Chapter 17 Ecology and Human Actions

Chapter Outline

17.1 The Biodiversity Crisis

Lesson Objectives

- Compare humans to other species in terms of resource needs and use, and ecosystem service benefits and effects.
- Define the concept of biodiversity.
- Quantify Earth's species diversity, according to scientists' current understanding.
- Describe patterns of biodiversity in space.
- Trace changes in biodiversity throughout Earth's history.
- Examine the evidence for the Sixth Extinction.
- Compare the Sixth Extinction to major extinctions before humans.
- Discuss the direct economic benefits of biodiversity.
- Evaluate ecosystem services provided by biodiversity.
- List the intangible (cultural, spiritual, religious) benefits of biodiversity.
- Relate biodiversity to social and political stability.
- Consider that biodiversity has intrinsic value apart from benefits to humans.
- Assess the potential for early human activities to contribute to Ice Age extinctions of large animals.
- Identify habitat loss as the primary cause of the Sixth Extinction.
- Relate the introduction of exotic species to loss of biodiversity.
- Explain the extent to which over exploitation has affected all levels of biodiversity.
- Connect energy use to extinction.
- Describe the effects of population growth and unequal distribution of resources on biodiversity.
- Recognize that pollution of water, land, and air contributes to the loss of species.
- Acknowledge that your daily activities and decisions can significantly help to protect biodiversity.
- Evaluate your consumption –of food, clothing, furniture, and cleaning products.
- Appreciate the importance of water resources and know how to use them wisely.
- Evaluate your choice and use of energy sources.
- Assess the importance of minimizing waste, and of using best practices for waste disposal.
- Know how to avoid transporting and releasing exotic species.
- Realize that you can practice sustainable management of your own land, from small yards to local, state, and federal lands which also belong to you.
- Describe sustainability and its role in decision-making.
- Explain how learning and active citizenship can contribute to protecting biodiversity.

Introduction

Humans, like all species, depend on certain natural resources for survival. We depend on land and soils to grow crops, which transform solar energy into food. We use the Earth's freshwater lakes, rivers, and groundwater for drinking. We rely on the atmosphere to provide us with oxygen and to shield us from radiation. We rely on Earth's biodiversity for food, clothing, and medicines. We utilize all of the "basic four" (biodiversity, land, water, air) for recycling of nutrients and disposal of waste. Natural ecosystems, as Odum suggests, provide services for all species: they maintain soil, renew the atmosphere, replenish freshwater supplies, dispose of wastes, and recycle nutrients. In our dependence on these services, we are like all other species.

Yet in many ways, we do not behave like other species. We supplement food and animal energy with fossil fuel energy. We harvest natural resources to exhaustion, and produce waste beyond levels that the Earth can process. We alter biodiversity, land, water, air and fossil fuels beyond nature's ability to repair. As you learned in your study of population biology, our population has grown beyond Earth's carrying capacity, compounding problems of resource use and waste disposal. Only recently have we learned to appreciate the full value of these resources –and the potential for harm from our own activities. Our economics have not caught up to our relatively new understanding: we do not yet pay the costs of maintaining all of "nature's services."

This lesson will explore biodiversity –the "millions of organisms and hundreds of processes - operating to maintain a livable environment." The topic is timely, critical, and colorful: you will encounter warnings of a Biodiversity Crisis and the Sixth Extinction, and species identified as "an Elvis taxon" or "a Lazarus taxon." More importantly, by the end of your study, you will have some tools you can use in your daily life to help protect the great diversity of Earth's life.

What is Biodiversity?

"The first rule of intelligent tinkering is to save all the pieces." –attributed to Aldo Leopold, but probably a shortened version of: ***"To save every cog and wheel is the first precaution of intelligent tinkering."* - Aldo Leopold, *Round River: from the Journals of Aldo Leopold* , 1953**

What are the "cogs" and "wheels" of life?

Although the concept of **biodiversity** did not become a vital component of biology and political science until nearly 40 years after Aldo Leopold's death in 1948, Leopold –often considered the father of modern ecology - would have likely found the term an appropriate description of his "cogs and wheels." Literally, biodiversity is the many different kinds (*diversity*) of life (*bio-*). Biologists, however, always alert to levels of organization, have identified three measures of life's variation. **Species diversity** best fits the literal translation: the number of different species (see the chapter on Evolution of Populations) in a particular ecosystem or on Earth (**Figure** 17.1). A second measure recognizes variation *within* a species: differences among individuals or populations make up **genetic diversity**. Finally, as Leopold clearly understood, the "cogs and wheels" include not only life but also the land (and sea and air) which supports life. **Ecosystem diversity** describes the many types of functional units formed by living communities interacting with their environments.

Although all three levels of diversity are important, the term biodiversity usually refers to species diversity. How many species do you think exist on Earth? What groups of species do you think are most abundant? Consider your own experience, and your study of biology up to this point. Think carefully, and write down your answer or exchange ideas with a classmate before you read further.

What is the Species Diversity of Earth?

There are three good answers to this question. As a member of one of Earth's most intriguing species, you should know them all!

1) Scientists have identified about 1.8-1.9 million species. (**Figure** 17.2)

The relative numbers of species in each of the six kingdoms of life is shown in **Figure A** 17.2. The Animal Kingdom (dominated by the Insects, as shown in **Figure B** 17.2) includes the great majority of known species, and Archaebacteria, by far the fewest. Most scientists agree that Eubacteria and Archaebacteria are seriously underrepresented, due to their small size and chemistry-based diversity. This leads to a second, and perhaps better answer to our question:

FIGURE 17.1

The most accessible definition of biodiversity is species diversity. How many species exist on Earth?

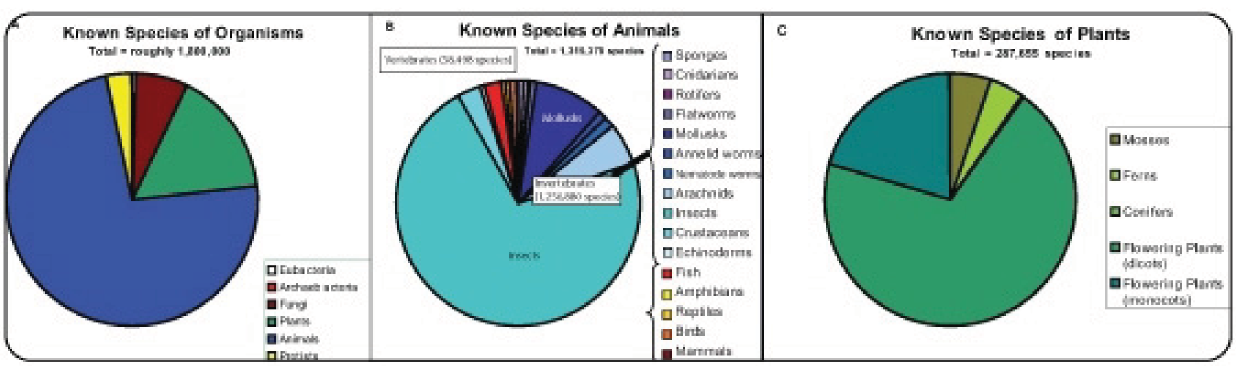


FIGURE 17.2

Among 1.8 million identified species (A), 1,315,378 are Animals (B), 287,655 are Plants (C), and only 259 are Archaebacteria. The Animal Kingdom is dominated by the Class Insecta, and the Plant Kingdom is dominated by flowering plants.

2) No One Knows How Many Species Currently Live on Earth!

Does this lack of knowledge surprise you? Scientists are still discovering new species - not only microorganisms but also plants, animals, and fungi. At least 5 new species of marsupials, 25 primates, 3 rabbits, 22 rodents, 30 bats, 4 whales or dolphins, a leopard, and a sloth were identified between 2000 and 2007 –and these include only mammals! The vast majority of Eubacteria, Archaebacteria, Protist, and even Insect species may be yet unknown because their small size, remote habitats, and the chemical distinctions between species make them so difficult to detect. These challenges, however, have not prevented scientists from estimating Earth's biodiversity –bringing us to the third answer to our question:

3) Scientists Estimate that Between 5 and 30 Million Species Inhabit the Earth.

Estimates vary widely –from 2 million to 117.7 million, underlining our lack of knowledge. Most estimates fall between 5 and 30 million. Much remains to be learned about the diversity of microorganisms. For example, scientists have recently discovered that Archaebacteria –originally considered limited to extreme environments - may constitute as much as 40% of the ocean's microbial biomass. Few species have been identified. Estimates of global diversity of the better-studied Eubacteria vary from millions to billions, with orders of magnitude of error. As for multicellular organisms, the most "species-dense" terrestrial ecosystems, such as coral reefs and tropical rain forests, harbor most of the undiscovered species (**Figure** 17.3). Ironically, these ecosystems are also disappearing quickly. In summary, our estimates of biodiversity remain crude. However, the following conclusion is clear: given the current rapid loss of species, we will never know many of the species we are losing.

FIGURE 17.3

Coral reefs (above) and tropical rain forests (below) have the greatest biodiversity of the many ecosystems on earth. They are also among the most threatened habitats. Because our knowledge of their species is incomplete, we are clearly losing species we do not (and never will) know.

Biodiversity Patterns in Space

Are Earth's 1.8 million known species evenly distributed across its surface? You may already be aware that the answer is a resounding "No!" We will compare two regions with relatively high diversity to begin our analysis.

Minnesota has relatively high ecosystem diversity, because three of the Earth's six major terrestrial biomes converge in this state (Prairie, Deciduous Forest, and Coniferous Forest). By contrast, Costa Rica comprises almost entirely of Tropical Rain Forest, and has only one quarter of the land area of Minnesota (**Figure** 17.4).

FIGURE 17.4
The state of Minnesota (*left*) includes three major biomes and four times the land area of the country of Costa Rica (*right*), which is predominately a tropical rainforest. **Figure** compares the biodiversity of Minnesota to that of Costa Rica.

You might expect, then, that Minnesota would have a higher species diversity. Several groups of organisms are compared in the **Figure** 17.5. Note that a column is included for you to research your own state or region!

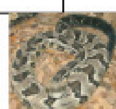
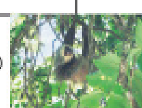
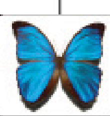
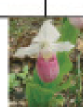
Group of Organisms	Number of Species: Minnesota	Number of Species: Costa Rica	Number of Species: Your State
Amphibians	18	150 	
Reptiles	27 	210	
Birds	400 (but 96 of these migrate, spending winter in the Rainforest)	848 	
Hummingbirds	1 	852	
Mamma ls	80	200 	
Bats	7 	100	
Butterflies	140	1000 	
Orchids	42 	1200	
Trees	43	2500 	

FIGURE 17.5
A comparison of species diversity within categories supports the increase in diversity from the poles to the equators. Costa Rica's increased diversity is due in part to greatly increased niches: diversity begets diversity! For example, poison dart frogs mature in tiny epiphyte pools, and strangler figs climb existing trees and "starve" their hosts of sunlight. Does your state or region support this overall spatial pattern of biodiversity?

Clearly, biodiversity is much higher in Costa Rica than in Minnesota. Collecting leaves for your biology class in

Costa Rica, you would need to study 2,500 different trees in order to identify the species! And you'd need to look carefully to distinguish tree leaves from those of the many **epiphytes** (plants which grow on top of others), vines, and strangler figs which climb the trunks and branches, "cheating" their way to the sunlight at the top of the canopy. In Minnesota, keys to native trees include just 42 species of conifers and deciduous broadleaved species. There, vines are relatively rare, and epiphytes are limited to colorful lichens.

The differences in biodiversity between Minnesota and Costa Rica are part of a general worldwide pattern: biodiversity is richest at the equators, but decreases toward the poles. Temperature is undoubtedly a major factor, with warmer, equatorial regions allowing year-round growth in contrast to seasonal limitations nearer the poles.

Generally, the more species, the more niches –so diversity begets diversity.

Does your country, state or region fit the general pattern of decreasing biodiversity from equator to poles?

Biodiversity Patterns in Time

How has Earth's biodiversity changed across time? The fossil record is our window into this pattern, although the window has limitations. Microorganisms are poorly preserved and distinguished only with difficulty; gene sequence studies of living bacteria have begun to fill in some missing data. For all organisms, recent rock layers are more accessible and better preserved than ancient ones.

Despite these drawbacks, fossils and gene studies show a distinct pattern of increasing biodiversity through time. As discussed in the chapter on the *History of Life,* the origin of life is not clearly understood; evidence suggests that life did not appear on Earth until perhaps 4 billion years ago. For several billion years, unicellular organisms were the only form of life. During that time, biodiversity clearly increased, as Eubacteria and Archaebacteria emerged from a common ancestor some 3 billion years ago, and Eukaryotes emerged by endosymbiosis about 2 billion years ago. However, we have not accurately measured the diversity of even today's microorganisms, so we have little understanding of changes in the diversity of microorganisms beyond these major events.

The emergence of multicellular life about 1 billion years ago certainly increased biodiversity, although we have little way of knowing whether it might have negatively affected the diversity of microorganisms. Fossils remain relatively rare until the famed Cambrian explosion 542 million years ago. Since then, a much more detailed fossil record (**Figure** 17.6) shows a pattern of increasing biodiversity marked by major extinctions.

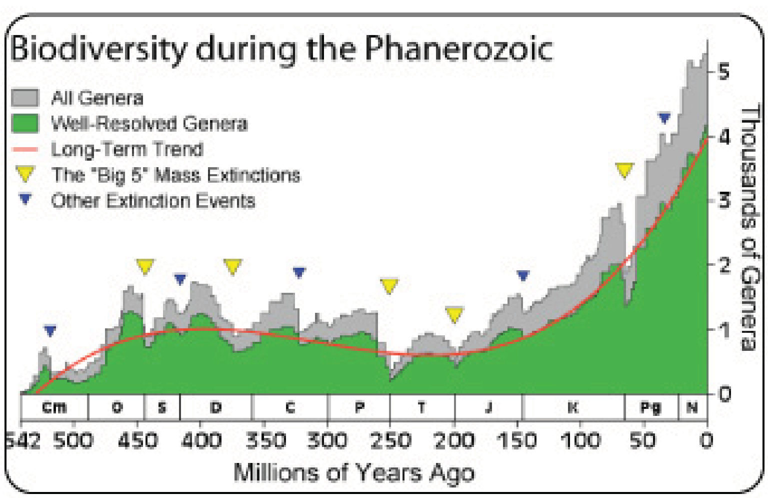


FIGURE 17.6

The fossil record for marine species over the past 542 million years shows a gradual increase in biodiversity interrupted by five major extinctions. Some scientists view the recent rapid rise in diversity as a result of better preservation of more recent rock layers and fossils.

The dramatic increase indicated for the last 200 million years is somewhat disputed. Some scientists believe it is a real increase in diversity due to expanding numbers of niches –diversity begets diversity, again. Others believe it is a product of sampling bias, due to better preservation of more recent fossils and rock layers. Most scientists accept the general pattern of increasing diversity through time, interpreting the magnificent biodiversity of life on Earth today as the result of billions of years of evolution.

Most scientists also accept at least the five major mass extinctions shown in **Figure** 17.6, and some hold that regular cycles govern extinction. Causes for these extinctions (more completely discussed in the *History of Life* chapter) remain incompletely understood; hypotheses include global climate change, major volcanic and continental drift events, dramatic oceanic change, and/or extraterrestrial impact or supernova events.

Increasingly accepted is a current Sixth or Holocene Extinction event. According to a 1998 survey by the American Museum of Natural History, more than 70% of biologists consider the present era to be a sixth mass extinction event - perhaps one of the fastest ever. We will explore the Sixth, or Holocene, Extinction in the next section of this lesson.

The Current Loss of Biodiversity

"For one species to mourn the death of another is a new thing under the sun." **-Aldo Leopold** *A Sand County Almanac,* 1949

Over 99% of all species that have ever lived on Earth are extinct. During the 5 major extinctions recorded in the Phanerozoic fossil record (**Figure** 17.6), more than 50% of animals disappeared. Evidently, extinction is natural. However, current extinctions may differ significantly in rate and cause. The IUCN (International Union of Concerned Scientists) has documented 758 extinctions since 1500 CE; for example, 6 species of giant, flightless *Moa* (**Figure A** 17.7) disappeared from New Zealand shortly after the arrival of Polynesians. Estimates of extinctions for the last century range from 20,000 to 2,000,000 species; as for diversity, we simply do not know the true figure.

