Pacific Ocean known as El Niño and La Niña. As a result, the distribution, timing, and amount of rain and snow are also changing, making the weather seem more unpredictable than ever. Unusually warm or cold winters, massive hurricanes like those that devastated the US Gulf Coast in 2005, and weather-related damage to human life and property are all predicted to increase with global warming. In the United States in 2005, weather-related damage totaled nearly $97 billion.

Where other nutrients are not limiting, rising carbon dioxide concentrations may enhance plant photosynthesis and growth. Rising temperatures may shift the ranges of many plants and animals – both wild and domestic – rearranging the composition and distribution of the world’s biomes, as well as those of agricultural systems. The resulting displacements will have far-reaching implications not only for the displaced plants and animals but also for the goods and services humans depend on from these living systems.

**Direct Depletion of Nonhuman Life**

From their beginnings as hunter-gatherers, humans have become highly efficient, machine-aided ecosystem engineers and predators. We transform the land so it produces what we need or want; we harvest the oceans in addition to reaping our own fields; we cover the land, even agricultural land, with sprawling cities. All these activities directly affect the ability of other life-forms to survive and reproduce. We deplete nonhuman life by eliminating some forms and favoring others; the result is a loss of genetic, population, and species diversity.

We are irreversibly homogenizing life on Earth, in effect exercising an unnatural selection that is erasing the diversity generated by millions of years of evolution by natural selection. One species is now determining which other species will survive, reproduce, and thereby contribute the raw material for future evolution.

**Overharvest of Renewable Resources**

In the 1930s, so many sardines were scooped from the waters off Monterey’s Cannery Row in California that the population collapsed, taking other sea creatures and human livelihoods with it; after rebounding somewhat in the first decade of the 2000s, the species has still not recovered fully. According to the US National Marine Fisheries Service, nearly 80% of commercially valuable fish of known status were overfished or fished to their full potential by 1993. Atlantic commercial fish species at their lowest levels in history include tuna, marlin, cod, and swordfish. Overfishing not only depletes target species but restructures entire marine food webs.

Marine mammals, including whales, seals, sea lions, manatees, and sea otters, were so badly depleted by human hunters that one species, Steller’s sea cow (*Hydrodamalis gigas*), went extinct; many other species almost disappeared. In the 19th century, Russian fur traders wiped out sea otters (*Enhydra lutris*) along the central California coast. With the otters gone, their principal prey, purple sea urchins (*Stronglyocentrotus purpuratus*), overran the offshore forests of giant kelp (*Macrocystis pyrifera*), decimating the kelp fronds and the habitat they provided for countless other marine creatures, including commercially harvested fishes. Thanks to five decades of protection, marine mammal populations began slowly recovering – only to face food shortages as regional marine food webs continue to unravel because of fishing, changing oceanic conditions, and contamination.

Timber harvest has stripped vegetation from the Amazonian rainforest to mountainsides on all continents, diminishing and fragmenting habitat for innumerable forest and stream organisms, eroding soils, worsening floods, and contributing significantly to global carbon dioxide emissions. In the Northern Hemisphere, 10% or less remains of old-growth temperate rainforests. The uniform stands of trees usually replanted after logging do not replace the diversity lost with the native forest, any more than monocultures of corn replace the diversity within native tallgrass prairies.

**Habitat Fragmentation and Destruction**

A great deal of human ecosystem engineering not only alters or damages the habitats of other living things but often destroys those habitats. Satellite-mounted remote-sensing instruments have revealed transformations of terrestrial landscapes on a scale unimaginable in centuries past. Together, cropland and pastures occupy 40% of Earth’s land surface. Estimates of the share of land wholly transformed or degraded by humans hover around 50%. Our roads, farms, cities, feedlots, and ranches either fragment or destroy the habitats of most large carnivorous mammals. Mining and oil drilling damage the soil, remove vegetation, and pollute marine areas. Grazing compacts soil and sends silt and manure into streams, where they harm stream life.

Landscapes that have not been entirely converted to human use have been cut into fragments. In *Song of the Dodo*, writer Quammen (1996) likens our actions to starting with a fine Persian carpet and then slicing it nearly into 36 equal pieces; even if we had the same square footage, we would not have 36 nice Persian rugs – only ragged, nonfunctional fragments. And in fact, we do not even have the original square footage because we have destroyed an enormous fraction of it.

Such habitat destruction is not limited to terrestrial environments. Human channelization of rivers may remove whole segments of riverbed. In the Kissimmee River of the US
state of Florida, for example, channelization in the 1960s transformed 165 km of free-flowing river into 90 km of canal, effectively removing 35 km of river channel and drastically altering the orphaned river meanders left behind.

Wetlands worldwide continue to disappear, drained to create shoreline communities for people and filled to increase cropland. The lower 48 United States lost 53% of their wetlands between the 1700s and mid-1800s. Such losses destroy major fish and shellfish nurseries, natural flood and pollution control, and habitat for countless plants and animals.

The mosaic of habitats in, on, or near the seafloor – home to 98% of all marine species – is also being decimated. Like clear-cutting of an old-growth forest, the use of large, heavy trawls dragged along the sea bottom to catch groundfish and other species flattens and simplifies complex, structured habitats such as gravel beds, coral reefs, crevices, and boulders and drastically reduces biodiversity. Studies reported on by the National Research Council of the US National Academy of Sciences have shown that a single tow can injure or destroy upward of two-thirds of certain bottom-dwelling species, which may still not have recovered after a year or more of no trawling.

Habitat fragmentation and destruction, whether on land or in freshwater and marine environments, may lead directly to extinction or isolate organisms in ways that make them extremely vulnerable to natural disturbances, climate change, or further human disturbance.

**Biotic Homogenization**

“The one process ongoing … that will take millions of years to correct,” Wilson (1994, p. 355) admonishes us, “is the loss of genetic and species diversity by the destruction of natural habitats. This is the folly our descendants are least likely to forgive us.” Both deliberately and unwittingly, humans are rearranging Earth’s living components, reducing diversity and homogenizing biotas around the world. The present, continuing loss of genetic diversity, of populations, and of species vastly exceeds background rates. At the same time, our global economy is transporting species worldwide at unprecedented scales.

The globe is now experiencing its sixth mass extinction, the largest since the dinosaurs vanished 65 Ma; present extinction rates are thought to be on the order of 100–1000 times those before people dominated Earth. According to the Millennium Ecosystem Assessment, a 5-year project begun in 2001 to assess the world’s ecosystems, an estimated 10–15% of the world’s species will be committed to extinction over the next 30 years. Approximately 20% of all vertebrates, including 33% of sharks and rays, are at risk of extinction.

At least one of every eight plant species is also threatened with extinction. Although mammals and birds typically receive the most attention, massive extinctions of plants, which form the basis of the biosphere’s food webs, undermine life-support foundations. The mutualistic relationships between animals and plants, particularly evident in tropical forests, mean that extinctions in one group have cascading effects in other groups. Plants reliant on animals for pollination or seed dispersal, for example, are themselves threatened by the extinction of the animal species they depend on. Not surprisingly, some scientists view extinction as the worst biological tragedy, but extinction is just another symptom of global biotic impoverishment.

Ever since they began to spread over the globe, people have transported other organisms with them, sometimes for food, sometimes for aesthetic reasons, and most often inadvertently. With the mobility of modern societies and today’s especially speedy globalization of trade, the introduction of alien species has reached epidemic proportions, causing some scientists to label it biological pollution.

Aliens – zebra mussels (*Dreissena polymorpha*) and tamarisks, or saltcedar (*Tamarix spp.*), in North America; the Red Sea sea jelly *Rhopilema nomadica* and the common aquarium alga *Caulerpa taxifolia* now choking the Mediterranean Sea; and Leidy’s comb jelly (*Mnemiopsis leidyi*) of northeastern America in the Black Sea, to name just a few – are present everywhere, and they usually thrive and spread at the expense of native species. On many islands, for example, more than half the plant species are not native, and in many continental areas the figure reaches 20% or more.

The costs of such invasions, in both economic and ecological terms, are high. In the United States, for example, annual economic losses due to damage by invasive species or the costs of controlling them exceed $137 billion per year – $40 billion more than the nation’s losses from weather-related damage in 2005. Furthermore, alien invasions cause extinctions and, when added to other extinctions and the deliberate monocultures of agricultural crops, homogenize biotas still more. Introduced species are fast catching up with habitat fragmentation and destruction as the major engines of ecological deterioration.

**Genetic Engineering**

Humans have been manipulating their crop plants and domesticated animals for 10,000 years or so – selecting seeds or individuals and breeding and cross-breeding them. The goal was something better, bigger, tastier, harder, or all of the above; success was sometimes elusive, but the result was crop homogenization. Of the myriad strains of potatoes domesticated by South American cultures, for example, only one was accepted and cultivated when potatoes first made it to Europe. The new crop made it possible to feed more people from an equivalent area of land and initially staved off malnutrition. But the strain succumbed to a fungal potato blight in the 1800s. Had more than one strain been cultivated, the tragic Irish potato famines might have been averted.

In the last few decades of the 20th century, people began to manipulate genes directly using the tools of molecular biotechnology, even cloning sheep and cows from adult body cells. US farmers routinely plant their fields with corn whose genetic material incorporates a bacterial gene resistant to certain pathogens. More than 40 genetically altered crops have been approved for sale to US farmers since 1992, with genes borrowed from bacteria, viruses, and insects. The United States accounts for nearly two-thirds of biotechnology crops planted globally. Worldwide in 2003, 67.6 million hectares in 18 countries on six continents were planted with genetically modified crops, as compared with 1.7 million hectares in six countries in 1996 – a 40-fold expansion in 8 years.

Biotechnologists focus on the potential of this new-millennium green revolution to feed the growing world
population, which has added almost 1 billion people in the past decade alone. But other scientists worry about unknown human and ecological health risks; these concerns have stirred deep scientific and public debate, especially in Europe, akin to the debate over pesticides in Rachel Carson’s time.

One worrisome practice is plant genetic engineers’ technique of attaching the genes they want to introduce into plants to an antibiotic-resistant gene. They can then easily select plants that have acquired the desired genes by treating them with the antibiotic, which kills any nonresistant plants. Critics worry that the antibiotic-resistant genes could spread to human pathogens and worsen an already growing antibiotic-resistance problem. Another concern arises from allergies humans might have or develop in response to genetically modified foods.

Although supporters of genetic engineering believe that genetically altered crops pose few ecological risks, ecologists have raised a variety of concerns. Studies in the late 1990s indicated that pollen from genetically engineered Bt corn can kill monarch butterfly caterpillars. Bt is a strain of bacterium that has been used since the 1980s as a pesticidal spray; its genes have also been inserted directly into corn and other crops. Ecologists have long worried that genetically engineered plants could escape from fields and cross-breed with wild relatives. Studies in radishes, sorghum, canola, and sunflowers found that genes from an engineered plant could jump to wild relatives through interbreeding. The fear is that a gene conferring insect or herbicide resistance might spread through wild plants, creating invasive superweeds that could potentially lower crop yields and further disturb natural ecosystems.

In fact, herbicide-resistant turf grass tested in Oregon in 2006 did escape and spread, and transgenic canola has been appearing throughout the US state of North Dakota, which has tens of thousands of hectares in conventional and genetically modified canola. According to the scientists who discovered the transgenic escapees growing in North Dakota – far from any canola field – the plants are likely to be cross-pollinating in the wild and swapping introduced genes; the plants’ novel gene combinations indicate that the transgenic traits are stable and evolving outside of cultivation.

Genetically engineered crops do confer some economic and environmental benefits: for farmers, higher yields, lower costs, savings in management time and gains in flexibility; for the environment, indirect benefits from using fewer pesticides and herbicides. But it is still an open question whether such benefits outweigh the potential ecological risks or whether the public will embrace having genetically modified foods as staples in their diet.

**Direct Degradation of Human Life**

Human biotic impacts are not confined to other species; human cultures themselves have suffered from the widening circles of indirect and direct effects humans have imposed on the rest of nature. Over the past hundred years, human technology has cut both ways with regard to public health. Wonder drugs controlled common pathogens at the same time that natural selection strengthened those pathogens’ ability to resist the drugs. Reservoirs in the tropics made water supplies more reliable for humans but also created ideal environments for human parasites. Industrialization exposed human society to a remarkable array of toxic substances.

Although man’s inhumanity to man has been both fact and the subject of discourse for thousands of years, the discussions have mostly been removed from any environmental context. Few people today regard social ills as environmental impacts or humans as part of a biota. But diminished societal well-being – whether manifest in high death rates or poor quality of life – shares many of its roots with diminished nonhuman life as a form of biotic impoverishment.

**Emerging and Reemerging Diseases**

The intersection of the environment and human health is the core of the discipline known as environmental health. Among the environmental challenges to public health are the direct effects of toxic chemicals; occupational health threats, including exposures to hazardous materials on the job; and sanitation and disposal of hazardous wastes.

Exploitation of nonrenewable natural resources – including coal mining, rock quarrying or other mining operations, and petroleum extraction and refining – often chronically impairs workers’ health and shortens their lives. Farmworkers around the world suffer long-term ills from high exposures to pesticides and herbicides. Partly because of increased air pollution, asthma rates are rising, particularly in big cities. Synthetic volatile solvents are used in products from shoes to semiconductors, producing lung diseases and toxic wastes. Nuclear weapons production starting in World War II, and associated contamination, have been linked to a variety of illnesses, including syndromes neither recognized nor understood at the time and whose causes were not diagnosed until decades afterward. The grayish metal beryllium, for example, was used in weapons production and was found decades later to scar the lungs of workers and people living near toxic waste sites.

Infectious diseases have challenged human populations throughout history, playing a significant role in their evolution and cultural development over the past 10,000 years, with 75% of human diseases linked to wildlife or domestic animals. The 20th century brought major successes in eradicating such infectious diseases as smallpox, polio, and many waterborne illnesses. But toward the century’s end, emerging and reemerging diseases were again reaching pandemic proportions.

Infectious diseases thought to be on the wane – including tuberculosis, malaria, cholera, diphtheria, leptospirosis, encephalitis, and dengue fever – have begun a resurgence. In addition, seemingly new scourges – Ebola virus, hantavirus, HIV/AIDS, Lyme disease, and West Nile fever – are also spreading, often, it appears, from wild animal hosts to humans as people encroach further upon previously undisturbed regions. A number of studies over the decade before 2010 show complex connections between biodiversity and disease: biodiversity loss often increases disease transmission, as in Lyme disease and West Nile fever, but diverse ecosystems also serve as sources of pathogens. Overall, however, the studies indicate that preserving intact ecosystems and their endemic biodiversity often reduces the prevalence of infectious diseases.
Human migrations – including their modern incarnation through air travel – also accelerate pathogen traffic and launch global pandemics, such as the 2003 outbreak of severe acute respiratory syndrome and the 2009 swine flu outbreak caused by the H1N1 virus. Even something as simple and apparently benign as lighting can become an indirect agent of disease. Artificial lighting, especially in the tropics, for example, can alter human and insect behavior in ways that speed transmission of insect-borne diseases, such as Chagas’s disease, malaria, and leishmaniasis.

In addition, especially in highly developed countries such as the United States, diseases of affluence and overconsumption are taking a toll. Heart disease is the number one cause of death in the United States; overnutrition, obesity, and diabetes due to sedentary, technology-driven lifestyles, particularly among children, are chronic and rising. One estimate put the share of US children considered overweight or obese at one in three. This rise in obesity rates has been stunningly rapid. As recently as 1980, just 15% of adults were obese; by 2008 the rate had hit 34%, and two-thirds of Americans are now considered either overweight or obese.