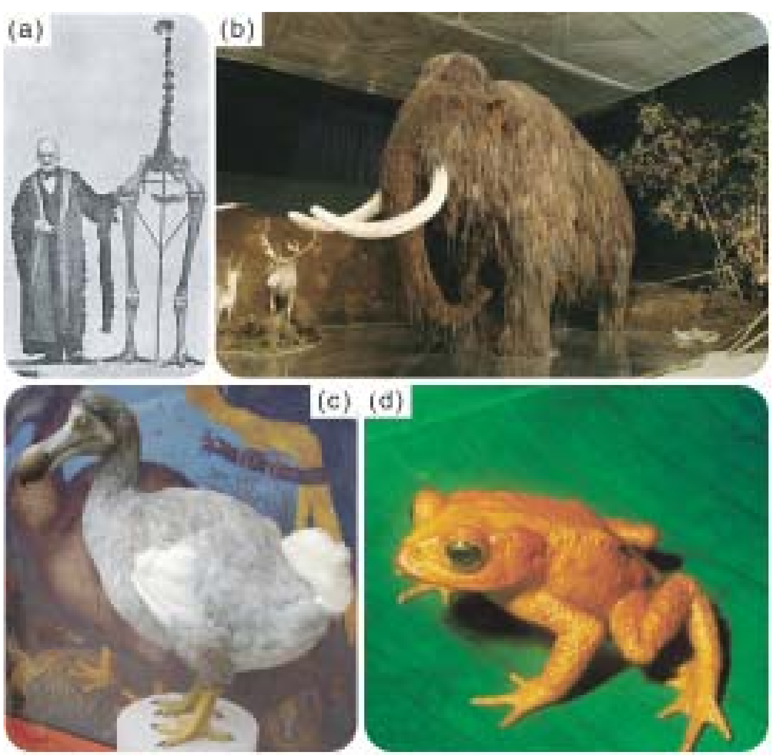


FIGURE 17.7

A gallery of species which have succumbed to the Sixth Extinction: A: one of six species of *Moa* birds which disappeared after Polynesians first arrived and began to hunt and clear forests in New Zealand about 1500 CE. B: reconstruction of a woolly mammoth, one of many large mammals which became extinct at the end of the last Ice Age, due to human hunting, disease, and/or climate change. C: a reconstruction of the meter-tall flightless Dodo, which disappeared within a hundred years of its discovery, probably due to forest destruction and introduced predators. D: the Golden Toad recently discovered in 1966, has been officially extinct since 1989. Amphibians as a group have declined sharply throughout the world during the past three decades.

Many scientists begin the Sixth Extinction with the Ice Age loss of large mammals and birds - part of a continuum of extinctions between 13,000 years ago and now. During that time, 33 of 45 genera of large mammals became extinct in North America, 46 of 58 in South America, and 15 of 16 in Australia. Climate change and/or human "overkill" are hypothetical causes. Supporting the significance of the "sudden" arrival of humans are the low numbers in Europe and South Africa, where humans had coevolved with large animals. The woolly mammoth (**Figure B** 17.7) is one of the many examples of large mammal extinctions from this period.

The first species to become extinct during recorded human history was the Dodo (**Figure C** 17.7), a flightless bird which had evolved without predators on an island in the Indian Ocean. Described in 1581, the fearless Dodo experienced hunting, forest habitat destruction, and introduced predators, and became extinct before 1700 –a story repeated for many more species over the following three centuries. Unfortunately, the story extends back in time, as well; over the past 1100 years, human activity has led to the extinction of as many as 20% of all bird species… a tragic loss of biodiversity.

Harvard Biologist E.O. Wilson estimated in 1993 that the planet was losing 30,000 species per year - around three species per hour. In 2002, he predicted that if current rates continue, 50% of today's plant and animal species will be extinct within the current century –compared to hundreds of thousands or even millions of years for pre-human mass extinctions. A dramatic global decline in amphibian populations in less than 30 years headlines the recent rise in extinction. Herpetologists report that as many as 170 species have become extinct within that time, and at least one-third of remaining species are threatened. Costa Rica's Golden Toad (**Figure D** 17.7), first described in 1966, was last seen in 1989 and has become a poster species for amphibian declines.

Why is Biodiversity Important? What are We Losing?

Why should humans care if biodiversity declines? Does it matter that we have 170 fewer amphibians, or that we are losing thousands of species each year, when the Earth holds millions of other species, and life has been through extinction before? The answer is a definitive yes! It matters to us even if we consider only the economic and spiritual benefits to humans. It matters to us because we do not even understand the myraid of indirect benefits –now recognized as **ecosystem services**- that we reap from other species. And, of course, it matters to other species as well.

Direct Economic Benefits of Biodiversity

- ***Food Supply***: **Monocultures** (large-scale cultivation of single varieties of single species) are extremely vulnerable to disease. A water mold caused the infamous Irish potato famine where potatoes had been bred from a single Incan variety. As recently as 1970, blight swept the corn belt where 80% of maize grown in the U.S. was a single type. According to the Food and Agricultural Organization of the United Nations, humans currently cultivate only 150 plant species, and just four provide over half of the food we eat. Just 15 animal species make up over 90% of our livestock.

Potential for hybridization requires a diverse "bank" of wild, native species. Contemporary breeders increase genetic diversity by hybridizing crop species with wild species adapted to local climate and disease (**Figure** 17.8).

- ***Clothing, Shelter, and Other Products***: As many as 40,000 species of plants, animals, and fungi provide us with many varied types of clothing, shelter and other products. These include timber, skins and furs, fibers, fragrances, papers, silks, dyes, poisons, adhesives, rubber, resins, rubber, and more.

- ***Energy***: In addition to these raw materials for industry, we use animals for energy and transportation, and biomass for heat and other fuels. Moreover, hydroelectric power depends on ecosystem structure: Chinese scientists calculated that the economic benefits of maintaining forest vegetation in the Yangtze River watershed "produced" more than twice the economic value of timber (had it been harvested) in annual power output.

FIGURE 17.8
Wild varieties of domesticated crops, such as this unusually shaped Latin American maize, hold the potential to enhance productivity, nutritional value, adaptation to local climates, and resistance to local diseases through hybridization. Loss of biodiversity limits our ability to increase the genetic diversity of crops.

- ***Medicine and Medical Models***: Since the first microorganisms competed for food, evolution has been producing chemicals for "warfare" and "defense" in bacteria, fungi, plants, and animals; **Figure** 17.9 shows several used by humans. According the American Museum of Natural History Center for Biodiversity Conservation (AMNH-CBC), 57% of the most important prescription drugs come from nature, yet only a fraction of species with medicinal potential have been studied.

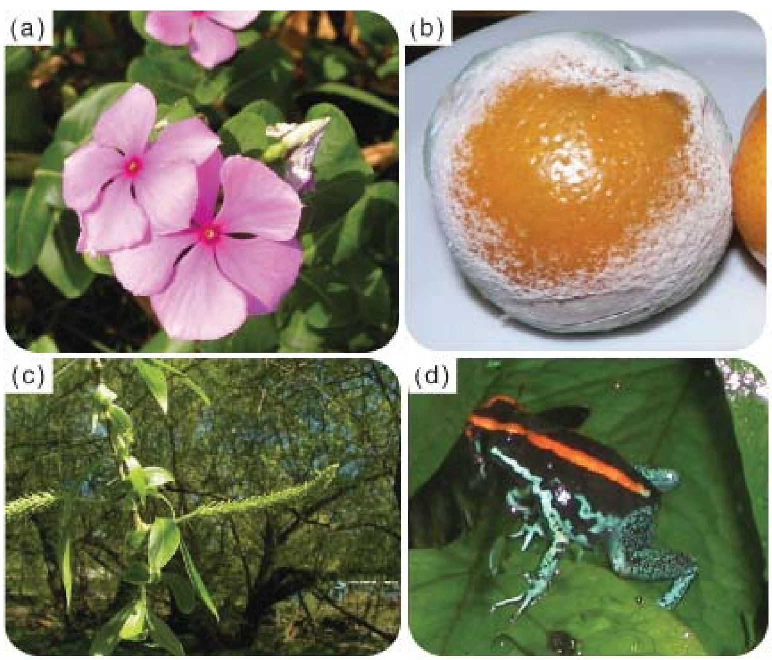


FIGURE 17.9
A pharmacopoeia of the living world: The Rosy Periwinkle (A) is the source of two chemotherapy drugs effective against leukemias. The mold *Penicillium* (B) produces the antibiotic penicillin to defend its territory (in this case, a mandarin orange) from competing microorganisms. Aspirin originates in the bark of the White Willow (C). And several species of tropical frogs in the genus *Phyllobates* (D) produce poisons used by South American tribes for hunting with darts.

Unique features of certain species have opened windows into how life works. For example, the Atlantic squid's giant axon revealed the basics of neurophysiology, and the horseshoe crab's (**Figure D** 17.11) optic nerve and photoreceptors taught us how vision works. Other animals serve as disease models; as far as we know, other than humans, only armadillos suffer from leprosy, and only sea squirts form kidney stones.

- ***Efficient Designs: Inspiration for Technology***: **Biomimicry**, also known as biomimetics or **bionics**, uses organisms for engineering inspiration and human innovation. Rattlesnake heat-sensing pits, for example, suggested infrared sensors. Zimbabwe's Eastgate Centre **Figure** 17.10 incorporates air-conditioning principles from termite mounds. The 2006 Mercedes-Benz *Bionic* employs the body shape of the yellow box fish to combine high internal volume and efficient aerodynamics. Biomimetics professor Julian Vincent estimates that only 10% of current technology employs the highly efficient biological designs crafted by evolution and natural selection. Loss of biodiversity can be viewed as the loss of millions of years of evolutionary wisdom.

FIGURE 17.10

Bionics, or biomimicry, engineers structures based on biological designs made efficient by millions of years of evolution and natural selection. Above: The air-conditioning efficiency of a termite mound (left) inspired the design of the Eastgate Centre in Zimbabwe (right), which requires just 10% of the energy needed for conventional building of the same size. Below: The rigid exoskeleton and low-drag body shape of the tropical yellow box-fish (left) inspired the 2006 Mercedes-Benz *Bionic* (right), which combines large internal volume with optimal aerodynamics.

- ***Warnings of Toxins and Other Ecosystem Disruptions***: If you know how miners use canaries to detect poisonous gases underground, you will understand how widespread extirpation of peregrine falcons (**Figure E** 17.11) warned us about the dangers of the pesticide DDT and food chain concentration of toxins.

Indirect Benefits of Biodiversity: Ecosystem Services

- ***Increasing Ecosystem Productivity***: Ecologist David Tilman compared grassland plots to show that increasing species diversity increased overall productivity (yield). Different plants utilize different resources, so a variety of plants may more completely use resources within an area. As noted above, diversity also reduces system vulnerability to pests and disease.

- ***Increasing Ecosystem Stability***: Tilman observed his grassland plots through several cycles of drought and documented a similar relationship between biodiversity and stability. Plots which were more diverse were more resistant to drought and later recovered more completely. Reducing ecosystem vulnerability to pests and disease may also be a factor in the relationship between diversity and stability. As you have learned before, diversity among individuals within a species increases the chance that at least some will survive environmental change; similarly, diversity among species within an ecosystem increases the chance that at least some species will survive environmental change.

- ***Maintaining the Atmosphere***: As you learned in the chapters on photosynthesis and respiration, plants and algae produce the O_2 which makes up 20% of the atmosphere essential to aerobic organisms, and remove CO_2 produced by respiration and burning fossil fuels. As Joseph Priestley expressed this service, plants "restore the air" which has been "injured by the burning of candles" or "infested with animal respiration." O_2 is also critical to life because it helps to maintain the ozone shield, protecting life from dangerous Ultra-Violet radiation.

- ***Maintaining Soils***: Soil microorganisms maintain nutrients in complex but critical chemical pathways. Vegetation and litter prevent erosion of soils which require thousands of years to form. Estimates suggest that erosion destroys as many as 3 million hectares of cropland annually, and that as much as one-fifth of the world's cropland is "desertified" through salination, acidification, or compacting.

- ***Maintaining Water Quality***: Water treatment plants rely in large part on microorganisms for water purification, and natural systems do the same. In nature, wetland, waterway, and watershed root systems combine with soil adsorption and filtration to accomplish water purification. When New York City decided to restore the Catskill watershed, their \$1-1.5 billion investment in "natural capital" contrasted favorably with the \$6-8 billion initial cost and \$300 million annual operating cost of a new treatment plant.

- ***"Fixing" Nitrogen***: One of the most amazing aspects of biological systems on earth is their absolute need for nitrogen –to build the proteins and nucleic acids upon which life depends –and their nearly universal dependence on microorganisms to "fix" atmospheric N_2 gas and recycle the nitrogen of waste and death. Only after the bacterial "service" of processing nitrogen is it available in usable chemical form to plants, and through them, to animals (**Figure A** 17.11).

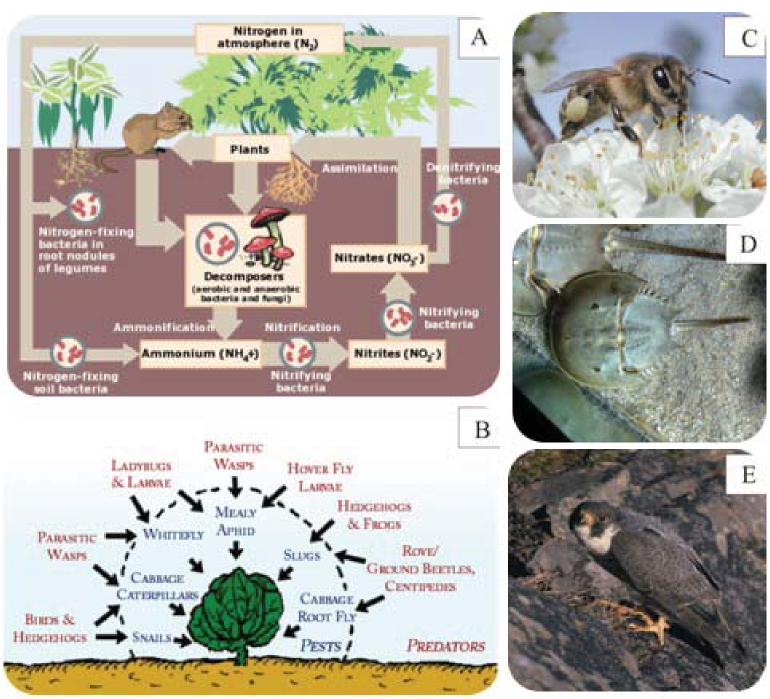


FIGURE 17.11

Ecosystem services which depend on biodiversity include nitrogen fixation (A), pest control (B), pollination (C), medical models such as the horseshoe crab optic nerve and photoreceptors (D), and early warning about toxins, e.g. the peregrine falcon's extirpation by the pesticide DDT (E).

- ***Nutrient Recycling and Waste Disposal***: Bacteria and nitrogen are not the only contributors to the waste management services of ecosystems. Fungi, protists, and scavengers help to decompose waste and dead organisms so that new life can reuse the available nutrients.

- ***Pollination***: The list of biotic pollinators, essential for sexual reproduction in many plants, is long including not only insects such as wasps, bees, ants, beetles, moths, butterflies, and flies, but also fruit bats and birds such as hummingbirds, sunbirds, spiderhunters, and honeyeaters. Although U.S. crops have relied on commercial honeybees (which are "migrated" to keep pace with maturing crops!), native pollinators in nearby forests or wild grasslands have been shown to improve the productivity of apples or almonds by 20%. The American Institute of Biological Sciences estimates that native insect pollination is worth $3.1 billion annually. Current alarm over honeybee colony collapse highlights the importance of biodiversity to the ecosystem service of pollination.