**Loss of Cultural Diversity**

Although not conventionally regarded as elements of biodiversity, human languages, customs, agricultural systems, technologies, and political systems have evolved out of specific regional environments. Like other organisms’ adaptive traits and behaviors, these elements of human culture constitute unique natural histories adapted, like any natural history, to the biogeographical context in which they arose. Yet modern technology, transportation, and trade have pushed the world into a globalized culture, thereby reducing human biological and cultural diversity.

Linguists, for example, are predicting that at least half of the 7000 languages spoken today will become extinct in the 21st century. With the spread of Euro-American culture, unique indigenous human cultures, with their knowledge of local medicines and geographically specialized economies, are disappearing even more rapidly than the natural systems that nurtured them. This loss of human biodiversity is in every way as troubling as the loss of nonhuman biodiversity.

**Reduced Quality of Life**

The effects of environmental degradation on human quality of life are another symptom of biotic impoverishment. Food availability, which depends on environmental conditions, is a basic determinant of quality of life. Yet according to the World Health Organization, nearly half the world’s population suffers from one of two forms of poor nutrition: undernutrition or overnutrition. A big belly is now a symptom shared by malnourished children, who lack calories and protein, and overweight residents of the developed world, who suffer clogged arteries and heart disease from eating too much.

Independent of race or economic class, declining quality of life in today’s world is manifest in symptoms such as increased asthma in the United States caused by environmental contaminants and the high disease rates in the former Soviet Bloc after decades of unregulated pollution. Even with explicit legal requirements that industries release information on their toxic emissions, many people throughout the world still lack both information and the decision-making power that would give them any control over the quality of their lives.

Aggrieved about the degraded environment and resulting quality of life in his homeland, Ogoni activist Ken Saro-Wiwa issued a statement shortly before he was executed by the Nigerian government in 1995 saying, “The environment is man’s first right. Without a safe environment, man cannot exist to claim other rights, be they political, social, or economic.” Kenyan Maathai (2009, p. 249), 2004 winner of the Nobel Peace Prize, has also written, “[If] we destroy it, we will undermine our own ways of life and ultimately kill ourselves. This is why the environment needs to be at the center of domestic and international policy and practice. If it is not, we don’t stand a chance of alleviating poverty in any significant way.”

Having ignored this kind of advice for decades, nations are seeing a new kind of refugee attempting to escape environmental degradation and desperate living conditions; the number of international environmental refugees exceeded the number of political refugees around the world for the first time in 1999. Environmental refugees flee homelands devastated by flooding from dam building, extraction of mineral resources, desertification, and unjust policies of national and international institutions. Such degradation preempts many fundamental human rights, including the rights to health, livelihood, culture, privacy, and property.

People have long recognized that human activities that degrade environmental conditions threaten not only the biosphere but also humans’ own quality of life. As early as 4500 years ago in Mesopotamia and South Asia, writings revealed an awareness of biodiversity, of natural order among living things, and of consequences of disrupting the biosphere. Throughout history, even as civilization grew increasingly divorced from its natural underpinnings, writers, thinkers, activists, and people from all walks of life have continued to see and extol the benefits of nature to humans’ quality of life.

Contemporary society still has the chance to relearn how important the environment is to quality of life. It is encouraging that the United Steelworkers of America in 1990 issued a report recognizing that protecting steelworker jobs could not be done by ignoring environmental problems and that the destruction of the environment may pose the greatest threat to their children’s future. It is also encouraging that the 2007 Nobel Peace Prize was awarded to a political figure and a group of scientists for their work on climate change.

**Environmental Injustice**

Making a living from nature’s wealth has consistently opened gaps between haves and have-nots, between those who bear the brunt of environmental damage to their home places and those who do not, and between the rights of people alive now and those of future generations; these disparities too are part of biotic impoverishment. Inequitable access to “man’s first right” – a healthy local environment – has come to be known as environmental injustice.

Environmental injustices, such as institutional racism, occur in industrial and nonindustrial nations. Injustice can be overt, as when land-use planning sites landfills, incinerators, and hazardous waste facilities in minority communities, or when environmental agencies levy fines for hazardous waste
violations that are lower in minority communities than in white communities.

Less overt, but no less unjust, is the harm done to one community when unsound environmental practices benefit another, as when clear-cut logging in the highlands of northwestern North America benefits logging communities while damaging the livelihoods of lowland fishing communities subjected to debris flows, sedimentation, and downstream flooding.

The plight of the working poor and the disparities between rich and poor are also examples of biotic impoverishment within the human community. According to the United Nations Research Institute for Social Development, the collective wealth of the world’s 358 billionaires equaled the combined income of the poorest 2.4 billion people in 1994. *Forbes Magazine* put the number of billionaires in early 2010 at 1011, with a total worth of $3.6 trillion.

In the United States during the last decade of the 20th century, the incomes of poor and middle-class families stagnated or fell, despite a booming stock market. The Center on Budget and Policy Priorities and the Economic Policy Institute reported that between 1988 and 1998, earnings of the poorest fifth of American families rose less than 1%, while earnings of the richest fifth jumped 15%. By the middle of the first decade of the 21st century, Americans’ income inequality had become the widest among industrialized nations, with the wealthiest 20% of the population holding 85% of the wealth. The wealthiest Americans continued to prosper even during the global recession late in that decade, while the less well-off kept losing ground.

But perhaps the grossest example of human and environmental domination leading to continued injustice is the creation of a so-called third world to supply raw materials and labor to the dominant European civilization after 1500 and the resulting schism between today’s developed and developing nations. Developing regions throughout the world held tremendous stores of natural wealth, some of it – like petroleum – having obvious monetary value in the dominant economies and some having a value invisible to those economies – like vast intact ecosystems. A 2010 United Nations study (TEEB) estimated that even today, Earth’s ecosystems – like vast intact ecosystems. A 2010 United Nations study (TEEB) estimated that even today, Earth’s ecosystems had tremendous stores of natural wealth, some of it – like petroleum – having obvious monetary value in the dominant economies and some having a value invisible to those economies – like vast intact ecosystems. A 2010 United Nations study (TEEB) estimated that even today, Earth’s ecosystems had tremendous stores of natural wealth, some of it – like petroleum – having obvious monetary value in the dominant economies and some having a value invisible to those economies – like vast intact ecosystems. A 2010 United Nations study (TEEB) estimated that even today, Earth’s ecosystems had tremendous stores of natural wealth, some of it – like petroleum – having obvious monetary value in the dominant economies and some having a value invisible to those economies – like vast intact ecosystems. A 2010 United Nations study (TEEB) estimated that even today, Earth’s ecosystems accounted for roughly half to 90% of the source of livelihoods for rural and forest-dwelling peoples; the study calls this value the gross domestic product (GDP) of the poor.

Dominant European civilizations unabashedly exploited this natural wealth and colonized or enslaved the people in whose homelands the wealth was found. But the dominant civilizations also exported their ways of thinking and their economic models to the developing world, not only colonizing places but also effecting what Wangari Maathai has called a colonization of the mind. Although dominant 21st century society tends to dismiss ancient wisdom as irrelevant in the modern world, perhaps the cruelest impoverishment of all is the cultural and spiritual deracination experienced by exploited peoples worldwide.

Exploitation of poor nations and their citizens by richer, consumer countries – and in many cases by the same governments that fought for independence from the colonists while adopting the colonists’ attitudes and economic models – persists today in agriculture, wild materials harvesting, and textile and other manufacturing sweatshops. In the mid-1990s, industrial countries consumed 86% of the globe’s aluminum, 81% of its paper, 80% of its iron and steel, 75% of its energy, and 61% of its meat; they are thus responsible for most of the environmental degradation associated with producing these goods. Most of the actual degradation, however, still takes place in developing nations.

As a result, continuing environmental and social injustice – environmental and social impoverishment perpetrated by outsiders and insiders alike – pervades developing nations. Such impoverishment can take the form of wrenching physical dislocation like the massive displacements enforced by China’s Three Gorges Dam. It can appear as environmental devastation of homelands and murder of the people who fought to keep their lands, as in the Nigerian government–backed exploitation of Ogoniland’s oil reserves by the Shell Petroleum Development Corporation. After Saro-Wiwa’s execution, the Ogoni were left, without a voice, to deal with a scarred and oil-polluted landscape.

Despite great advances in the welfare of women and children over the past century, poverty still plagues both groups. Children from impoverished communities, even in affluent nations, suffer from the lethargy and impaired physical and intellectual development known as failure to thrive. Poverty forces many children to work the land or in industrial sweatshops; lack of education prevents them from attaining their intellectual potential. This impoverishment in the lives of women and children is as much a symptom of biotic impoverishment as are deforestation, invasive alien organisms, or species extinctions.

Little by little, community-based conservation and development initiatives are being mounted by local citizens to combat this impoverishment: Witness Maathai’s Green Belt Movement, which began with tree planting to restore community landscapes and provide livelihoods for residents, and the rise of ecotourism and microlending (small loans made to individuals, especially women, to start independent businesses) as ways to bring monetary benefits directly to local people without further damaging their environments. Ultimately, one could see all efforts to protect the ethnosphere and the biosphere as a fight for the rights of future generations to an environment that can support them.

**Political Instability**

Only during the last two decades of the 20th century did environmental issues find a place on international diplomatic agendas, as scholars began calling attention to – and governments began to see – irreversible connections between environmental degradation and national security. British scholar Myers (1993), noting that environmental problems were likely to become predominant causes of conflict in the decades ahead, was one of the first to define a new concept of environmental security. National security threatened by unprecedented environmental changes irrespective of political boundaries will require unprecedented responses altogether different from military actions, he warned. Nations cannot deploy their armies to hold back advancing deserts, rising seas, or the greenhouse effect.
Canadian scholar Homer-Dixon (1999) showed that environmental scarcities – whether created by ecological constraints or sociopolitical factors including growing populations, depletion of renewable resources such as fish or timber, and environmental injustice perpetrated by one segment of a population on another – were fast becoming a permanent, independent cause of civil strife and ethnic violence. He found that such scarcity was helping to drive societies into a self-reinforcing spiral of dysfunction and violence, including terrorism. Environmental and economic injustices worldwide leave no country immune to this type of threat.

Typically, diplomacy has stalled in conflicts over natural resources: arguments over water rights have more than once held up Israeli-Palestinian peace agreements; fights over fish erupted between Canada and the United States, Spain, and Portugal. In contrast, in adopting the Montreal Protocol on Substances That Deplete the Ozone Layer in 1987, governments, nongovernmental organizations, and industry successfully worked together to safeguard part of the environmental commons. The treaty requires signatory nations to curb their use of CFCs and other ozone-destroying chemicals and has been, according to former United Nations secretary general Kofi Annan, perhaps the most successful international agreement to date.

**Cumulative Effects**

If scientists have learned anything about the factors leading to biotic impoverishment, they have learned that the factors’ cumulative effects can take on surprising dimensions. As scholars like Fagan (1999) and Diamond (2005) have chronicled, the multiple stresses of global climatic cycles such as El Niño, natural events like droughts or floods, resource depletion, and social upheaval have shaped the fates of civilizations.

Societies as far-flung as ancient Egypt, Peru, the American Southwest, and Easter Island prospered and collapsed because of unwise management of their environments. The city of Ubar, built on desert sands in what is now southern Oman, literally disappeared into the sinkhole created by drawing too much water out of its great well. In modern Sahelian Africa, a combination of well digging and improved medical care and sanitation led to a threefold population increase; sedentary ways, heavy taxes imposed by a colonial government, and an impoverished people took the place of a nomadic culture evolved within the desert’s realities.

During the first decade of the 21st century, numerous natural disasters befell nations around the world: wildfires in Australia, Bolivia, Canada, and Russia; flooding in China, India, Romania, and West Africa; devastating hurricanes and typhoons in the Caribbean, Philippines, Taiwan, and southeastern United States; catastrophic landslides and floods in China, Guatemala, Pakistan, and Portugal; and destructive earthquakes in Chile, China, Haiti, Indonesia, and Pakistan. Neither the rains nor the earthquakes were caused by human activity, but the cumulative effects of human land uses and management practices – from dikes separating the Mississippi from its floodplain to deforestation in Haiti – made the losses of human life and property much worse than they might have been otherwise.

**Root Causes of Human Impact**

The ultimate cause of humans’ massive environmental impact is our individual and collective consumptive and reproductive behavior, which has given us spectacular success as a species. But the very things that enabled humans to thrive in nearly every environment have magnified our impacts on those environments, and the technological and political steps we take to mitigate our impacts often aggravate them. Too many of us simply take too much from the natural world and ask it to absorb too much waste.

**Fragmented Worldviews, Fragmented Worlds**

For most of human history, people remained tied to their natural surroundings. Even as agriculture, writing, and technology advanced, barriers of geography, language, and culture kept humans a diverse lot, each group depending on mostly local and regional knowledge about where and when to find resources necessary for survival. Their worldviews, and resulting economies, reflected this dependency.

For example, in northwestern North America starting about 3000 years ago, a native economy centered on the abundance of salmon. At its core was the concept of the gift and a belief system that treated all parts of the Earth – animate and inanimate – as equal members of a community. In this and other ancient gift economies, a gift was not a possession that could be owned; rather, it had to be passed on, creating a cycle of obligatory returns. Individuals or tribes gained prestige through the size of their gifts, not the amount of wealth they accumulated.

This system coevolved with the migratory habits of the salmon, which moved en masse upriver to spawn each year. Because the Indians viewed salmon as equals to themselves, killing salmon represented a gift of food from salmon to people. Fishers were obligated to treat salmon with respect or risk losing this vital gift. The exchange of gifts between salmon and humans – food for respectful treatment – minimized waste and overharvest and ensured a continuous supply of food. Further, the perennial trading of gifts among the people effectively redistributed the natural wealth brought each year by fluctuating populations of migrating fish, leveling out the boom-and-bust cycles that usually accompany reliance on an uncertain resource.

In modern times, the gift economy along with the egalitarian worldview that accompanied it, has been eclipsed by a redistributive economy tied not to an exchange of gifts with nature but to the exploitation of nature and to the technologies that enhance that exploitation. Nature became a resource for humans, rather than an equal to humans. In economic terms, natural resources fell under the heading of ‘land’ in an economic trinity comprising three factors of production: land, labor, and capital. Land and resources, including crops, became commodities – expendable or easily substitutable forms of capital – whose value was determined solely by their value in the human marketplace.

In 1776 Adam Smith published his famous Inquiry into the Nature and Causes of the Wealth of Nations, in which he argued that society is merely the sum of its individuals, that the social good is the sum of individual wants, and that the
market (the so-called invisible hand) automatically guides individual behavior to the common good. Crucial to his theories were division of labor and the idea that all the factors of production were freely mobile. His mechanistic views created an economic rationale for no longer regarding individuals as members of a community linked by ethical, social, and ecological bonds.

About the same time, fueling and fueled by the beginnings of the Industrial Revolution, the study of the natural world was morphing into modern physics, chemistry, geology, and biology. Before the mid-19th century, those who studied the natural world – early 19th century German biogeographer Baron Alexander von Humboldt and his disciple Charles Darwin among them – took an integrated view of science and nature, including humans. Both scientists regarded the understanding of the complex interdependencies among living things as the noblest and most important result of scientific inquiry.

But this integrated natural philosophy was soon supplanted by more atomistic views, which fit better with industrialization. Mass production of new machines relied on division of labor and interchangeable parts. Like automobiles on an assembly line, natural phenomena too were broken down into their supposed component parts in a reductionism that has dominated science ever since. Rushing to gain in-depth, specialized knowledge, science and society lost sight of the need to tie the knowledge together. Disciplinary specialization replaced integrative scholarship.

Neoclassical economics, which arose around 1870, ushered in the economic worldview that rules today. A good’s value was no longer tied to the labor required to make it but derived instead from its scarcity. A good’s price was determined only by the interaction of supply and demand. As part of ‘land,’ natural resources therefore became part of the human economy, rather than the material foundation making the human economy possible. Because of its doctrine of infinite substitutability, neoclassical economics rejects any limits on growth; forgotten are the classical economic thinkers and contemporaries of von Humboldt, including Thomas Malthus and John Stuart Mill, who saw limits to the growth of human population and material well-being.