- ***Pest and Disease Control***: According to the AMNH-CBC, farmers spend $25 billion annually on pesticides, while predators in natural ecosystems (**Figure B** 17.11) contribute 5 to 10 times that value in pest control. Costs associated with the use of chemical pesticides (such as water pollution) add to the value of natural pest control. Natural enemies are adapted to local environments and local pests, and do not threaten each other's survival (or ours!) as do broad-spectrum chemical pesticides. Preservation of natural enemies is associated with preservation of plant diversity, as well. Disrupted ecosystems can lead to increasing problems with disease. In Africa, deforestation has led to erosion and flooding, with consequent increases in mosquitoes and malaria.

Aesthetic Benefits of Biodiversity

- ***Cultural, Intellectual, and Spiritual Inspiration***: Music, art, poetry, dance, mythology, and cuisine all reflect and depend on the living species with whom we share the Earth. Our cultures reflect local and regional variations, and as such, biodiversity underlies our very identities. The beauty and tranquility of living ecosystems have inspired environmentalists (Rachel Carson, Aldo Leopold), spiritualists (Thomas Berry), and writers such as (Barry Lopez) throughout history. Recently, the increasing distance of human society from the natural world has raised concerns about our psychological and emotional health; E.O. Wilson has proposed that *biophilia* (love of the living world) is an increasingly ignored part of our human psyche, and Richard Louv believes that too many of our children suffer from "nature deficit disorder" caused by our increasing alienation from nature.

- ***Recreational Experiences***: Many people choose to use vacation and recreation time to explore natural ecosystems. Outdoor recreational activities –many of which are increasing in popularity - include hunting, fishing, hiking, camping, bird-, butterfly- and whale- watching, gardening, diving, and photography. Indoor hobbies such as aquariums also celebrate biodiversity. For Costa Rica, Ecuador, Nepal, Kenya, Madagascar, and Antarctica, ecotourism makes up a significant percentage of the gross national product. Ideally, ecotourism involves minimal environmental impact, conservation of bio- and cultural diversity, and employment of indigenous peoples.

Political and Social Benefits of Biodiversity

Some analysts relate biodiversity to political and social stability. Unequal access to food, clothing, water, and shelter provided by diverse ecosystems threatens social equity and stability. Land ownership and land use practices which threaten biodiversity often marginalize poorer people, forcing them into more ecologically sensitive areas and occupations. Poverty, famine, displacement, and migrations are problems related to loss of biodiversity which have already led to billions of dollars in relief costs and significant local armed conflict.

Intrinsic Value of Biodiversity

Many people value biodiversity for its inherent worth, believing that the existence of such a variety of genes, species, and ecosystems is reason enough for our respect. Intrinsic value goes beyond economic, aesthetic, environmental, and political benefits. For many people, intrinsic value alone imposes great responsibility on us to monitor our actions in order to avoid destroying the diversity of life.

Why is biodiversity important? It supplies us with essential resources, raw materials, and designs which have direct economic value. It enhances the stability and productivity of ecosystems which in turn provide essential, under-appreciated services. These services, too, have great economic value, although we are only beginning to recognize their importance as we experience their loss. Biodiversity is critical for cultural identity, spiritual and intellectual inspiration, and our own re-creation. Biodiversity goes hand-in-hand with social and political stability. And for many people, biodiversity has inherent worth apart from its many benefits for us and our environment.

Biodiversity is critically important for us and for the Earth, and it is declining at an unprecedented rate. What is causing current extinctions? What can we –what can YOU –do to help?

Causes of the Sixth Extinction: Human Actions and the Environment

What are the causes of the Sixth Extinction? There is nearly universal agreement that most result from human activities (**Table** 17.1 and **Figure** 17.12). Although our activities have changed, we remain the single species most able to alter the Earth's genetic, species, and ecosystem biodiversity.

TABLE 17.1:

Continent/Island	Human Settlement (Years Before Present)	Extinctions Which Followed
Africa, Eurasia	Humans evolve here	relatively few extinctions
Indonesia	50,000	50% of large mammal species
Australia	40,000	55 species large mammals, reptiles, and birds
North and South America	10,000 - 12,500	70-80% of large mammals (at least 135 species) within 1000 years
Mediterranean Islands	10,000	large mammals and reptiles
West Indies	7,000	Mammals, birds, reptiles all 5 endemic mammals of Puerto Rico
Madagascar	2,000	virtually all large endemic land mammals, reptiles, and birds within 1500 years
Hawaiian Islands	1,500 (Polynesians) 250 (Europeans)	2/3 of native vertebrate species, 90% of bird species after European arrival, 20 more bird species
New Zealand	1,300	No mammals originally Frogs, lizards, and over 1/3 (40 species) of birds

Convincing evidence for human responsibility for Ice Age extinctions is outlined in **Figure** 17.12. Comparing Ice Age to pre-human extinctions provides more evidence:

- Ice Age extinctions affected large animals disproportionately; pre-human extinctions affected all body sizes.
- Ice Age extinctions occurred at different times in different regions; pre-human extinctions were global and simultaneous.
- Recent extinctions follow human migration with regularity.
- The "syncopated" pattern does not fit climate change, and earlier interglacial periods did not see similar extinctions.

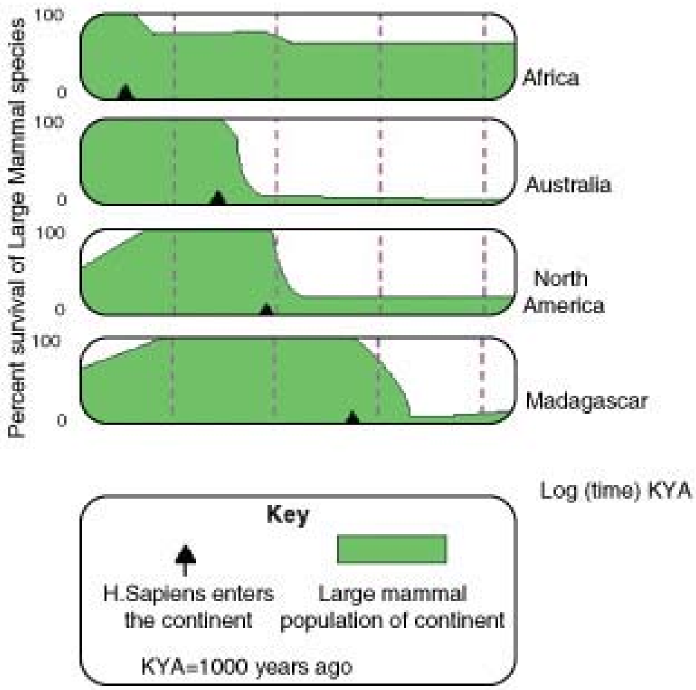


FIGURE 17.12

Large animal extinctions followed the arrival of humans in many regions of the world, suggesting that human activities caused the extinctions.

Although the data above has led to considerable agreement about human responsibility for the early Holocene extinctions, scientists still debate exactly how human activities caused extinctions. Hypotheses include:

1. **Overkill**: Animals outside Africa and Eurasia evolved in the absence of humans. Many did not fear humans and would have been easily killed, explaining the disproportionate numbers of large species affected.
2. **Cascade effects**: Extinctions of very large animals could have had major effects on ecosystems, including secondary extinctions. Loss of predators could have led to overpopulation and starvation of prey species. Loss of large herbivores would have affected their predators. Removal of even a single **keystone species** could have destabilized complex ecosystem interactions, leading to multiple extinctions.
3. **Disease**: Humans often brought along rats, birds, and other animals as they migrated to new regions. Animals in those new regions, however, would not have evolved resistance to the diseases they carried. Avian malaria, for example, is still spreading through Hawaii, having already caused the extinctions of many bird species.
4. **Predation by exotic animals**: The rats, birds, and other animals accompanying humans brought not only disease but also new appetites to regions where animals had evolved without predators. Like humans, these animals found the "naïve" prey easy to capture.
5. **Habitat destruction**: Deforestation and agriculture accompanied humans, and the loss of habitat inevitably resulted in loss of species.

These effects of early human habitation foreshadow today's even greater threats to biodiversity. Overpopulation, industrialization, technology, cultural differences, and socioeconomic disparities compound the six major causes of today's Biodiversity Crisis. Most experts agree on the primary cause of extinction today:

Causes of Extinction #1: Habitat Loss

Habitat loss, degradation and fragmentation is universally accepted as the primary threat to biodiversity. Agriculture, forestry, mining, and urbanization have disturbed over half of Earth's vegetated land. Inevitably, species disappear and biodiversity declines.

Conversion for **agriculture** is a major reason for habitat loss. Within the past 100 years, the area of land cultivated worldwide has increased 74%; grazing land increased 113%. Agriculture has cost the United States 50% of its wetlands and 99% of its tallgrass prairies. Native prairie ecosystems (**Figure** 17.13) - which comprise of thick, fertile soils, deep-rooted grasses, a colorful diversity of flowers, burrowing prairie dogs, owls and badgers, herds of bison and pronghorns, and booming prairie chickens, - are virtually extinct.

FIGURE 17.13
Habitat loss is the #1 cause of extinction today. In the U.S., over 99% of tallgrass prairies have been eliminated in favor of agriculture. Big bluestem grasses as tall as a human (center) and (clockwise from top) prairie chickens, prairie dogs, burrowing owls, yellow and purple coneflowers, blue grama grass, and bison make up part of the prairie community.

The largest cause of deforestation today is **slash-and-burn agriculture** (**Figure** 17.14), used by over 200 million people in tropical forests throughout the world. Depletion of the surprisingly thin and nutrient-poor soil often results in abandonment within a few years, and subsequent erosion can lead to desertification. Half of Earth's mature tropical forests are gone; one-fifth of tropical rain forests disappeared between 1960 and 1990. At current rates of deforestation, all tropical forests will be gone by 2090.

Poverty, inequitable land distribution, and overpopulation combine in third world countries to add pressure to already stressed habitats. Use of firewood, charcoal, crop waste, and manure for cooking and other energy needs further degrade environments, threatening biodiversity through habitat loss.

Causes of Extinction #2: Exotic (Alien or Invasive) Species

Technology has made the human species the most mobile species of any which has ever lived. Both intentionally and inadvertently, humans have extended their mobility to a great number of other species, as well. Ships from Polynesian times (as long ago as 3500 BP) to the present have transported crop species and domesticated animals as well as stowaway rats and snakes. Recently, cargo ships have transported Zebra Mussels, Spiny Waterfleas, and Ruffe deep into the Great Lakes via ballast water. Europeans brought Purple Loosestrife and European Buckthorn to

FIGURE 17.14
Slash-and-burn agriculture is practiced by over 200 million people throughout the world; this photo was taken in Panama. Because of thin, nutrient-poor soils, plots are abandoned within just a few years. Experts predict that if current rates continue, all tropical forests will be gone by 2090.

North America to beautify their gardens. Shakespeare enthusiast Eugene Schieffelin imported the now-ubiquitous European Starling to Central Park in the 1890s because he thought Americans should experience every bird mentioned in the works of Shakespeare. Australians imported the Cane Toad in an attempt to control the Cane Beetle, a native pest of sugar cane fields. The Brown Tree Snake (**Figure** 17.15) may have hitchhiked in the wheel-wells of military aircraft to Guam - and subsequently extirpated most of the island's "naïve" vertebrate species.

FIGURE 17.15
Many scientists consider exotic species to be the #2 cause of loss of biodiversity. One of the most infamous, the Brown Tree Snake (left), hitch-hiked on aircraft to Pacific Islands and caused the extinctions of many bird and mammal species which had evolved in the absence of predators. The Nile Perch (right) was intentionally introduced to Lake Victoria to compensate for overfishing of native species. The Perch itself overfished smaller species, resulting in the extinction of perhaps 200 species of cichlids.

Many of these **exotic** (non-native) **species**, away from the predation or competition of their native habitats, have unexpected and negative effects in new ecosystems. Freed from natural controls, introduced species can disrupt food chains, carry disease, out-compete natives for limited resources, or prey on native species directly - and lead to extinctions. Some hybridize with native species carefully tuned to local climate, predation, competition, and disease, resulting in **genetic pollution** which weakens natural adaptations. Others change the very nature of the habitats they invade; Zebra Mussels, for example, colonize most manmade and natural surfaces (including native mussels), filter-feeding so intensely that they increase water clarity and enrich bottom habitats with their waste.

Globalization and tourism are increasing the number of exotics which threaten biodiversity throughout the world, breaking down geographic barriers and threatening the wisdom of millions of years of evolution and natural selection. If current trends continue, our increasingly interconnected world will eventually be dominated by just a few fast-growing, highly adaptable, keenly competitive "super-species" rather than the rich diversity we have today. Some biologists, noting that invasive exotics closely resemble what we consider to be "weed" species, have concluded that the world's #1 weed species is –did you guess it? –none other than *Homo sapiens.*

Causes of Extinction #3: Overexploitation

The modern equivalent to overkill, **overexploitation** threatens fisheries, tropical rain forests, whales, rhinos, large carnivores and many other species. Practices such as clear-cutting old growth forests, strip mining, and driftnet fishing go beyond harvesting of single species or resources to degrade entire ecosystems. Technology-aided overharvesting has reduced one of the richest fisheries in the world - the Grand Banks off the coast of Newfoundland –to an estimated 1% of what they were in 1977 (**Figure** 17.16). In 2003 in the journal *Nature,* Canadian biologists published an analysis of data showing that "industrialized" fishing has reduced large predatory fish worldwide by 90%. Some species' stocks are so depleted that less desirable species are illegally sold under the names of more expensive ones; in 2004, University of North Carolina graduate students tested DNA from fish sold as "red snapper" from eight states and found that different species made up 77% of the fish tested! Overexploitation happens on the level of genes and ecosystems as well as individual species. Forest plantations, fish hatcheries and farms, and intensive agriculture reduce both species diversity and genetic diversity within species.

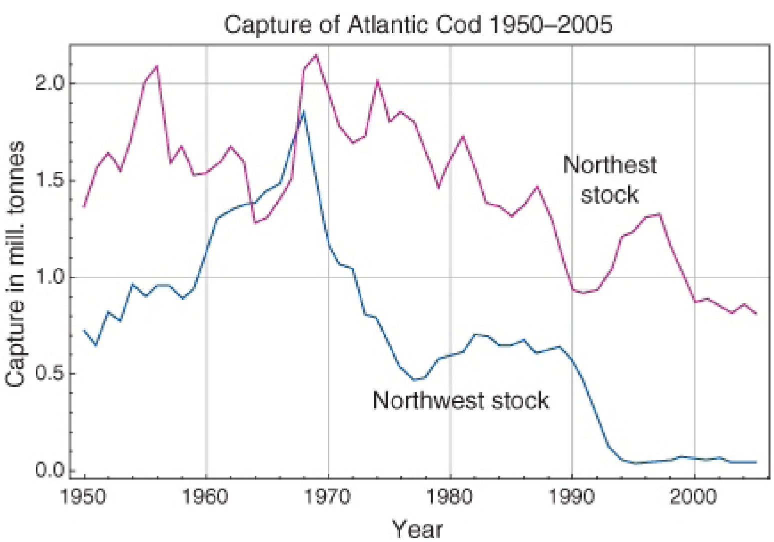


FIGURE 17.16

Overexploitation of Atlantic cod threatens one of the world's most productive fisheries: the Grand Banks off the coast of Newfoundland.

Causes of Extinction #4: Global Climate Change

Our increasing reliance on fossil fuels is altering the Earth's atmosphere and climate. The effects include acid rain, breaks in the ozone layer shielding us from ultraviolet radiation, and greenhouse gases which raise the Earth's air and ocean temperatures and sea levels. Burning tropical rain forests compounds the effect, releasing carbon as CO_2 and eliminating the forest's ability to **sequester** carbon –remove carbon as CO_2 from the atmosphere - via photosynthesis. Inevitably, changing air and water temperatures, rainfall patterns, and salinity threaten species adapted to pre-warming conditions, and biodiversity declines globally. This concern is the topic of the Climate Change Lesson .