Consequently, the 19th and 20th centuries saw the rise to dominance of economic indicators that fostered the economic invisibility of nature, misleading society about the relevance of Earth’s living systems to human well-being. Among the worst offenders in this regard are gross national product (GNP) and its cousin, GDP. GNP measures the value of goods and services produced by a nation’s citizens or companies, regardless of their location around the globe. GDP, in contrast, measures the value of goods and services produced within a country’s borders, regardless of who generates those goods and services.

In effect, both GNP and GDP measure money changing hands, no matter what the money pays for; they make no distinction between what is desirable and undesirable, between costs and benefits. Both indicators ignore important aspects of the economy like unpaid work or nonmonetary contributions to human fulfillment – parenting, volunteering, checking books out of the library. Worse, the indicators also omit social and environmental costs, such as pollution, illness, or resource depletion; they only add and do not subtract. GDP math adds in the value of paid daycare or a stay in the hospital and ignores the value of unpaid parenting or being cared for at home by friends. It adds in the value of timber sold, but fails to subtract the losses in biodiversity, watershed protection, or climate regulation that come when a forest is cut.

Efforts have been made in the past few decades to create less blinkered economic indicators. Social scientists Herman Daly and John Cobb in 1989 developed an index of sustainable economic welfare, which adjusts the United States’ GNP by adding in environmental good things and subtracting environmental bad things. Public expenditures on education, for example, are weighted as “goods” while costs of pollution cleanup, depletion of natural resources, and treating environment-related illnesses are counted as ‘bads.’ Unlike the soaring GDP of recent decades, this index of sustainable economic welfare remained nearly unchanged over the same period.

Still other work aims to reveal nature’s worth in monetary terms by assigning dollar values to ecological goods and services. A 1997 study by ecologist David Pimentel and colleagues calculated separate values for specific biological services, such as soil formation, crop breeding, or pollination; by summing these figures, these researchers estimated the total economic benefits of biodiversity for the United States at $319 billion – 5% of US GDP at the time – and for the world at $2928 billion. A 2000 analysis by Pimentel and colleagues reported that the approximately 50,000 nonnative species in the United States cause major environmental damage and reparation costs amounting to $137 billion a year.

As part of the United Nations International Year of Biodiversity in 2010, several studies have translated the value of the world’s ecosystems into dollar values. One report estimated the worth of crucial ecosystem services delivered to humans by living systems at $21–72 trillion per year – comparable to a world gross national income of $58 trillion in 2008. Another study reported, among other things, that as many as 500 million people worldwide depend on coral reefs – valued between $30 billion and $172 billion a year – for fisheries, tourism, and protection from ocean storms and high waves, services threatened by warmer and more acidic seas.

Although a monetary approach does not create a comprehensive indicator of environmental condition, it certainly points out that ecological values ignored by the global economy are enormous.

Too Many Consuming Too Much

The US Census Bureau predicts that by 2012, the global human population will top 7 billion – having grown by nearly 1 billion people during the decade between the first and second editions of this encyclopedia. From the appearance of H. sapiens about 200,000 years ago, it took humans until 1804 to reach their first billion, 123 years to double to 2 billion, and 33 years to achieve 3 billion. Human population doubled again from 3 to 6 billion in about 40 years – before most post-World War II baby boomers reached retirement age. Even with fertility rates declining in developed countries, China, and some developing countries where women are gaining education and economic power, and with pandemics like AIDS claiming more lives, the Census Bureau predicts that world population will reach 9 billion by 2044.
Humans appropriate about 40% of global plant production, 54% of Earth’s freshwater runoff, and enough of the ocean’s bounty to have depleted 63% of assessed marine fish stocks. In energy terms, one person’s food consumption amounts to 2500–3000 calories a day, about the same as that of a common dolphin. But with all the other energy and materials humans use, global per capita energy and material consumption have soared even faster than population growth over the past 50 years. Now, instead of coevolving with a natural economy, global society is consuming the foundations of that economy, impoverishing Earth’s living systems, and undermining the foundations of its own existence (Figure 1).

**Measuring Environmental Impacts**

For most of the 20th century, environmental measurements, or indicators, tracked primarily two classes of information: counts of activities directed at environmental protection and the supply of products to people. Regulatory agencies are typically preoccupied with legislation, permitting, or enforcement, such as the numbers of environmental laws passed, permits issued, enforcement actions taken, or treatment plants constructed. Resource protection agencies concentrate on resource harvest and allocation. Water managers, for example, measure water quantity; they allocate water to domestic, industrial, and agricultural uses but seldom make it a priority to reserve supplies for sustaining aquatic life, to protect scenic and recreational values, or simply to maintain the water cycle. Foresters, farmers, and fishers count board-feet of timber, bushels of grain, and tons of fish harvested. Governmental and nongovernmental organizations charged with protecting biological resources also keep counts of threatened and endangered species.

As in the parable of the three blind men and the elephant – each of whom thinks the elephant looks like the one body part he can touch – these or similar indicators measure only one aspect of environmental quality. Counting bureaucratic achievements focuses on actions rather than on information about real ecological status and trends. Measurements of resource supply keep track of commodity production, not necessarily a system’s capacity to continue supplying that commodity. And measuring only what we remove from natural systems, as if we were taking out the interest on a savings account, overlooks the fact that we are usually depleting principal as well.

Even biologists’ counts of threatened and endangered species – which would seem to measure biotic impoverishment directly – still focus narrowly on biological parts, not ecological wholes. Enumerating threatened and endangered species is just like counting any other commodity. It brings our attention to a system already in trouble, perhaps too late. And it subtly reinforces our view that we know which parts of the biota are most important.

Society needs to rethink its use of available environmental indicators, and it needs to develop new indicators that represent current conditions and trends in the systems humans depend on (Table 2). It particularly needs objective measures more directly tied to the condition, or health, of the environment so that people can judge whether their actions are compromising that condition.

Such measures should be quantitative, yet easy to understand and communicate; they should be cost-effective and applicable in many circumstances. Unlike narrow criteria tracking only administrative, commodity, or endangered species numbers, they should provide reliable signals about status and trends in ecological systems. Ideally, effective indicators should describe the present condition of a place, aid in diagnosing the underlying causes of that condition, and make predictions about future trends. They should reveal not only risks from present activities but also potential benefits from alternative management decisions.

Most important, these indicators should, either singly or in combination, give information explicitly about living systems. Measurements of physical or chemical factors can sometimes act as surrogates for direct biological measurements, but only when the connection between those measures and living systems is clearly understood. Too often we make assumptions – when water managers assume that chemically clean water equals a healthy aquatic biota, for example – that turn out to be wrong and fail to protect living systems.

**General Sustainability Indexes**

As environmental concerns have become more urgent – and governmental and nongovernmental organizations have struggled to define and implement the concept of sustainable development – the effort has grown to create indicator systems that explicitly direct the public’s and policymakers’ attention to the value of living things. Moving well past solely economic indexes like GDP, several indexes now integrate ecological, social, and economic well-being.