Causes of Extinction #5: Overpopulation

In 1960, Earth's human population stood at 3 billion. By 1999, we had grown to 6 billion. This unprecedented growth, together with developments in technology, has added immense pressure to resource and land use. Overpopulation compounds all of the aforementioned threats to biodiversity, and unequal distribution of resources extends the consequences to social and political instability. Human population growth continues (see the chapter on Biology of Populations). Growth rates vary –ominously, from a biodiversity perspective: the highest rates are in third world tropical countries where diversity is also highest. We have already seen how slash-and-burn agriculture and Lake Victoria fisheries connect socioeconomic changes to loss of biodiversity.

Causes of Extinction #6: Pollution

Pollution adds chemicals, noise, heat or even light beyond the capacity of the environment to absorb them without harmful effects on life. To a certain extent, pollution has not kept pace with population growth, at least in Europe and the US. Startling events such as the oil-and-debris-covered and lifeless Cuyahoga River catching fire in 1969 finally provoked the U.S. to stop viewing air and waterways as convenient dumping grounds for waste. Environmental legislation, including the establishment of the Environmental Protection Agency (EPA) has improved both water and air quality. Heeding the warning provided by the extirpation of the Peregrine Falcon from the Eastern U.S., scientists discovered that many synthetic chemicals concentrate as they move through the food chain (**biological magnification**), so that toxic effects are multiplied. DDT –the cause of the Peregrine's decline –was banned in the U.S., and regulation of pesticides was transferred from the Department of Agriculture to the EPA.

And yet, pollution continues to contribute to habitat degradation worldwide, especially in developing countries.

- **Air Pollution**: Knows no boundaries and growing concern about its effects on climate earn this topic two lessons later in this chapter. Acid rain, ozone depletion, and global warming each affect diversity.
- **Water Pollution**: Especially from threatens vital freshwater and marine resources in the US and throughout the world. Industrial and agricultural chemicals, waste, acid rain, and global warming threaten waters which are essential for all ecosystems. Threats to water resources are discussed in Lesson 2.
- **Soil Contamination**: Toxic industrial and municipal wastes, salts from irrigation, and pesticides from agriculture all degrade soils - the foundations of terrestrial ecosystems and their biodiversity. These and other threats to soils are discussed in Lesson 2, Natural Resources.

Outside the developed world, pollution controls lag behind those of the U.S. and Europe, and developing nations such as China are rapidly increasing levels of pollution. Many pollution problems remain in industrialized countries, as well: industry and technology add nuclear waste disposal, oil spills, thermal pollution from wastewater, light pollution of the night skies, acid rain, and more to the challenges facing Earth's biodiversity. Many will be discussed in the following lesson on Natural Resources, and you can certainly research more about those which interest or concern you. Our next task will be to switch from the doomsday report of problems and causes to a discussion of what WE –ordinary citizens –can do to help protect Earth's biodiversity.

Protecting Biodiversity

Consider the following facts from the American Museum of Natural History's Center for Biodiversity and Conservation (AMNH-CBC) and the Environmental Protection Agency (EPA):

Every year, Americans:

- Throw away at least 2 billion disposable razors

- Discard enough paper and wood to heat 5 million homes for 200 years
- Drink more than two billion gallons of bottled water, costing 900 times more money than tap water –not counting the energy and toxics involved in packaging and shipping
- Retire up to 130 million cell phones, containing toxic metals such as arsenic, cadmium, and lead
- Generate about 3 million tons of toxic electronics waste (e-waste), and recycle only about 11%

Do any of these everyday experiences apply to you? You may be surprised to learn there is quite a lot you can do to help. Read carefully through the suggestions below, noting those that appeal to you strongly and those which seem most feasible. Many involve little more than awareness in decisions you already or will soon make.

Consume Thoughtfully and Wisely: Reduce Your Consumption Where Possible. Re-use, and Recycle. Make Durability and Efficiency Your Criteria for Product Purchases.

In general, when you buy:

- Buy locally whenever possible to reduce transportation costs for you and for the environment.
- Be aware of the natural resources used to make and transport any product you buy.
- Substitute other materials for plastics - which are made from petroleum and produce toxic waste.

FIGURE 17.17

Eat with the environment and your health in mind! In the United States, the Department of Agriculture (USDA) sets standards for organic products and certification. The green-and-white seal identifies products which have at least 95% organic ingredients. The program is helpful to consumers, but not without controversy (read Barbara Kingsolver's *Animal, Vegetable, Miracle,* and/or Michael Pollan's *Omnivore's Dilemma*).

- When you buy food plan your diet for your own health and that of the environment.
- Eat low on the food chain. Top carnivores get the least energy and the most poison.
- Buy local produce in season –to reduce transportation costs and the need for pesticides.
- Buy at farmers' markets or a Community Supported Agriculture (CSA) programs to support local farmers and reduce demand for energy-consuming and polluting large-scale agriculture and marketing.
- Choose organic produce - for your own health and to protect the environment from excessive nutrients and pesticides (**Figure** 17.17).

- ***When you buy fish for food or for your aquarium***
- Check to be sure that commercial species are not from overharvested areas,
- Verify that tropical saltwater fish were not collected using cyanide.

- ***When you need paper products,*** be sure they are made of recycled fiber.
- Or consider alternative materials such as hemp, kenaf, cornstarch, or old money or maps.
- Replace paper napkins and paper towels with cloth.
- Reuse envelopes and boxes. Wrap gifts in the comics or reusable cloth gift bags.

- ***When you buy products for cleaning,painting,or washing your car,***check the ingredients to be sure you are not exposing yourself and the environment to unnecessary toxins. Vinegar and baking soda work wonders!

- ***When you buy wood or wood products*** be sure harvesting followed **sustainable forest management** –practices which ensure future productivity, biodiversity, and ecosystem health.
- Look for SmartWood, FSC (Forest Stewardship Council) or similar labels.
- Consider recycled or salvaged wood.

FIGURE 17.18
One drop per second from a dripping faucet wastes 2,700 gallons of water per year and adds to sewer and/or septic costs, as well.

When You Use Water, Remember Its Importance To All Life

- Check for water leaks and repair drips with new washers (**Figure** 17.18).
- Use low-flush toilets and low-flow faucets and shower heads.
- Have your tap water tested; use filters or refillable delivery if needed, rather than bottled water.

When You Must Use Energy, Consider Consequences and Choose Your Source Carefully

- Unplug electronic equipment such as fax machines, power tools, and anything connected to a remote control.
- Turn off power sources and lights when not in use.
- Use your bicycle, and support bike-friendly cities and roads.
- Walk! It's good for you, as well as the environment.
- Use public transportation, and support its expansion.
- Make energy-efficiency your #1 priority when you purchase appliances.
- Make fuel-efficiency your #1 priority if you purchase a car.
- Turn down your thermostat, especially at night. Just 2^oF saves 500 pounds of greenhouse-inducing CO_2!
- Weatherstrip and caulk doors and windows.
- Replace incandescent with fluorescent light bulbs, which are four times as efficient and last far longer.
- The EPA Energy Star Logo helps consumers to identify energy-efficient products. The less fossil fuel energy we use, the fewer greenhouse gases we release, reducing the threat of climate change.

FIGURE 17.19
Computer equipment becomes obsolete quickly and contains toxins such as lead and mercury. Consider donating your obsolete equipment, and if you must discard it, be sure you follow specific guidelines for recycling and hazardous waste disposal.

When You Must Dispose of Waste, Learn the Best Practice for Its Disposal

- Reduce or eliminate your use of plastic bags, sandwich bags, and six-pack plastic rings (and don't release balloons!) so that endangered sea turtles do not mistake these for their favorite food - jellyfish.
- Minimize and compost food waste.
- Recycle motor oil and unused paint.
- Use appropriate local hazardous waste facilities for recommended chemicals and medicines.
- Donate obsolete computers and other electronic equipment –or if you cannot, recycle such "e-waste" properly (**Figure** 17.19).

Don't Contribute to the Burgeoning Problem of Exotic Species

(The following points reference **Figure** 17.20.)

- Don't release aquarium fish, turtles, birds, or other pets into the wild.

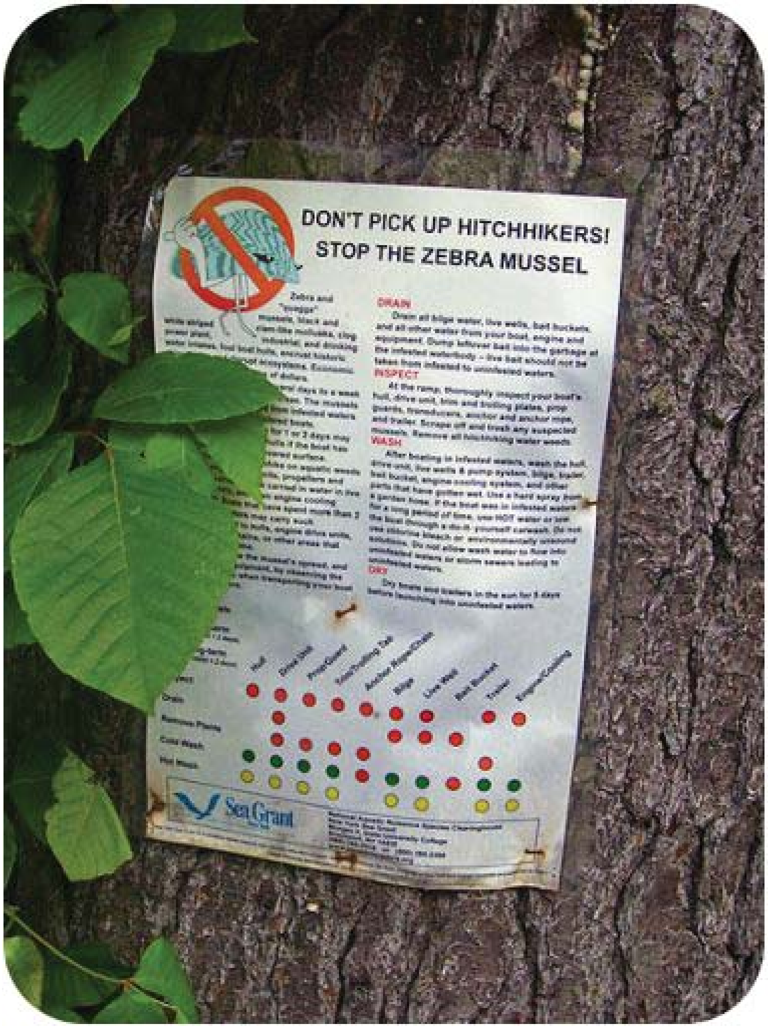


FIGURE 17.20
Exotic (invasive or alien) species are often considered the #2 cause of extinction. Learn how to avoid transporting them!

- Clean your boat thoroughly after use, and avoid traveling with wild plants and animals.
- Your pet is also considered to be an exotic species. Don't let your pets hunt birds or wild animals.

Practice Sustainable Management on Your Own Land, Even If it is "Only" a Small Yard

- Minimize nonpoint source pollution by using organic or natural pesticides and fertilizers.
- Plant shade trees for air-conditioning and to absorb CO_2.
- Water plants and lawns in the evening.
- Better yet, use native and/or drought-tolerant plants for landscaping.
- Remember that City, County, State, and Federal lands are your lands, too. Get involved in local zoning and land use planning to ensure that development follows sustainable guidelines.

Adopt and Spread Sustainable Perspectives and Philosophy

- Focus on diversity as a whole –genes, communities and ecosystems –rather than single "poster" species.

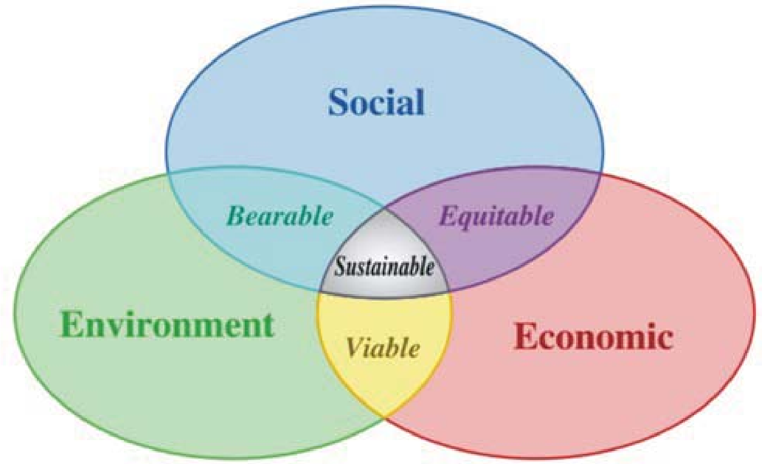


FIGURE 17.21
Sustainability as a goal in decision-making seeks the intersection of three sets of values. The environmental component includes maintaining ecosystem quality indefinitely.

- Support the inclusion of ecosystems services in economic valuations.
- Encourage protection of areas large enough to accommodate migration, flooding, buffer zones, pollution from nearby development, and people and their activities.
- Realize that inequitable distribution of population, land, resources, education, and wealth threatens biodiversity.
- Promote the concept of sustainability as a guide for conservation decisions (**Figure** 17.21).
- Join philosophers and religious and community groups to explore environmental ethics.
- Help *everyone* understand basic ecology and the wealth of biodiversity shaped by billions of years of evolution.

Learn More!

- About the species with which you share the Earth.
- About local, national, and international threats to biodiversity
- About more solutions as they develop
- Jump in! Join local groups which monitor ecosystem health: Frog Watch, River Watch, or Bird Counts.
- Educate yourself about complex issues such as government subsidies and new technologies.
- Find out about local protected lands and volunteer your time and energy to restore native ecosystems.

Activate!

- Exercise your citizenship to protect biodiversity. Vote, communicate your views, and push for stronger environmental protection laws.
- Support organizations which promote national reserves, international treaties, and resource conservation.
- Support efforts by zoos, arboretums, museums and seed banks to help maintain genetic diversity through research, breeding, educational, and fundraising programs.

Lesson Summary

- Like all species, humans depend on land, water, air, and living resources for food, energy, clothing, and **ecosystem services** such as nutrient recycling, waste disposal, and renewal of soil, freshwater, and clean air.
- Unlike other species, human technology supplements “natural” energy resources with fossil fuels and exploits both biotic and abiotic resources and produces wastes beyond the biosphere’s capacity for renewal.
- Biodiversity encompasses all variation in living systems, including genetic, species, and ecosystem diversity.
- Scientists do not know how many species currently inhabit the Earth; the vast majority of Bacteria and Archaea, Protists and Insects, are probably unknown. We discover new species of animals, plants, and fungi each year.
- About 1.8 million species have been identified, and most estimates of Earth’s overall species biodiversity fall between 5 and 30 million.
- In general, biodiversity is highest near the equator, and decreases toward the poles.
- Biodiversity “hotspots” such as the California Floristic Province and unique habitats such as bogs occasionally disrupt the overall pattern.
- The fossil record and DNA analysis reveal a gradual increase in Earth’s biodiversity after the first prokaryotes appeared roughly 4 billion years ago.
- Within the past 600 million years, a more detailed fossil record shows increasing biodiversity interrupted by five major extinctions in which at least 50% of species disappeared.
- According to a 1998 survey by the American Museum of Natural History, more than 70% of biologists consider the present era to be a sixth mass extinction event.
- Many scientists regard the Ice Age extinctions of large birds and mammals as the beginning of a continuum of extinctions caused by human activity which extends to the present.
- Dramatic losses of large mammal species follow a pattern of human dispersal across the globe from tens of thousands of years ago in Indonesia to just over 1,000 years ago in New Zealand, and over 20% of all bird species have become extinct within the past 1,100 years.
- Rates of extinction have accelerated in the past 50 years; current estimates include 3 species per hour and as many as 140,000 per year.
- In 2002, Harvard biologist E.O. Wilson predicted that if current rates of extinction continue, 50% of plant and animal species will be lost within the next 100 years –compared to hundreds of thousands or even millions of years for previous mass extinctions.
- Direct economic benefits include the potential to diversify our food supply, resources for clothing,shelter, energy, and medicines, a wealth of efficient designs which could inspire new technologies, models for medical research, and an early warning system for toxicity.
- Ecosystem services provided by biodiversity include ecosystem stability and productivity; maintaining and renewing soils, water supplies, and the atmosphere; nitrogen fixation and nutrient recycling; pollination, pest and disease control, and waste disposal.
- Less tangible but equally important are the cultural, aesthetic, and spiritual values and the importance of biodiversity to many modes of recreation.
- Finally, many people believe that biodiversity has intrinsic value, inherent in its existence.
- Human hunting, secondary effects on other species, disease carried and predation by exotic animals, and habitat destruction contributed to Ice Age extinctions.
- Habitat loss, including degradation and fragmentation, is the primary cause of extinction today; agriculture and deforestation continue to claim vegetated land and pollute both fresh and salt water seas.

1. Slash-and-burn agriculture is destroying tropical forest at rates which could result in total loss by 2090.
2. In the U.S., agriculture has eliminated 50% of wetlands and 99% of tallgrass prairies.
3. Logging and development have destroyed more than 90% of Temperate Rainforest in the U.S.

- Exotic species disrupt food chains and entire ecosystems to contribute to extinction.

- The modern equivalent to overkill, overexploitation of economically important species and ecosystems, threatens fisheries, tropical rain forests, whales, rhinos, large carnivores and many other species.
- Global climate change caused by the burning of fossil fuels disrupts weather patterns and, as it has throughout Earth's history, holds the potential to force the extinction of carefully adapted species.
- Pollution of land, air, and water poisons life and destroys ecosystems.
- Between 1960 and 1999, the Earth's human population increased from 3 billion to 6 billion people. Overpopulation combined with unequal distribution of resources dramatically intensifies pressures on biodiversity.
- Our daily activities and decisions can significantly help to protect biodiversity.
- After reducing consumption and reusing and recycling, careful consumption can help to conserve ecosystems.

1. Local, seasonal products save energy costs for transportation.
2. Durable and efficient products reduce long-term resource consumption.

- Wise use of water resources helps to prevent desertification of ecosystems.
- Energy alternatives to fossil fuels reduce greenhouse gases, although nuclear energy has its own dangers.
- After minimizing waste, best practices for waste disposal ensure less pollution of ecosystems.
- The threats to biodiversity posed by exotic species mean that everyone should learn to avoid transporting them.
- Sustainable management of land, from small yards to local, state, and federal lands, conserves ecosystems.
- Sustainability as a guide for decision-making balances social, economic, and environmental values to structure human activities such that they can continue indefinitely.
- Learning about biodiversity and ecology is an important part of valuing and protecting the diversity of life.
- Voting, membership in conservation organizations, and working toward protective legislation can contribute to genetic, species, and ecosystem diversity.

Review Questions

1. Compare humans to other species in terms of resource needs and use and ecosystem service benefits and effects.
2. Define biodiversity and explain its three major components.
3. Give the three quantitative values for Earth's species diversity, and compare biodiversity across the Earth's surface and throughout the history of life.
4. Construct a chart showing why you consider biodiversity important. Your chart should include four categories (of the five presented in the chapter, or of your own choosing) and the 2-3 examples from each chapter that you consider most critical).
5. Analyze humans' role in extinctions by comparing the causes we think contributed to the Ice Age extinctions to the causes important to extinction today.
6. How might Tallgrass Prairies, the Brown Tree Snake, the Atlantic Cod, and the Peregrine Falcon serve as "poster species" to explain and highlight some of the causes of extinction?
7. "Reduce, Re-use, and Recycle" is so familiar to many people that it has lost much of its meaning. Yet it remains an efficient summary of the best conservation principles. Explain. Choose one new idea to add to these workhorses.
8. What two (or three) ecological principles can govern your food choices to help protect your health, biodiversity, and even global stability?
9. How does the concept of sustainable use differ from "reduce, re-use, and re-cycle"? How is it similar?
10. According to Barry Commoner, there are Four Laws of Ecology:
    - Everything is connected to everything else.
    - Everything must go somewhere.
    - Nature knows best.

- There is no such thing as a free lunch.

Explain how his laws govern the way nature does –and humans should –use energy and material resources in order to protect biodiversity.

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Vocabulary

air pollution
Alteration of the Earth's atmosphere by chemical, particulate, or biological materials.

biodiversity hotspot

A biogeographic region which has lost at least 70% of its original habitat, yet contains at least 1500 endemic species of vascular plants.

biodiversity
Variation in life –at all levels of organization: genes, species, and ecosystems.

biological magnification (food chain concentration)
The process in which synthetic chemicals concentrate as they move through the food chain, so that toxic effects are multiplied.

bionics
Engineering which uses biological organisms' design principles to develop efficient products.

carbon sequestration
Process which removes CO_2 from the atmosphere.

desertification
Degradation of formerly productive land (usually at least semi-arid).

ecosystem diversity
The variety of ecosystems on Earth.

ecosystem services
Indirect benefits provided by ecosystem processes, such as nutrient cycling and waste disposal.

ecosystem
A functional unit comprised of living things interacting with their nonliving environment.

endemic
A unique species found only within a certain area and nowhere else.

epiphyte
Plant which grows on top of another plant.

exotic (alien) species
A species introduced either intentionally or unintentionally to a completely new ecosystem –a non-native species.

extirpation
Elimination of a species from a particular region of its range.

genetic diversity
Variation among individuals and populations within a species.

genetic pollution
Hybridization or mixing of genes of a wild population with a domestic or feral population.

global warming
The recent increase in the Earth's average near-surface and ocean temperatures.

greenhouse effect
The trapping by the atmosphere of heat energy radiated from the Earth's surface.

keystone species
Species having a functional importance to ecosystem diversity and stability which far outweighs its numerical or mass importance.

monoculture
Large-scale cultivation of single varieties of single species.

natural resource
Something supplied by nature which supports life, including sources.

pollution
Release into the environment of chemicals, noise, heat or even light beyond the capacity of the environment to absorb them without harmful effects on life.

salination
Increase in salt levels in soils.

species diversity
The number of different species in an ecosystem or on Earth.

sustainable forest management
Forest management which ensures that the goods and services yielded from a forest remain at a level that does not degrade the environment or the potential for similar levels of goods and services in the future.

sustainable use
Use of resources at a rate which meets the needs of the present without impairing the ability of future generations to meet their needs.

Points to Consider

- Most of this lesson considered species and ecosystem diversity. Why is genetic diversity also very important?
- How does biodiversity in your area compare to the general global pattern of biodiversity? Give some reasons why it may or may not follow general trends.
- Choose one other area in which you are interested, and make the same comparison.
- Do you find the extinction statistics presented in this lesson alarming? Why do you think we don't hear more about the Sixth Extinction and the predicted loss of biodiversity?
- Which values of biodiversity do you feel are most compelling?
- Which solutions will you adopt in your daily life?

17.2 Natural Resources

Lesson Objectives

- Distinguish between renewable and non-renewable resources.
- List the major energy and material resources upon which humans depend.
- Discuss the stresses increasing human consumption places on resource renewal.
- Sequence the events which lead to the formation of fossil fuels.
- Assess levels of depletion of non-renewable energy resources.
- Analyze the ways in which technology and consumption result in overharvesting, pollution, atmospheric changes, and habitat loss.
- Evaluate the effects of population growth on resource use and environmental pollution.
- Relate inequalities in resource distribution to global political stability.
- Compare the concept of sustainable use to that of renewable vs. nonrenewable resources.
- Describe the nature and uses of soil resources.
- Describe how human activities including technology affect ecosystem services such as

1. Soil generation
2. Waste disposal
3. Nutrient cycling
4. Recycling dead organic materials
5. Fertility of the land

- Discuss effects of population growth, technology, and consumption on land and soil resources.
- Relate soil erosion, pollution, and land development to ecosystem stability.
- Connect soil erosion, pollution, and land development to global stability.
- Evaluate the effects of changes in these services for humans.
- Review conflicts between agricultural technology, environment, and society.
- Recognize tradeoffs required by nuclear power plants: reduced emissions vs. radioactive fuels and waste.
- Analyze the ways in which humans have altered soil and land resources for other species.
- Identify the extent of terrestrial ecosystem loss, and its effects on biodiversity.
- Interpret the effects of soil pollution on biodiversity.
- Describe how human activities including technology affect ecosystem services such as:

1. The hydrologic cycle
2. Waste disposal
3. Nutrient cycling

- Evaluate the effects of changes in these services for humans.
- Discuss the effects of population growth, technology, and consumption on water resources.
- Explain the effects of overdrafting, pollution, and atmospheric changes on ecosystem stability.
- Relate overdrafting and pollution to global stability.
- Analyze the ways in which humans have altered water resources for other species.
- Identify the extent of wetland loss, and its effects on biodiversity.
- Interpret the effects of water pollution on biodiversity.

Introduction

Defining **natural resources** raises important philosophical questions.

"Resources" are useful or valuable. But are resources useful for and valuable to humans –or all life? If we "use" them, do we necessarily "consume" them? Is value limited to economics? Are resources limited to materials, or can they include processes, systems, and living things?

Definitions of "natural" go straight to the heart of our views about ourselves. Most definitions include a tension or conflict between the human and the non-human parts of the Earth: Anything that is natural is "not altered or disguised," "not produced or changed artificially," or, rather unhelpfully, "found in nature." We often define nature as separate from humans: "the world of living things and the outdoors" or with elements of inner conflict ("a primitive state of existence, untouched and uninfluenced by civilization or artificiality") or even religion ("humankind's natural state as distinguished from the state of grace").

It is not an idle exercise to think carefully about your own definition of natural resources, because such thinking can clarify your relationship and responsibilities to the Earth. Do natural resources exist only for humans to use (or "exploit" –a term repeated in many definitions)? Are we apart from nature, or a part of nature? In what ways are we similar to other species? How are we different? How do those similarities and differences help us to define our responsibilities to "nature" –to other species and our physical environment?

Historically, the concept of natural resources was intended as a measure of respect and appreciation for the materials Earth provided, and the supplies humans used and modified to develop the civilization in which they lived. Economic value was primary, and a list of natural resources would include energy sources such as coal or oil and raw materials such as iron or copper. Living things could be, but often were not added: fibers from plants, and skins from animals.

As use became exploitation and later depletion, we began to better appreciate our dependence on natural resources, as well as our power over them. Economist E.F. Schumacher, in a 1973 series of essays titled *Small is Beautiful,* suggested that our economy is unsustainable because natural resources (especially energy) can be depleted. He made the case that natural resources should be considered capital, rather than expendable –*conserved,* rather than simply *used.* He also argued that nature's capacity to resist pollution is limited, pointing to the value of whole ecosystems and ecosystem services. During the 1990s, ecological economist Robert Constanza calculated that "nature's services" were worth \$33 trillion per year –more than the \$25 trillion total of the inter-human economy at that time. Although awareness of resource depletion and ecosystem services is increasing, their values remain inadequately recognized by our economy, and sustainability remains a goal for the future.

What definition for natural resources shall we use? On the Department of Energy's "Ask a Scientist" website, Bob Hartwell defines a natural resource as "something supplied by nature which supports life on this planet." This concise description includes most of the ideas we've discussed above, and views human use with an ecological perspective appropriate for the study of biology. Humankind is a part of nature, one species in an interdependent web which includes the Earth and all life. Without question, we are a unique species: we have the power to change that interdependent web in ways no other species can, we have the ability to learn about and understand the patterns and processes which maintain the web, and we have the responsibility to use our natural resources together with that understanding in ways which sustain the web –for our ourselves and for all life.

Most biologists today would probably classify ecosystems, their processes and "services," and their species as natural resources, together with energy sources and materials from the environment. **Biodiversity** (which includes both species and ecosystems) is certainly a natural resource, according to this definition. In this sense, this entire chapter explores natural resources. The first lesson dealt with biodiversity as well as some of the ecosystem services which depend on biodiversity. This lesson will focus on energy, land and soil, and water resources. Because several unique problems (acid rain and **ozone depletion**, for example) apply to atmospheric resources, we will focus on the atmosphere in a third lesson. A final lesson will combine our concerns about the closely related issues of energy use and atmospheric change to focus on **climate change**. These lessons will by no means address all natural resources, but they should give you an overview of the complexities of and need for sustainable use, and provide you with some detailed insight into several major problems.

Renewable and Nonrenewable Resources: Energy and Sustainable Use

Applied to natural resources, **renewable** or **non-renewable** are relative rather than precise terms. Not surprisingly, we use human parameters to classify resources into these two categories.

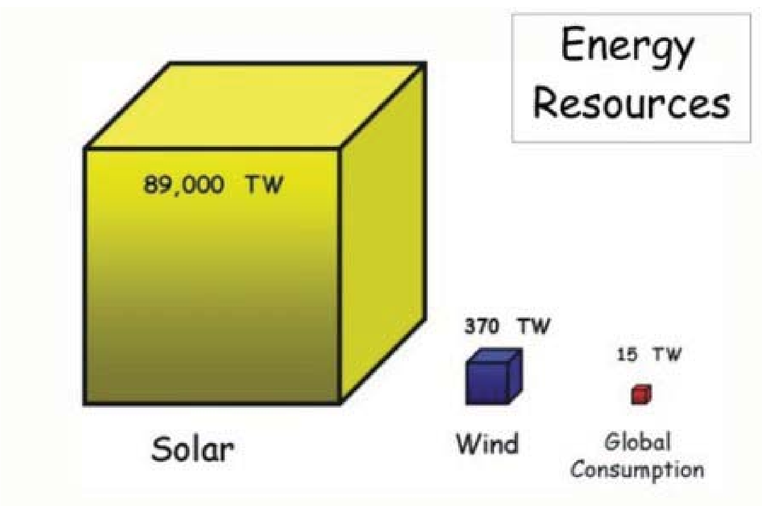

FIGURE 17.22

Solar radiation and wind energy are considered renewable resources because their availability far exceeds our rates of consumption. Here, availability is shown as volume equal to the annual flux in terawatts (1 TW = 10^{12} watts). Eighty-nine thousand TW represents the amount of sunlight that falls on the Earth's surface, 370 TW depicts all the energy in the wind, and 15 TW was the global rate of energy consumption in 2004.

A resource replenished by natural processes at a rate roughly equal to the rate at which humans consume it is a **renewable resource**. Sunlight and wind, for example, are in no danger of being used in excess of their longterm availability (**Figures** 17.22, 17.23). Hydropower is renewed by the Earth's hydrologic cycle. Water has also been considered renewable, but overpumping of groundwater is depleting aquifers, and **pollution** threatens the use of many water resources, showing that the consequences of resource use are not always simple depletion. Soils are often considered renewable, but erosion and depletion of minerals proves otherwise. Living things (forests and fish, for example) are considered renewable because they can reproduce to replace individuals lost to human consumption. This is true only up to a point, however; overexploitation can lead to extinction, and overharvesting can remove nutrients so that soil fertility does not allow forest renewal. Energy resources derived from living things, such as ethanol, plant oils, and methane, are considered renewable, although their costs to the environment are not always adequately considered. Renewable materials would include sustainably harvested wood, cork, and bamboo as well as sustainably harvested crops. Metals and other minerals are sometimes considered renewable because they are not destroyed when they are used, and can be recycled.

A **non-renewable resource** is not regenerated or restored on a time scale comparative to its consumption. Non-renewable resources exist in fixed amounts (at least relative to our time frame), and can be used up. The classic examples are fossil fuels such as petroleum, coal, and natural gas. Fossil fuels have formed from remains of plants (for coal) and phyto- and zoo-plankton (for oil) over periods from 50 to 350 million years. Ecologist Jeff Dukes estimates that 20 metric tons of phytoplankton produce 1 liter of gasoline! We have been consuming fossil fuels for less than 200 years, yet even the most optimistic estimates suggest that remaining reserves can supply our needs for

Oil: 45 years
Gas: 72 years
Coal: 252 years.

FIGURE 17.23
Wind power is considered a renewable resource because the rate of supply far exceeds the rate of use (**Figure**). Although current use supplies less than 1% of the world's energy needs, growth in harvesting wind energy is rapid, with recent annual increases of more than 30 percent.

Nuclear power is considered a non-renewable resource because uranium fuel supplies are finite. Some estimates suggest that known economically feasible supplies could last 70 years at current rates of use - although known, and probably unknown reserves are much larger, and new technologies could make some reserves more useful.