The index of environmental trends for nine industrialized countries, developed by the nonprofit National Center for Economic and Security Alternatives, incorporates ratings of air, land, and water quality; chemical and waste generation; and
**Table 2**  Plausible indicators of environmental quality

| Indirect depletion of living systems through alterations in physical and chemical environments |
|------------------------------------------------------------------------------------------|
| 1. Degradation of water (chemical contaminant concentrations, river flows, rainfall, runoff) |
| 2. Soil depletion (erosion rates, desertification rates, salt accumulation in soils)      |
| 3. Chemical contamination (pollutant and toxic emissions, pollutant and toxic concentrations in air, water, soil, and living organisms) |
| 4. Altered biogeochemical cycles (river flows and lake levels; amount of nutrients going into water bodies, or nutrient loading; nutrient concentrations in water bodies; chlorophyll concentrations, reflecting nutrient-triggered algal blooms; oxygen depletion in water bodies; trophic status of lakes; changes in air and soil chemistry; atmospheric greenhouse gas concentrations) |
| 5. Global climate change (atmospheric greenhouse gas concentrations, change in atmospheric temperatures, distribution and intensity of severe storms or droughts) |

**Direct depletion of nonhuman life**

1. Overharvest of renewable resources such as fish and timber (tons of fish harvested; for a given anadromous fish population, number of adult fish returning to rivers to spawn; hatchery fish released and recovered; board-feet of timber harvested; forest regrowth rates; quantity of standing timber; ecological footprints)

2. Habitat fragmentation and destruction (area of remaining grassland, wetland, and other habitats; landscape connectivity; rates of habitat destruction)

3. Biotic homogenization (number of extinct, threatened, and endangered taxonomic groups; spread of nonindigenous species; local or regional diversity; damage and repair costs due to invasions or extinctions; major relocations in species distributions)

4. Genetic engineering (diversity among cultivated crop strains, genetic diversity within strains, escape of genetically engineered organisms or traits to wild populations)

**Direct degradation of human life**

1. Emerging and reemerging diseases (death or infection rates caused by diseases, geographic spread of diseases, recovery rates, frequency and spread of resistance to antibiotics and other drugs)

2. Loss of cultural diversity ( extinction of cultures, death of languages)

3. Reduced quality of life (population size and growth; starvation, malnutrition, and obesity rates; infant mortality rates; teen pregnancy rates; literacy rates; rates of stress and other diseases of affluence; length of work week; child or other forced labor; changes in death rates or average life spans)

4. Environmental injustice (siting of toxic waste dumps or waste emissions relative to resident communities, economic exploitation of certain groups, worker strikes, wage and income gaps, unemployment rates for different economic sectors)

5. Political instability (frequency of domestic and international strife, environmental terrorism rates, number of environmental refugees, genocide)

6. Cumulative effects (frequency of catastrophic natural disasters; costs of weather-related property damage; human death tolls; government subsidies of environmentally destructive activities such as fishery overcapitalization, below-cost timber sales, water projects, and agricultural supports; replacement costs for ecological services; pricing that reflects environmental costs; “green” taxes; rise in polycultural agricultural practices; number of organic farms)

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4 These indicators have been or could be used to monitor status and trends in environmental quality, including dimensions of biotic impoverishment. Without a full spectrum of indicators, however, and without coupling them to direct measures of biological condition, only a partial view of the degree of biotic impoverishment will emerge.

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energy use since 1970. By its 1995 rankings, environmental quality in the United States had gone down by 22% since 1970, while Denmark had declined by 11%.

In 2000, world leaders, supported by the United Nations Development Programme, defined a set of eight millennium development goals to be attained by 2015, which combine poverty, education, employment, and environmental sustainability. They include human rights and health goals – such as universal primary education, gender equality, and combating AIDS and other diseases – as well as ensuring environmental sustainability. In the decade since the program began, progress has been made in reducing poverty; expanding educational opportunities for children, especially in Africa; slowing deforestation; and providing better water for many people, among others. But progress controlling climate change, halting biodiversity loss, and achieving gender equality has lagged.

A later environmental performance index spearheaded by Yale and Columbia universities ranks 163 countries on 25 performance indicators in 10 well-established policy categories to determine whether and how well countries are meeting established environmental goals. This index incorporates measurements addressing environmental stresses to human health plus ecosystem health and natural resource management, collectively referred to as ecosystem vitality. The categories representing environmental health include the environmental burden of disease and the effects of air and water quality on human health. Those representing ecosystem vitality include air and water resources for ecosystems; biodiversity and habitat; and climate change, among others.

Although hampered by data gaps and the inability to track changes in countries’ performance through time, the index provides a sense of countries’ relative performance with regard to the environmental challenges faced by all. Top performers in the 2010 rankings included Iceland, Switzerland, Costa Rica, and Sweden. The United States ranked 61st well below Japan and nations in the European Union.

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**Ecological Footprints**

A resource-accounting approach pioneered in the 1990s by geographers Rees and Wackernagel (1996) translates humans’ impact on nature, particularly resource consumption, into a metaphorical ecological footprint. This accounting estimates the area required by a city, town, nation, or other human community to produce consumed resources and absorb generated wastes; it then compares the physical area occupied by a city or country with the area required to supply that city or country’s needs. The 29 largest cities of Baltic Europe, for example, appropriate areas of forest, agricultural, marine, and wetland ecosystems that are at least 565–1130 times larger than the areas of the cities themselves.

According to the Global Footprint Network, national ecological footprints in 2010 ranged from a high of 10.7 hectares per person for the United Arab Emirates to 0.4 hectares per person for Timor-Leste and 0.6 for Afghanistan and Bangladesh. The United States’ ecological footprint – 8.0 hectares per person – tied for fourth among 152 nations with populations of at least 1 million. One-hundred and four of these nations operate under ecological deficits; that is, their
consumption exceeds the biological capacity of their lands and waters to provide needed resources and absorb their wastes. At their present rates of consumption, these nations are therefore overexploiting either their own resources or those of other nations.

By ecological footprint accounting, raising the nearly 7 billion people on Earth in the early 21st century to living standards – and thus ecological footprints – equal to those in the United States would require four planets more than the only one we have. Clearly, humans are consuming more resources, and discarding more waste, than Earth’s living systems can produce or absorb in a given time period. This gap is the global sustainability gap the world now faces.

Measuring the State of Living Systems

Most environmental indexes and accounting systems are still human centered; they still do not measure the condition of the biosphere itself. We may know that biodiversity’s services are worth huge sums of money and that our hometown’s ecological footprint is much bigger than the town’s physical footprint, but how do we know whether specific actions damage living systems or that other actions benefit them? How do we know if aggregate human activity is diminishing life on Earth? To answer this question, we need measures that directly assess the condition of living systems.

Biological assessment directly measures the attributes of living systems to determine the condition of a specific landscape. The very presence of thriving living systems – sea otters and kelp forests off the central California coast; salmon, orcas, and herring in Pacific Northwest waters; monk seals in the Mediterranean Sea – says that the conditions those organisms need to survive are also present. A biota is thus the most direct and integrative indicator of local, regional, or global ecological condition. Biological assessments give us a way to evaluate whether monetary valuations, sustainability indexes, and ecological footprints are telling the truth about human impact on the biosphere. Biological assessments permit a new level of integration because living systems, including human cultures, register the accumulated effects of all forms of degradation caused by human actions.

Direct, comprehensive biological monitoring and assessment has been done for many aquatic systems; measures are less developed for terrestrial systems. The index of biological integrity (IBI), for example, was developed in 1981 to assess the health of streams in the US Midwest and has since helped scientists, resource managers, and citizen volunteers understand, protect, and restore rivers in at least 67 countries worldwide (Karr 2006). Borrowing from the same page as more recent sustainability indexes, IBI takes the concept behind economic indexes like GDP or the consumer price index – that of multiple indicators integrated into a multimetric index – and applies it to animals and plants in bodies of water or other environments. The specific measurements (Table 3) are sensitive to a broad range of human effects in waterways, such as sedimentation, nutrient enrichment, toxic chemicals, physical habitat destruction, and altered flows. The resulting index combines the responses of biological parts such as species, as well as processes such as food web dynamics, to human actions.

| Table 3 | Biological attributes in two indexes of biological integrity |
|---------|----------------------------------------------------------|
| Benthic invertebrates | Fish |
| Total number of taxa | Number of native fish species |
| Number of mayfly taxa | Number of riffle-benthic insectivore species |
| Number of stonefly taxa | Number of water-column insectivore species |
| Number of caddisfly taxa | Number of pool-benthic insectivore species |
| Number of intolerant taxa | Number of intolerant species |
| Number of long-lived taxa | Relative abundance of omnivores |
| Number of intolerant species | Relative abundance of invertibrates |
| Relative abundance of tolerant taxa | Relative abundance of tolerant taxa |
| Relative abundance of predators | Relative abundance of top carnivores |
| Dominance | Relative abundance of diseased or deformed individuals |

Indexes of biological integrity have been developed for a number of aquatic and terrestrial environments; the most widely used indexes for assessing rivers examine fishes and benthic (bottom-dwelling) invertebrates. These groups are abundant and easily sampled, and the species living in virtually any water body represent a diversity of anatomical, ecological, and behavioral adaptations. As humans alter watersheds and water bodies, changes occur in taxonomic richness (biodiversity), species composition (which species are present), individual health, and feeding and reproductive relationships.