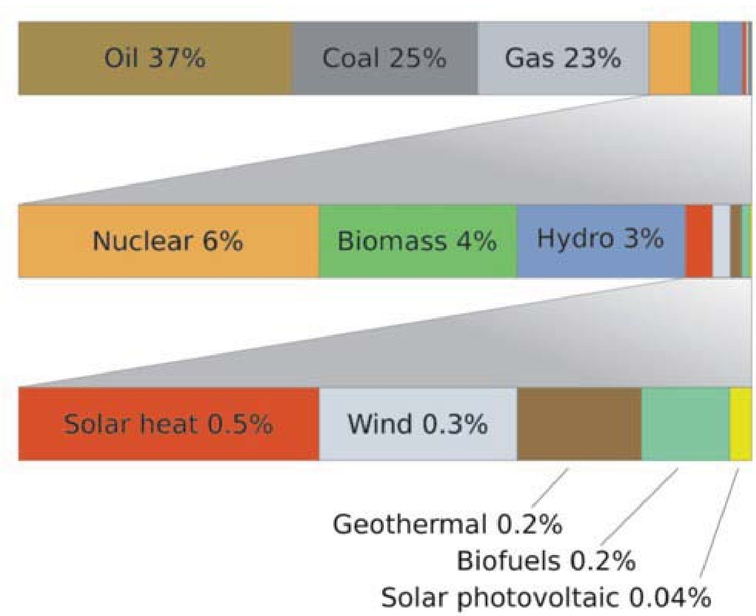

FIGURE 17.24
Global energy use includes mostly non-renewable (oil, coal, gas, and nuclear) but increasing amounts of renewable (biomass, hydro, solar, wind, geothermal, biofuels, and solar photovoltaic) resources.

Recall that the Second Law of Thermodynamics (which states that the entropy of an isolated system which is not in equilibrium will tend to increase over time) reinforces this view of "renewable" and "non-renewable" resources: Energy flows downhill –gets used up, is transformed into heat; only materials that can be recycled are "renewable." It is only our time scale which makes any form of energy renewable. Eventually, the sun will burn out, as well.

Population growth, industrialization of developing countries, and advances in technology are placing increasing pressures on our rates of consumption of natural resources. Pollution and overexploitation foreshadow resource depletion, habitat loss, and atmospheric change. Unequal distribution of wealth, technology, and energy use (**Figure** 17.25) suggest that developing nations will further increase demands on natural resources. With these increases in demand, current levels of resource use cannot be maintained into the future, and social and political instability may increase. Improvements in technology could mitigate these problems to some extent.

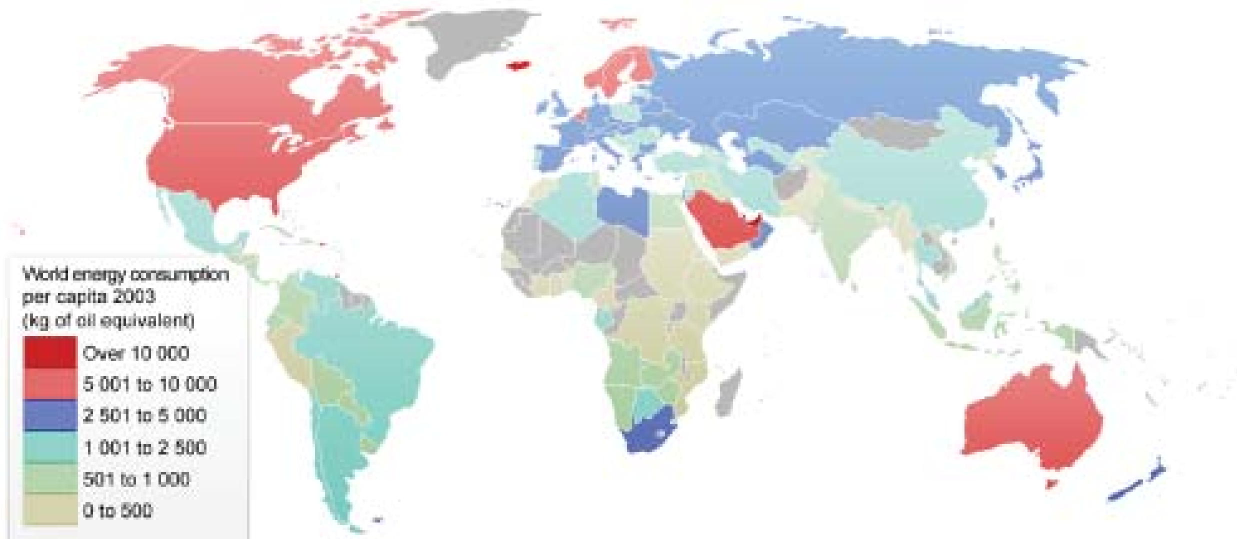

FIGURE 17.25

Per capita energy consumption illustrates the unequal distribution of wealth and natural resource use which threatens long-term resource supplies as developing nations demand higher standards of living. These inequalities threaten not only resource supplies but also global political stability.

The concept of renewable vs. non-renewable resources clearly depends on rates of human use (**Figure** 17.24); less clearly, its usefulness depends on the effects of use on other natural resources, such as pollution. Of course, we could change our rates of consumption. Indeed, if we increase our rate of consumption, renewable resources may need to be reclassified as non-renewable. This is the foundation of the concept of **sustainable use** –use of resources at a rate which meets the needs of the present without impairing the ability of future generations to meet their needs. Notice that this concept continues to focus on human needs; however, a solid understanding of ecology recognizes that human needs depend on entire ecosystems, which in turn depend on all species. Sustainable use could also apply to ecosystem services, which can be overwhelmed by overuse even though their "use" does not involve consumption. Perhaps we should shift our natural resource focus from rate of consumption (renewable vs. non-renewable) to sustainable use!

Soil and Land Resources

What negative connotations we give to soil resources in our daily conversation! Hands are "dirty;" clothing is "soiled." Yet the formation of soils require thousands and even millions of years of physical, geological, chemical, and biological processes. Soil's complex mixture of eroded rock, minerals, ions, partially decomposed organic material, water, air, roots, fungi, animals, and microorganisms supports the growth of plants, which are the foundation of terrestrial ecosystems (**Figure** 17.26). Soil is a balanced intersection of air, water, and land resources, sensitive to changes in any one element. We use soils for agriculture, gardening, landscaping, earth sheltered buildings, and to absorb waste from composting and septic drain fields. Peat, an accumulation of partially decayed plant material, can be burned for energy.

FIGURE 17.26
Soil resources are a complex mixture of eroded rock, minerals, ions, partially decomposed organic material, water, air, roots, fungi, animals, and microorganisms, formed over thousands or even millions of years.

Soils can assimilate and remove low levels of **contamination**, thus it is useful for waste treatment. Not surprisingly, high levels of contamination can kill soil microorganisms, which help to accomplish this service. Toxics from industry, underground storage tanks, pesticide use, and leaching from landfills and septic tanks contaminate soils across the globe. Contaminated soils endanger human and ecosystem health.

In 1980, after several years of health concerns and protests, the U.S. Government relocated and reimbursed 800 families from the Love Canal housing development built atop a landfill which had "disposed of" 22,000 tons of toxic waste from Hooker Chemical and Plastics Corporation. Increased awareness of the problems of abandoned toxic waste sites led to the passage later that year of **Superfund** legislation, which holds polluters accountable for effects of toxic waste, and taxes chemical and petroleum industries to pay for cleanup of sites where responsible parties cannot be identified. As of early 2007, the EPA listed 1,245 Superfund sites; 324 are delisted, and 66 new sites are proposed. In general, developing countries lag behind in identification, cleanup, and prevention.

Agriculture, as one of the largest land uses, has altered soils in a number of ways. When we harvest crops repeatedly from soil, we remove basic ions such as Calcium, Magnesium, Potassium, and Sodium. One result is **acidification**, which lowers soil fertility and productivity. **Acid rain** and the use of nitrogen fertilizers accelerate acidification, and acid rain can increase soil contamination.

Irrigation can degrade soils through **salination** –the accumulation of salts. High concentrations of salt make it difficult for plants to absorb water by osmosis, so salination reduces plant growth and productivity, and can lead to **desertification** (degradation of formerly productive land –usually at least semi-arid) and **soil erosion**.

Agriculture, deforestation, overgrazing, and development can remove vegetation to cause unnatural levels of erosion by wind and water. In the U.S., erosion forced its way into public awareness during the 1930s after drought compounded exposed soils. The famous Dust Bowl (**Figure** 17.27) resulted in the loss of at least 5 inches of topsoil from nearly 10 million acres of land and the migration of 2.5 million people out of the Great Plains. Today in the U.S., contour plowing, cover crops, terracing, strip farming, no-till farming, reforestation, and better construction practices prevent some soil erosion (**Figure** 17.28), but the USDA reports that 1.6 billion metric tons of topsoil were lost annually between 1997 and 2001. Since Great Plains agriculture began some 200 years ago, the U.S. has lost one-third of its topsoil. Alarming rates of slash-and-burn agriculture in tropical forests expose thin soils to erosion, and development in China sends 1.6 billion tons of sediment annually into the Yellow River.

FIGURE 17.27
Soil erosion in the U.S. peaked during the Dust Bowl years of 1933-1939. Intense dust storms (left) shifted vast quantities of unprotected rich prairie soil (right) –much of it all the way into the Atlantic Ocean.

FIGURE 17.28
Conservation practices such as terracing, contour plowing and conservation buffers (left) and conservation tillage (right) prevent soil erosion and improve water quality.

With –or sometimes without –its soil, **land resources** are used by humans for agriculture, forestry, mining, industry, waste disposal, and cities. Modification of land for these uses inevitably alters ecosystems, and in many cases, the resulting urban sprawl, pollution, salination, erosion, and/or desertification lead to the loss of species, as well. As you learned in the lesson on biodiversity, habitat loss is the primary cause of extinction. Within the past 100 years, the area of land cultivated worldwide has increased 74%; grazing land increased 113%. Agriculture has cost the United States 50% of its wetlands and 99% of its tallgrass prairies. Land changes also result in fragmentation, yet another threat to biodiversity. Pressures from population growth cause the loss of land for human use, as well: ecologist David Pimental reports that erosion and salination destroy more than 2 million acres of prime agricultural land each year, and urban growth, transportation systems, and industry remove a million additional acres from production. Global increases in cropland and pasture from 1700 to 1990 are shown in **Figure** 17.29.

Land use changes affect global processes as well as the ecosystems they directly involve. Deforestation –even if it is replaced by agriculture –reduces photosynthesis, which means that less CO_2 is removed from the atmosphere. The result is that CO_2 builds up –and as you will see in the fourth lesson of this chapter, an increase in CO_2 means an increase in the **greenhouse effect** and **global warming**. The International Panel on Climate Change (IPCC) estimates that land use change contributes 1.6 gigatons of carbon (as CO_2) per year to the atmosphere. This is highly significant when compared to the better-known fossil fuel-burning carbon contributions of 6.3 gigatons.

Urbanization and industry contribute to yet another land use issue that affects water resources and the atmosphere. Increasingly, impervious surfaces such as parking lots, building roofs, streets and roadways are covering land areas. Impervious surfaces prevent water infiltration and groundwater recharge, increasing runoff and altering waterways. They deprive tree roots of aeration and water, decreasing productivity and increasing CO_2. Far more than vegetated surfaces, they absorb solar radiation and convert it to heat, increasing runoff, which eventually degrades streams. In the U.S., impervious surfaces cover an area almost as large as the state of Ohio. Solutions to this harmful impact include the development of porous pavements and green roofs (**Figure** 17.30).

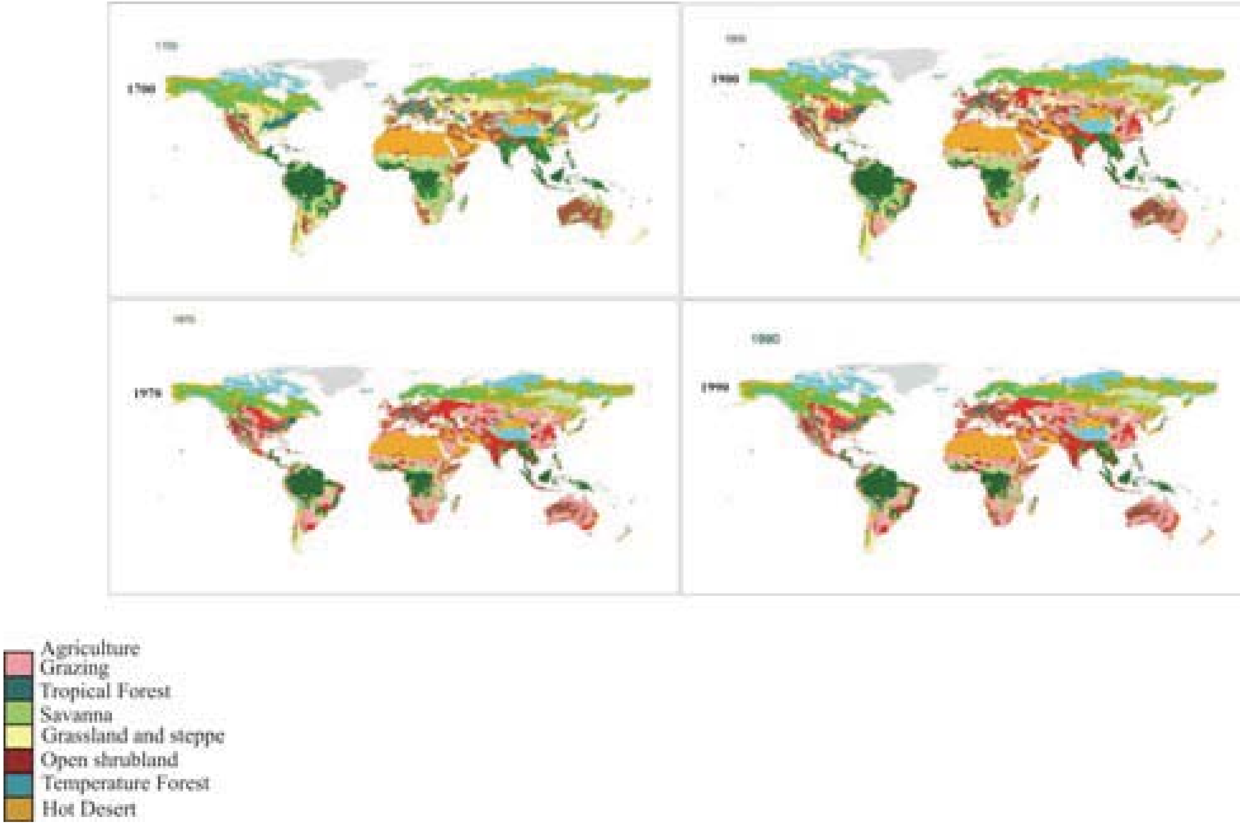

FIGURE 17.29

Changes in land use from 1700 to 1990 show the conversion of forests, grasslands, steppes, shrubland, and savannas to cropland (red) and grazing (pink).

FIGURE 17.30

Impervious surfaces (left) fragment habitats, increase runoff, degrade water sources, reduce photosynthesis, and effectively increase CO_2 in the atmosphere. In the U.S., they cover an area of land almost the size of Ohio. Permeable pavements and green roofs (right) are beginning to reverse their effects.

Water Resources

At the intersection of land and water resources are **wetlands**: swamps, marshes and bogs whose soil is saturated (**Figure** 17.31). Historically, humans have viewed wetlands as wasted land; the U.S. has lost as much of 50% of its wetlands to agriculture, development, and flood control. Recently, wetland loss and the loss wetland species has taught us the importance of this ecosystem. Ecosystem services provided by wetlands include:

1. water storage and replenishment of aquifers
2. protection of coastlands from tides and storms
3. flood control
4. water purification I: slowing of water flow allows sedimentation to remove particulates
5. water purification II: denitrification of excess nutrients
6. rich habitat for wildlife
7. rich habitat for plants (30% of U.S. plant diversity)
8. recreation: hunting, fishing, ecotourism (e.g., The Everglades)

In the U.S., at least, recognition of the economic value and biodiversity of wetlands has led to restoration efforts and requirements for replacement of those lost through development. The Ramsar "Convention on Wetlands of International Importance, especially as Waterfowl Habitat," signed by 18 nations in 1971, works to conserve wetlands throughout the world for their ecological services and their economic, scientific, cultural, and recreational values. Signatories today number 157, and they meet every 3 years.