Sampling the inhabitants of a stream can tell us much about that stream and its landscape. Biological diversity is higher upstream of wastewater treatment plants than downstream, for example, whereas, at the same location, year-to-year variation is low (Figure 2). Biological sampling can also reveal differences between urban and rural streams. For instance, samples of invertebrates from one of the best streams in rural King County, in the US state of Washington, contain 27 kinds, or taxa, of invertebrates; similar samples from an urban stream in the city of Seattle contain only 7. The rural stream has 18 taxa of mayflies, stoneflies, and caddisflies; the urban stream, only 2 or 3. When these and other metrics are combined in an index based on invertebrates, the resulting benthic IBI (B-IBI) ranks the condition, or health, of a stream numerically (Table 4).

A benthic IBI can also be used to compare sites in different regions. Areas in Wyoming’s Grand Teton National Park where human visitors are rare have near-maximum B-IBIs. Streams with moderate recreation taking place in their watersheds have B-IBIs that are not significantly lower than those with no human presence, but places where recreation is heavy are clearly damaged. Urban streams in the nearby town of Jackson are even more degraded, yet not as bad as urban streams in Seattle.

Nation-specific biological assessments also can be and are being done. The US Environmental Protection Agency (2006), for example, performed a nationwide survey of stream condition using an IBI-like multimetric index. The survey found that 28% of US stream miles were in good condition in
comparison with least-disturbed reference sites in their regions, 23% were in fair condition, and 42% were in poor condition (5% were not assessed). The agency has been expanding this effort to include other water resource types, including coastal waters, coral reefs, lakes, large rivers, and wetlands.

Since 2000, the Heinz Center (2008) has published two editions of its report on the state of US ecosystems, which seek to capture a view of the large-scale patterns, conditions, and trends across the United States. The center defined and compiled a select set of indicators – specific variables tracking ecosystem extent and pattern, chemical and physical characteristics, biological components, and goods and services derived from the natural world – for six key ecosystems: coasts and oceans, farmlands, forests, fresh waters, grasslands and shrublands, and urban and suburban landscapes.

Among the many conclusions of the 2008 report were that the acreage burned every year by wildfires was on the increase; nonnative fish had invaded nearly every watershed in the lower 48 states; and chemical contaminants were found in virtually all streams and most groundwater wells, often at levels above those set to protect human health or wildlife. On the plus side, ecosystems were increasing their storage of carbon, soil quality was improving, and crop yields had grown significantly.

The massive international UN Millennium Ecosystem Assessment (2005) remains the gold standard for synthesizing ecological conditions at a variety of scales. From 2001 through 2005, the project examined the full range of global ecosystems – from those relatively undisturbed, such as natural forests, to landscapes with mixed patterns of human use to ecosystems intensively managed and modified by humans, such as agricultural land and urban areas – and communicated its findings in terms of the consequences of ecosystem change for human well-being.

The resulting set of reports drew attention to the many kinds of services people derive from ecosystems, specifically, supporting services, such as photosynthesis, soil formation, and waste absorption; regulating services, such as climate and flood control and maintenance of water quality; provisioning services, such as food, wood, and nature's pharmacopoeia;

![Figure 2](a) Biodiversity is higher at sites upstream of wastewater treatment outfalls than downstream. At Tickle Creek near Portland, Oregon (United States), taxa richness differed little between years but differed dramatically between sites upstream of a wastewater outfall and sites downstream. (b) Taxa richness also differed between two creeks with wastewater outfalls (Tickle and North Fork Deep) and one creek without an outfall (Foster). All three streams flowed through watersheds with similar land uses.

![Table 4](Biological responses to different land uses)

| Region                        | Land use                              | B-IBI<sup>a</sup> |
|-------------------------------|---------------------------------------|-------------------|
| King County, Washington, USA  | Rural                                 | 46                |
|                               | Urban Seattle                         | 12                |
| Grand Teton Region, Wyoming, USA | Little or no human activity           | 48                |
|                               | Light to moderate recreation          | 44                |
|                               | Heavy recreation                      | 32                |
|                               | Urban Jackson Hole                    | 21                |
| Clackamas County, Oregon, USA<sup>b</sup> | Upstream of wastewater treatment plant |                   |
|                               | Tickle Creek up (1997, 1998)          | 40, 42            |
|                               | Foster Creek                          | 34                |
|                               | Downstream of wastewater treatment plant |                   |
|                               | Tickle Creek down (1997, 1998)        | 14, 16            |
|                               | North Fork Deep Creek                 | 10                |

<sup>a</sup>Benthic index of biological integrity; the highest possible score is 50, the lowest is 10.

<sup>b</sup>See Fig. 2 for graphs of selected B-IBI metrics at these sites.
and cultural services from scientific to spiritual. In addition, the reports explicitly tied the status of diverse ecosystems and their capacity to provide these services to human needs as varied as food and health, personal safety and security, and social cohesion. Even while recognizing that the human species is buffered against ecological changes by culture and technology, the reports highlighted our fundamental dependence on the flow of ecosystem services and our direct responsibility for the many faces of biotic impoverishment.

Among other findings, the assessment found that 60% of the services provided by ecosystems are being degraded at levels that derail efforts to stem poverty, hunger, and disease among the poor everywhere. Government subsidies that provide incentives to overharvest natural resources are a leading cause of the decline in renewable natural resources. Such declines are not limited to coral reefs and tropical forests, which have been on the public’s radar for some time; they are pervasive in grasslands, deserts, mountains, and other landscapes as well. Moreover, the degradation of ecosystem services could grow worse during the first half of the 21st century, effectively blocking achievement of the United Nations’ eight millennium development goals.

The core message embodied in ecological, especially biological, assessments is that preventing harmful environmental impacts goes beyond narrow protection of clean water or clear skies, even beyond protecting single desired species. Certain species may be valuable for commerce or sport, but these species do not exist in isolation. We cannot predict which organisms are vital for the survival of commercial species or species we want for other reasons. Failing to protect all organisms – from microbes and fungi to plants, invertebrates, and vertebrates – ignores the key contributions of these groups to healthy biotic communities. No matter how important a particular species is to humans, it cannot persist outside the biological context that sustains it. Direct biological assessment objectively measures this context and is fundamental to advancing the kinds of syntheses like those of the Millennium Ecosystem Assessment.

### Recognizing and Managing Environmental Impacts

Every animal is alert to dangers in its environment. A microscopic protozoan gliding through water responds to light, temperature, and chemicals in its path, turning away at the first sign of something noxious. A bird looking for food must decide when to pursue prey and when not, because pursuit might expose the bird to predators. The bird might risk pursuit when it is hungry but not when it has young to protect. Animals that assess risks properly and adjust their behavior are more likely to survive; in nature, flawed risk assessment often means death or the end of a genetic line.

Humans, too, are natural risk assessors. Each person chooses whether to smoke or drink, fly or take the train, drive a car or ride a motorcycle and at what speeds. Each decision is the result of a partially objective, partially subjective internal calculus that weighs benefits and risks against one another.

Risk is a combination of two factors: the numerical probability that an adverse event will occur and the consequences of the adverse event. People may not always have the right signals about these two factors, however, and may base their risk calculus on the wrong clues. City dwellers in the United States generally feel that it is safer to drive home on a Saturday night than to fly in an airplane, for example. Even though the numerical odds of an accident are much higher on the highway than in the air, people fear more the consequences of an airplane falling out of the sky.