FIGURE 17.31
Wetlands such as this area in Cape May, New Jersey, filter water both physically and chemically, protect coastal lands from storms and floods, and harbor an exceptional diversity of plants and animals.

Water is the quintessential resource of life; its unique physical, chemical and biological properties make it difficult for us to imagine life on any planet which lacks liquid water. For human use, however, water must be fresh. About 97% of Earth's water is found in the oceans. Of the 3% which is fresh water, over 2/3 is locked in ice. The 1% which is fresh liquid water is mostly below ground, leaving just 0.3% as surface water in lakes and rivers (**Figure** 17.32). The atmosphere contains just .001%.

As industry, agriculture, development, and a growing world population use more water, fresh water supplies are shrinking due to over-drafting of groundwater and pollution of surface and groundwater. Over-drafting has lowered water tables in Texas, California, and India, leaving many wells dry. New Orleans is below sea level, and San Jose, California dropped 13 feet, because over-pumping caused the land to subside. The UN and others have labeled the current state of water resources throughout the world a Water Crisis (**Figure** 17.33). You might wonder why we don't tap the oceans; the answer is that desalination is extremely costly in terms of energy and economics. The UN estimates that 1.1 billion people worldwide are without adequate fresh water, and that 2.6 billion lack enough water for sanitation to protect from disease. Water conflicts in the Middle East, Eastern Europe, and Korea have threatened regional political stability.

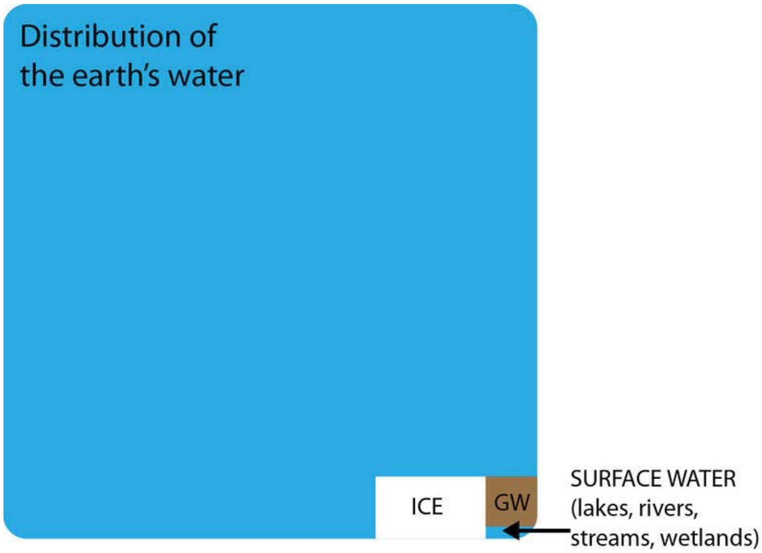

FIGURE 17.32
Earth is a watery planet, but only 3% is fresh water, and 2/3 of that is locked in ice. A little less than 1/3 is groundwater (GW), leaving 0.3% in surface water –the bright blue in the diagram above.

Water pollution, especially from **nonpoint sources** or runoff, threatens vital freshwater and marine resources in the U.S. and throughout the world. A single example dramatically illustrates the potential for disruption of natural cycles and loss of biodiversity. Runoff of fertilizers applied to vast expanses of agricultural land and other sources such as wastewater have led to what ecologists say is a doubling of the amount of nitrogen available to plants and animals, and that amount could increase by another 60% by 2050. At first glance this may seem like a benefit to life, but it is not. Especially in aquatic ecosystems, excessive nutrients lead to overgrowth of algae, creating **algal blooms**. Some species are toxic in themselves, but more often, this **eutrophication** - literally, "feeding too well" - leads to such high levels of respiration (recall that photosynthesizers must respirate –especially at night!) that dissolved oxygen levels plummet, resulting in the death of fish and other species. Death results in decomposition and further nutrient input –compounding the problem. Eutrophication threatens one of the most diverse habitats on earth –coral reefs, which cover just 1% of the earth's surface yet harbor 25% (over 4000) - of marine fish species. Adapted to low-nutrient environments and characterized by tight nutrient cycles, reefs in the pathway of excess nutrient runoff from agriculture and development become overgrown with algae, which block light from coral polyps. The Nature Conservancy predicts that 70% of Earth's coral reefs will have disappeared by 2050 if current rates of destruction continue.

Among the most devastating consequences of eutrophication are at least 146 **dead zones**, where low oxygen levels caused by eutrophication have extinguished all ocean life. The most notorious extends into the Gulf of Mexico at the mouth of the Mississippi River, which brings fertilizer runoff from the U.S. corn belt (**Figure** 17.34). In July of 2007, this dead zone covered an area of ocean the size of New Jersey and affected shrimp and fishing industries as well as countless species of marine organisms. Interestingly, a similar zone in the Black Sea disappeared between 1991 and 2001, after political changes in the Soviet Union and Eastern Europe made fertilizers too expensive to use for most agriculture. Unfortunately, most are growing, and the nitrogen cycle disruption affects many bodies of freshwater throughout the world, as well.

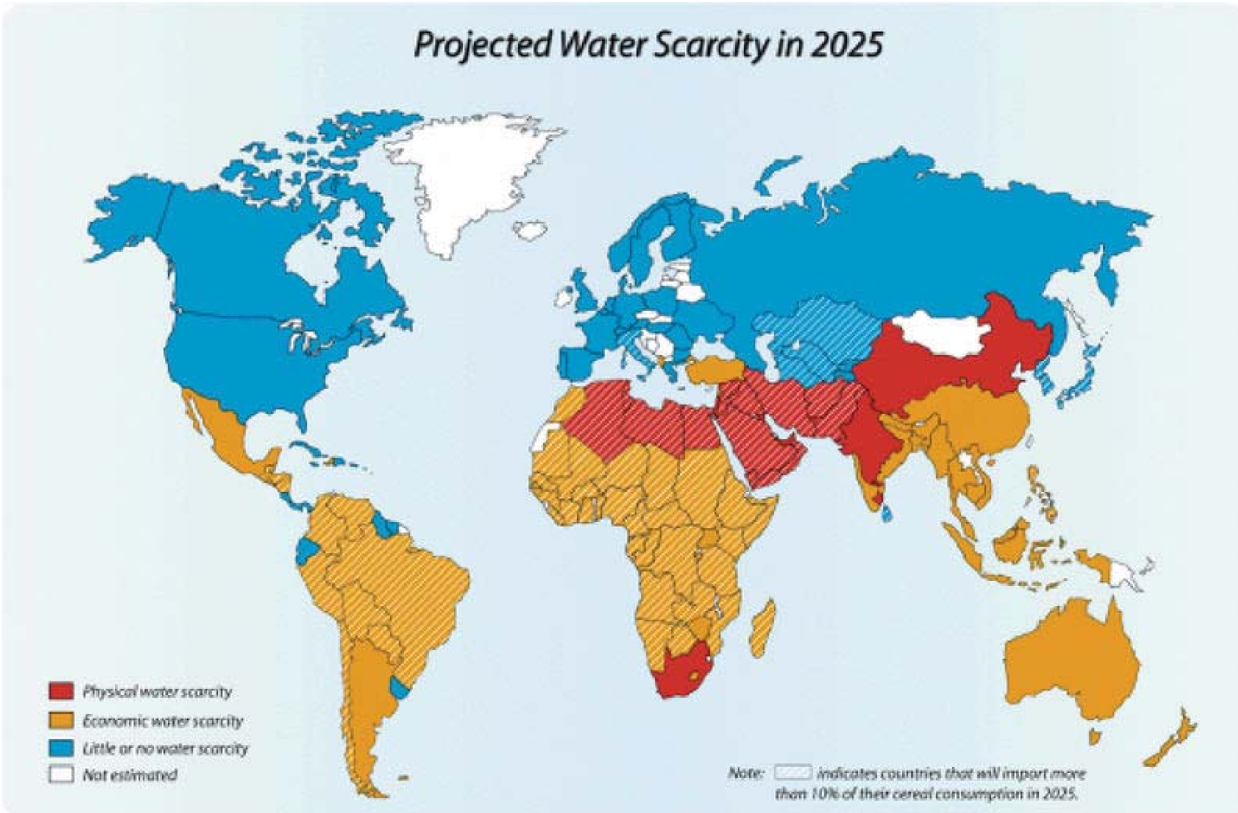

FIGURE 17.33
International Water Management Institute predicts expanding water shortages by 2025. The UN suggests a worldwide Water Crisis already exists. This map may oversimplify water problems; in the US, at least, drought and overdraft already threaten municipal and agricultural water supplies.

FIGURE 17.34
Eutrophication destroys marine and freshwater habitats and threatens biodiversity. Left: Nutrients and sediment flow from the Mississippi River watershed - into the Gulf of Mexico, creating a dead zone literally devoid of life. Right: A satellite photo of the Caspian Sea shows overgrowth of algae in the northern region where the Volga River brings excess nutrients from agricultural fertilizer runoff. Respiration by the algae and their bacterial decomposers lowers levels of dissolved oxygen so that most aquatic life dies.

Conserving Water and Other Natural Resources

Can you imagine what the expression **"virtual water"** could mean? It is an important concept in the conservation of water resources.

Virtual water is the water used in the production of a good or service. Although it is no longer contained in the product, its use is a part of the cost of production, and as such should be factored into the product's value. Here are some estimates of virtual water "contained" in various products, from the United Nations Education, Scientific, and Cultural Organization (UNESCO) Institute for Water Education:

- 1 kg wheat:1,300 liters
- 1 kg beef:15,000 liters
- 1 pair of jeans: 10,850 liters

The more water we use, the more likely we are to draw down wells and rivers beyond the hydrologic cycle's power to recharge them. The more water we use, the more we are likely to pollute the 1% of Earth's waters which are fresh (as well as the oceans). Protecting soils and lands (especially wetlands and watersheds) is a critical part of protecting water resources, because the hydrologic cycle integrates terrestrial and aquatic ecosystems.

Thus, as for all conservation (wise use) or **sustainable use** (meeting needs of the present without impairing those of future generations), the first step is to reduce our use of water. This and other strategies to protect our water resources are summarized below. Don't forget the list of what you can do as an individual, at the end of the lesson on biodiversity!

1. Reduce the use of water, and the abuse of soil, land, and wetlands.

- Landscape with native, drought-resistant vegetation.
- Use low-flow toilets, faucets, and showerheads. Check out possible local government subsidies for installing these water saving mechanisms.
- Purchase foods from water-efficient crops which do not require irrigation.

2. Reuse water where appropriate.

- Gray water, which has been used for laundry or washing, can be used to water gardens or flush toilets.
- On a municipal level, sewage water can be used for fountains, watering public parks or golf courses, fire fighting, and irrigating crops that will be boiled or peeled before consumption.

3. Catch runoff, which will also slow non-point source pollution and erosion.

- Place rainbarrels adjacent to buildings.
- Recharge pits which will re-fill aquifers.

4. Support legislation that reduces pollution.

- For example in the U.S., the 1977 Clean Water Act, through the EPA, regulates industrial discharge of contaminants and sets standards for water quality.

5. Work locally, nationally and internationally to make clean fresh water available.

- The United Nations Depart of Economic and Social Affairs has initiated a second Decade for Water for Life, 2005-2015 to increase awareness of water shortages and work toward sustainable use of freshwater resources.
- The World Water Council unites 300 member organizations from 60 countries to work to "build political commitment and trigger action on critical water issues at all levels... to facilitate the efficient management and use of water . . . on an environmentally sustainable basis."

Lesson Summary

- One's definition of natural resources clarifies human relationships and responsibilities to the Earth.
- Robert Hartwell's definition defines natural resources as: "something supplied by nature which supports life on this planet." This definition includes ecosystems, ecosystem services, biodiversity, energy sources and raw materials.
- Renewable resources are replenished by natural processes as fast as, or faster than humans consume them.
- A non-renewable resource is not regenerated or restored on a time scale comparative to its consumption. Fossil fuels are a classic example of nonrenewable resources.
- In practice, pressure from growing populations and increasing industrialization can lead to overconsumption and/or degradation, changing a renewable resource into a non-renewable resource.
- According to the Laws of Energy, energy resources are not renewable because they get used up, but materials or matter is constant because it can theoretically be recycled.
- The concept of sustainable use –the use of resources at a rate which meets the needs of the present without impairing the ability of future generations to meet their needs –may be more helpful in decision making.
- The world's current energy use is unsustainable, especially if increases in developing countries are considered.
- Soils are complex mixtures which evolved over thousands of years to support terrestrial ecosystems.
- Humans use soils for agriculture, forestry, and waste disposal.
- Although soils have been considered renewable resources, human activities have changed them through:

1. Contamination with heavy metals and toxins
2. Acidification
3. Erosion
4. Salination
5. Conversion to cropland, cattle production, forestry, and urban centers

- Despite soil conservation practices, the U.S. continues to lose topsoil to erosion, and developing countries are losing even more.
- Land resources are used for agriculture, forestry, industry, mining, waste disposal, and urban areas.
- In the process of converting land resources, the U.S. has lost:

1. 99% of tallgrass prairies
2. at least 50% of wetlands
3. an area the size of Ohio to impervious surfaces

- Worldwide, conversion of forests to other uses, especially by slash-and-burn, adds CO_2 to the atmosphere and reduces the potential for absorption of CO_2 by photosynthesis, adding to greenhouse gases.
- Wetlands, greatly reduced because of earlier views that they were wasted land, provide many ecosystem services, including flood control, water purification, aquifer recharge, plant and wildlife habitat, and recreation.
- Liquid fresh water, the primary water resource for human use, comprises less than 1% of all water on Earth; most of this is groundwater.
- As industry, agriculture, development, and a growing world population use more water, fresh water supplies are shrinking due to over-drafting of groundwater and pollution of surface and groundwater.
- According to the United Nations, the current Water Crisis involves 1.1 billion people without adequate water supplies and 2.6 billion people who lack adequate water for sanitation.
- Agricultural fertilizer runoff and waste water add excess nutrients to surface waters, leading to algal blooms and eutrophication.
- Dead zones in coastal areas such as the Gulf of Mexico result from agricultural runoff from large areas of land. The dead zone at the mouth of the Mississippi River was the size of New Jersey in the summer of 2007.

- Virtual water is the water used in the production of a good or service.
- The more water we use, the more likely we are to overdraft aquifers and pollute water supplies.
- Concepts similar to virtual water highlight the importance of REDUCING USE as a first principle in conservation or sustainable use.
- A second principle is to REUSE resources. For water conservation, this can mean re-using gray water from laundry or showers for gardens or flush toilets.
- Legislation can set standards for water quality and limits on pollution.
- Local, national, and international organizations can work to promote awareness and encourage action.

Review Questions

1. Distinguish between renewable and nonrenewable resources, and relate these concepts to the Laws of Energy.
2. Classify the following resources as renewable or nonrenewable: coal, copper, iron, natural gas, nuclear power, oxygen, sunlight, water, wood, wool. Briefly explain your reasoning for each resource.
3. Describe the formation of soil, and classify it as a renewable or nonrenewable resource.
4. Compare and contrast land which has undergone desertification to ecosystems which harbor natural deserts. How can the apparently life-promoting act of irrigation eventually have the opposite effect?
5. We no longer experience the obvious tragedies associated with the Dust Bowl of the 1930s. Does this mean that soil erosion is no longer a significant problem?
6. Connect land use changes (e.g. forest to agriculture) to global warming. How important is this relationship?
7. List the ecosystem services of wetlands, and describe the extent of their loss.
8. Earth is the "water planet." Why are we threatened with a Water Crisis?
9. Explain why eutrophication –"too much a good thing" results in problems for aquatic life.
10. Analyze the disappearance of the Black Sea "dead zone" for its potential to help solve water pollution problems.