Human society also strives to reduce its collective exposure to risks. Governments seldom hesitate to use military power to defend their sovereignty or, albeit more reluctantly, their regulatory power to reduce workplace risks and risks associated with consumer products like automobiles. But people and their governments have been much less successful in defining and reducing a broad range of ecological risks, largely because they have denied that the threats are real.

Policies and plans generated by economists, technologists, engineers, and even ecologists typically assume that the lost and damaged components of living systems are unimportant or can be repaired or replaced. Widespread ecological degradation has resulted directly from the failure of modern society to properly assess the ecological risks it faces. Like the fate of Old Kingdom Egypt or Easter Island, our civilization’s future depends on our ability to recognize this deficiency and correct it.

Risk assessment as formally practiced by various government agencies began as a way to evaluate the effects of toxic substances on human health, usually the effects of single substances, such as pollutants or drugs, from single sources, such as a chemical plant. During the 1990s, the focus widened to encompass mixtures of substances and also ecological risks. Ecological risk assessment by the US Environmental Protection Agency (1998) asks five questions: Is there a problem? What is the nature of the problem? What are the exposure and ecological effects? (A hazard to which no one or nothing is exposed is not considered to pose any risk.) How can we summarize and explain the problem to affected parties, both at-risk populations and those whose activities would be curtailed? How can we manage the risks?

Even though these are good questions, ecological risk management has not made any visible headway in stemming biotic impoverishment. Its central failing comes from an inability to correctly answer the second question, What is the nature of the problem? Our present political, social, and economic systems simply do not give us the right clues about what is at risk. None of society’s most familiar indicators – whether GDP or number of threatened and endangered species – measure the consequences, or risks, of losing living systems.

If biotic impoverishment is the problem, then it only makes sense to direct environmental policy toward protecting the integrity of biotic systems. Integrity implies a wholeness or unimpaired condition. In present biological usage, integrity refers to the condition at sites with little or no influence from human activity; the organisms there are the products of natural evolutionary and biogeographic processes in the absence of humans. Tying the concept of integrity to an evolutionary framework provides a benchmark against which to evaluate sites that humans have altered.

Directing policy toward protecting biological integrity – as called for in the United States’ Clean Water Act, Canada’s
National Park Act, and the European Union’s Water Framework Directive, among others – does not, however, mean that humans must cease all activity that interferes with a “pristine” earthly biota. The demands of feeding, clothing, and housing billions of people mean that few places on Earth will maintain a biota with evolutionary and biogeographic integrity. Rather, because humans depend on living systems, it is in our interest to manage our activities so they do not compromise a place’s capacity to support those activities in the future; that capacity can be called ecological health.

Ecological health describes the preferred state of sites heavily used for human purposes: cities, croplands, tree farms, water bodies stocked for fish, and the like. At these places, it is impractical to set a goal of integrity in an evolutionary sense, but we should avoid practices that damage these places to the point where we can no longer derive the intended benefits indefinitely. For example, agricultural practices that leave behind saline soils, depress regional water tables, and erode fertile topsoil faster than it can be renewed destroy the land’s biological capacity for agriculture; such practices are unhealthy in both ecological and economic terms.

Biological integrity as a policy goal redirects our focus away from maximizing goods and services for the human economy toward ways to manage human affairs within the bounds set by the natural economy. It begins to turn our attention away from questions such as, How much stress can landscapes and ecosystems absorb? to ones such as, How can responsible human actions protect and restore ecosystems? In contrast to risk assessment, striving to protect biological integrity is more likely to lead away from mandated corrective actions in the form of technological fixes for environmental problems and toward practices that prevent ecological degradation and encourage ecological restoration.

Leopold (1949, pp. 224–225), in A Sand County Almanac, was the first to invoke the concept of integrity in an ecological sense: “A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.” Managing for biological integrity requires the kind of ethical commitment inherent in Leopold’s words. We are called to curb consumerism and limit population size, to embrace less-selfish attitudes toward land stewardship, and to understand that the biosphere matters. Instead of calling on human technical and spiritual well-springs to manage resources, we have to call on them for managing human affairs.

We have to find and use appropriate measurements for all the factors contributing to biotic impoverishment, be they climate change, overharvesting, agriculture, or environmental injustice. Measurement of environmental impact founded on the evolutionary idea of integrity allow us to directly assess biotic condition and to compare that condition with what might be expected in a place with little or no human influence. At least then we can make an informed choice: continue with activities that degrade biotic condition or think of an alternative.

The ecological world is a complex, variable, and often unpredictable system. When managing for ecological risks, people and their governments need to expect the unexpected and develop formal, yet flexible means of coping with environmental surprises. Rather than plunge ahead with projects entailing ecological risks because they can be done, decision makers should follow the precautionary principle, which holds that regulators should act to prevent potential environmental harm even in the absence of certainty. It acknowledges the existence of uncertainty rather than deny it, and it includes mechanisms to safeguard against potentially harmful effects.

Although inappropriate ecological risk assessment and management are more often the norm today, modern institutions are capable of recognizing ecological threats correctly and responding to them in time, as they did with the Montreal Protocol. A decade after the agreement’s adoption, satellite measurements in the stratosphere indicated that ozone-depleting pollutants were in fact on the decline. Given the treaty’s success, some policy experts have suggested using it to help curb global warming. Specifically, negotiators at the 2010 annual meeting of signatory parties were considering a proposed expansion of the ozone treaty to phase out the production and use of industrial chemicals called hydrofluorocarbons, which have thousands of times the global warming potential of carbon dioxide. Even though the Montreal Protocol was not designed to fight climate change, policymakers in favor of the new proposal say that it could and should be used to achieve broader environmental objectives.

Reuniting the Fragments

Early in the 20th century, two sciences of “home maintenance” began to flourish: the young science of ecology (from the Greek eikos, meaning home) and a maturing neoclassical economics (also from eikos). Ecology arose to document and understand the interactions between organisms and their living and nonliving surroundings – in essence, how organisms make a living in the natural economy. In fact, Ernst Haeckel, who coined the term in the 1860s, defined ecology in an 1870 article as the body of knowledge concerning the economy of nature. Neoclassical economics, in contrast, reinforced humans’ self-appointed dominion over nature’s wealth. It brought unparalleled gains in societal welfare in some places, but it also divorced the human economy from the natural one on which it stands (see Figure 1).

By now it is clear to economists and ecologists alike that human actions and their effects have reached scales unprecedented in the history of life. We have altered Earth’s physical and chemical environment, changed the planet’s water and nutrient cycles, and perturbed its climate. We have unleashed the greatest mass extinction in 65 My and distorted the structure and function of nonhuman and human communities worldwide. In trying to make our own living, we have jeopardized the Earth’s capacity to sustain other species and our own species as well. We are losing the bio in biosphere.

Now, faced with these unprecedented losses, we need to understand – not deny – the ecological consequences of what we do. We urgently need a new science and art of home maintenance, one that sees the human species’ role as ecosystem engineer for what it has become and reconnects human and natural economies. This new science can help us understand and correctly interpret the consequences of
human-driven change. By using indicators that measure what matters for sustaining living systems, this new science can make nature visible again and shed new light on the value of the ancient heritage we share with the larger biosphere. It can help us reunite the fragments of our worldview and re-create ethical, social, and ecological bonds that were put aside two centuries ago in the name of progress. And such a science can enable us to reengineer our own social, political, and economic institutions instead of ecosystems. This we must do – now – before we impoverish the biosphere and ourselves for all time.

See also: Biodiversity and Human Health, Biodiversity as a Commodity, Biogeochemical Cycles, Climate Change and Ecology, Synergism of, Conservation and the World’s Poorest of the Poor, Domestication of Crop Plants, Ecological Footprint, Concept of, Economic Value of Biodiversity, Measurements of, Ecosystem Services, Ecotoxicology, Endangered Ecosystems, Energy Use, Human, Environmental Ethics, Human Impact on Biodiversity, Overview, Hunter-Gatherer Societies, Ecological Impact of, Justice, Equity and Biodiversity, Market Economy and Biodiversity

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