Further Reading / Supplemental Links

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- http://www.lifewater.org/
- http://www.amnh.org/exhibitions/water/
- http://www.smm.org/deadzone/
- http://www.iisd.org/natres/
- http://en.wikipedia.org

Vocabulary

acid rain
Precipitation in any form which has an unusually low pH.

algal bloom
A rapid increase in the growth of algae, often due to a similar increase in nutrients.

anthropogenic sources
Sources of pollution related to human activities.

biodiversity
Variation in life –at all levels of organization: genes, species, and ecosystems.

biological magnification (food chain concentration)
The process in which synthetic chemicals concentrate as they move through the food chain, so that toxic effects are multiplied.

dead zone
Region of the ocean in which nutrient runoff and consequent eutrophication lower oxygen levels to the point at which life can no longer survive; less often applies to similar conditions in freshwater lakes.

desertification
Degradation of formerly productive land (usually at least semi-arid).

ecosystem
A functional unit comprised of living things interacting with their nonliving environment.

eutrophication
An increase in nutrient levels in a body of water, often followed by an increase in plant or algae production.

global warming
The recent increase in the Earth's average near-surface and ocean temperatures.

greenhouse effect
The trapping by the atmosphere of heat energy radiated from the Earth's surface.

natural resource
Something supplied by nature which supports life, including sources of energy and materials, ecosystems, and ecosystem services.

nonpoint source pollution
Runoff of nutrients, toxins, or wastes from agricultural, mining, construction, or developed lands.

nonrenewable resource
A resource which is not regenerated or restored on a time scale comparative to its consumption.

ozone depletion
Reduction in the stratospheric concentration of ozone molecules, which shield life from damaging ultraviolet radiation.

point source pollution
Single site sources of nutrients, toxins, or waste, such as industrial or municipal effluent or sewer overflow.

pollution
Release into the environment of chemicals, noise, heat or even light beyond the capacity of the environment to absorb them without harmful effects on life.

primary pollutants
Substances released directly into the air by processes such as fire or combustion of fossil fuel.

renewable energy sources
Sources of energy which are regenerated by natural sources within relatively short time periods, e.g. solar, wind, and geothermal, as opposed to fossil fuels.

renewable resource
A resource which is replenished by natural processes at a rate roughly equal to the rate at which humans consume it.

salination
Addition of salts to soils, often by irrigation.

secondary pollutants
Substances formed when primary pollutants interact with sunlight, air, or each other.

soil erosion
Removal of soil by wind and water in excess of normal processes.

sustainable use
Use of resources at a rate which meets the needs of the present without impairing the ability of future generations to meet their needs.

virtual water
The water used in the production of a good or service.

wetland
Swamps, marshes and bogs whose soil is saturated.

Points to Consider

- What is your own concept of natural resources? What relationship between humans and the Earth does it contain?
- Aldo Leopold wrote:"There are two spiritual dangers in not owning a farm. One is the danger of supposing that breakfast comes from the grocery, and the other that heat comes from the furnace." (http://en.wikiquote.org/wiki/Aldo_-Leopold
- Were you surprised by the virtual water data for beef or jeans? What other "virtual resources" are part of the products we consume?
- What kinds of legislation help to incorporate this level of water use in prices? What types of legislation prevent water use from being included in costs?
- Compare this statement from The Great Law of the Iroquois Confederacy to the contemporary concept of sustainable use: "In every deliberation we must consider the impact on the seventh generation... even if it requires having skin as thick as the bark of a pine." (http://en.wikipedia.org/wiki/Seven_generation_sustainability

17.3 Natural Resources II: The Atmosphere

Lesson Objectives

- Recognize that the Earth's atmosphere provides conditions and raw materials essential for life.
- Review the changes in the atmosphere over the history of the Earth.
- Describe the dynamic equilibrium which characterizes the natural atmosphere.
- Analyze the ways in which population growth, fossil fuel use, industrialization, technology, and consumption result in atmospheric changes.
- Explain the effects of these changes on ecosystems.
- Relate these effects to current global stability.
- Describe how human activities including technology affect ecosystem services such as:

1. nutrient cycling
2. hydrologic cycle
3. waste disposal

- Evaluate the effects of changes in these services for humans.
- Identify the ways in which humans have altered the air for other species.
- Relate air pollution to ecosystem loss.
- Interpret the effects of air pollution on biodiversity.
- Define acid rain.
- List the natural and anthropogenic causes of acid rain.
- Identify the effects of acid rain.
- Discuss solutions specific to the problem of acid rain.
- Locate and describe the origin of the ozone layer.
- Distinguish between ozone depletion and the ozone hole.
- Explain the role of ozone in absorbing ultraviolet radiation.
- Indicate the ways in which the ozone layer varies naturally.
- Discuss the relationship between recent changes in the ozone layer and human activities.
- Describe the measures taken to restore the ozone layer and evaluate their effectiveness.

Introduction

Air: so easy to take for granted. In its pristine state, we cannot see it, smell it, taste it, feel it, or hear it, except when the wind blows or clouds form. Yet its complex and dynamic mix of gases is essential for life. Nitrogen (78%) provides atoms which build proteins and nucleic acids via the nitrogen cycle. Oxygen (21%) permits the production of the ATP through cellular respiration, to power life. Carbon dioxide (.04%) provides the carbon for carbohydrate fuels and carbon skeletons to build life's bodies. Water (1-4% near the Earth's surface) has so many unique properties (adhesion, surface tension, cohesion, capillary action, high heat capacity, high heat of vaporization. . . and more) that it is difficult for us to imagine any form of life on any planet which does not depend on it. As a major component of the hydrologic cycle, the atmosphere cleans and replenishes Earth's fresh water supply, and refills the lakes, rivers, and oceans habitats for life (**Figure** 17.35). The Earth's atmosphere thins but reaches away from its surface for 100 kilometers toward space; between about 15 and 35 km lies the Ozone Layer –just a few parts per million which shields life from the sun's damaging Ultra-Violet radiation. Earth's atmosphere appears ideal for life, and indeed, as far as we know it is the only planetary atmosphere which supports life.

FIGURE 17.35
A composite photo of satellite images shows Earth and its life-supporting waters and atmosphere.

As we noted in the History of Life chapter, the Earth's atmosphere has not always been this hospitable for life. Life itself is probably responsible for many dramatic changes, including the addition of oxygen by photosynthesis, and the subsequent production of ozone from accumulated oxygen. Changes in CO_2 levels, climate, and sea level have significantly altered conditions for life, even since the addition of oxygen some 2 billion years ago. On a daily time scale, dramatic changes take place:

- most organisms remove O_2 and add CO_2 through cellular respiration
- most autotrophs remove CO_2 and add O_2 through photosynthesis
- plants transpire vast quantities of water into the air
- precipitation returns it, through gentle rains or violent storms, to the Earth's surface

On a human time scale, the daily dynamics balance, and the atmosphere remains at equilibrium –an equilibrium upon which most life depends.

Upsetting the Equilibrium of the Atmosphere: Air Pollution

Despite the atmosphere's apparent vastness, human activities have significantly altered its equilibrium in ways which threaten its services for life. Chemical substances, particulate matter, and even biological materials cause **air pollution** if they modify the natural characteristics of the atmosphere. **Primary pollutants** are directly added to the atmosphere by processes such as fires or combustion of fossil fuels (**Figure** 17.36). Secondary pollutants, formed when primary pollutants interact with sunlight, air, or each other, can be equally damaging. The chlorine and bromine which threaten the Ozone Layer are **secondary pollutants**, formed when refrigerants and aerosols (primary pollutants) decompose in the stratosphere (**Figure** 17.37).

FIGURE 17.36
Burning fossil fuels –by factories, power plants, home furnaces, and motor vehicles –is a major source of air pollution.

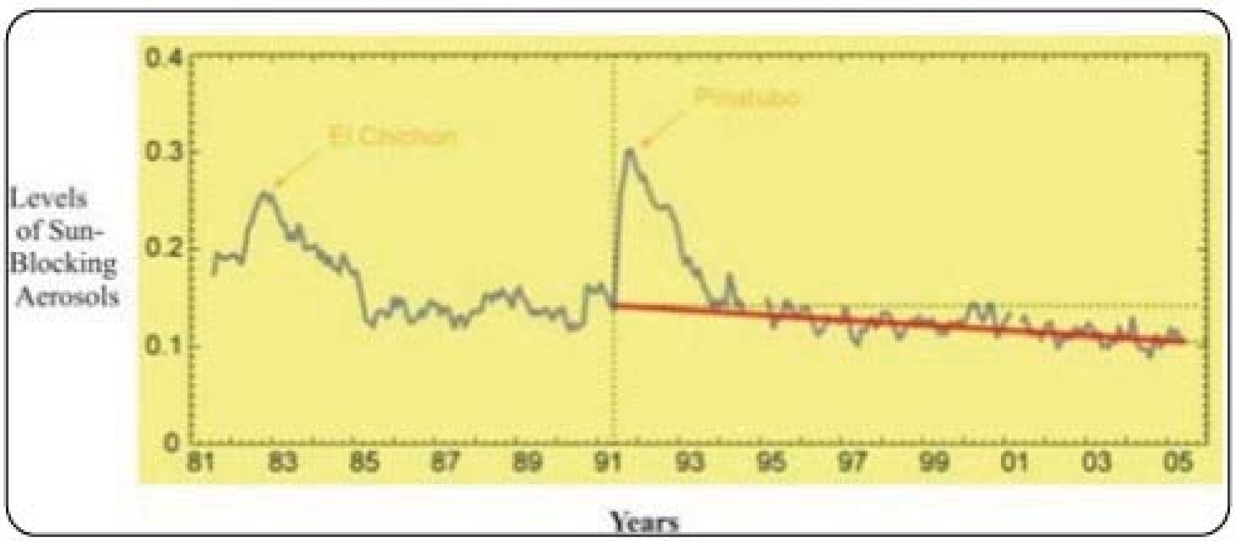

FIGURE 17.37
Levels of sun-blocking aerosols declined from 1990 to the present. A corresponding return to pre-1960 levels of radiation suggests that pollution control measures in developed countries have counteracted Global Dimming. However, particulates are still a problem in developing countries, and could affect the entire global community again in the future. Aerosol increases in 1982 and 1991 are the result of eruptions of two volcanoes, El Chichon and Pinatubo.

The majority of air pollutants can be traced to the burning of fossil fuels. We burn fuels in power plants to generate electricity, in factories to power machinery, in stoves and furnaces for heat, in airplanes, ships, trains, and motor vehicles for transportation, and in waste facilities to incinerate waste. Since long before fossil fuels powered the Industrial Revolution, we have burned wood for heat, fireplaces, and campfires and vegetation for agriculture and land management. The resulting primary and secondary pollutants and the problems to which they contribute are included in **Table** 17.2.

TABLE 17.2:

Pollutant	Example/Major Source	Problem
Sulfur oxides (SO_x)	Coal-fired power plants	Acid Rain
Nitrogen oxides (NO_x)	Motor vehicle exhaust	Acid Rain
Carbon monoxide (CO)	Motor vehicle exhaust	Poisoning
Carbon dioxide (CO_2)	All fossil fuel burning	Global Warming
Particulate matter (smoke, dust)	Wood and coal burning	Respiratory disease, Global Dimming
Mercury	Coal-fired power plants, medical waste	Neurotoxicity
Smog	Coal burning	Respiratory problems; eye irritation
Ground-level ozone	Motor vehicle exhaust	Respiratory problems; eye irritation

Beyond the burning of fossil fuels, other **anthropogenic** (human-caused) **sources** of air pollution are shown in **Table** 17.3.

TABLE 17.3:

Activity	Pollutant	Problem
Agriculture: Cattle Ranching	Methane (CH_4)	Global Warming
Fertilizers	Ammonia (NH_3), Volatile Organic Chemicals(VOCs)	Toxicity, Global Warming
Herbicides and Pesticides	Persistent Organic Pollutants(POP): DDT, PCBs, PAHs*	Cancer
Erosion	Dust	Global Dimming
Industry (solvents, plastics)	VOCs, POPs CFCs	Cancer, Global Warming Ozone Depletion
Refrigerants, Aerosols		
Nuclear power and defense	Radioactive waste	Cancer
Landfills	Methane (CH_4)	Global Warming
Mining	Asbestos	Respiratory problems
Biological Warfare	Microorganisms	Infectious Disease
Indoor Living	CO, VOCs, asbestos, dust, mites, molds, particulates	Indoor air pollution

- DDT = an organic pesticide; PCB = poly-chlorinated biphenyls, used as coolants and insulators; DDT and most PCBs are now banned at least in the U.S., but persist in the environment; PAHs = polycyclic aromatic hydrocarbons –products of burning fossil fuels, many linked to health problems

Many pollutants travel indoors in building materials, furniture, carpeting, paints and varnishes, contributing to indoor air pollution. In 2002, the World Health Organization estimated that 2.4 million people die each year as a consequence of air pollution –more than are killed in automobile accidents. Respiratory and cardiovascular problems are the most common health effects of air pollution, but accidents which release airborne poisons (the nuclear power plant at Chernobyl, the Union Carbide explosion in Bhopal, and the "Great Smog of 1952" over London) have killed many people –and undoubtedly other animals –with acute exposure to radiation or toxic chemicals.

If you study the problems caused by air pollution (third column in the tables, above), you will note that beyond human health, air pollution affects entire **ecosystems**, worldwide. **Acid Rain, Ozone Depletion**, and **Global Warming** are widespread and well-recognized global concerns, so we will explore them in detail in independent sections of this lesson, –and an entire lesson on Global Warming. Effects of toxins, which poison wildlife and plants as well as humans, were addressed in discussions of soil and water pollution in the last chapter. Before we move on to the "Big Three," let's take a brief look at the problems caused by particulates and aerosols, since these are unique pollutants of air, rather than soil or water.

"Global dimming" refers to a reduction in the amount of radiation reaching the Earth's surface. Scientists observed a drop of roughly 4% between 1960 and 1990, and attributed it to particulates and aerosols (in terms of air pollution, **aerosols** are airborne solid particles or liquid droplets). These pollutants absorb solar energy and reflect sunlight back into space. The consequences for life are many:

- Less sunlight means less photosynthesis.
- Less photosynthesis means less food for all trophic levels.
- Less sunlight means less energy to drive evaporation and the hydrologic cycle.
- Less sunlight means cooler ocean temperatures, which may lead to changes in rainfall, drought and famine.
- Less sunlight may have cooled the planet, masking the effects of Global Warming.

Recent measurements of sunlight-absorbing particulates show a decline since 1990, which corresponds to a return to normal levels of radiation (**Figure** 17.37). These data suggest that Clean Air legislation enacted by developed nations may have improved air quality and prevented most of the above effects, at least for now. Two caveats remain:

1. If "Global Dimming" did indeed mask Global Warming for 30 years, predictions about future climate change may be too conservative. Keep this in mind when we address Global Warming in the next lesson.
2. Population growth and industrialization of developing countries continues to increase levels of **pollution**.

Massive waves of pollution from Asian industry have blown across the Pacific by prevailing winds (**Figure** 17.38). On some days, atmospheric physicists at the Scripps Institution of Oceanography have traced nearly one-third of the air over Los Angeles and San Francisco directly to Asian sources. The waves are made of dust from Asian deserts combined with pollution from increasing industrialization, making the level of particulates and aerosols in Beijing, for example, reach levels 7 times World Health Organization standards. Scientists estimate that the clouds may be blocking 10% of the sunlight over the Pacific. By seeding clouds, the aerosols and particulates may be intensifying storms. In addition to direct effects on the global atmosphere (such waves can circle the Earth in three weeks), these pollution clouds can, as we stated above, mask Global Warming.

One additional topic relates to atmospheric change. **Light pollution** (**Figure** 17.39) results from humans' production of light in amounts which are annoying, wasteful, or harmful. Light is essential for safety and culture in industrial societies, but reduction in wasteful excess could mitigate its own harmful effects, as well as the amounts of fossil fuel used to generate it. Astronomers –both amateur and professional –find light interferes with their observations of the night skies. Some studies show that artificial spectra and excessive light exposure has harmful effects on human health. Life evolved in response to natural cycles and natural spectra of light and dark, so it is not surprising that our changes in both of those might affect us and other forms of life. Light pollution can affect animal navigation and migration and predator/prey interactions. Because many birds migrate by night, Toronto, Canada has initiated a program to turn out lights at night during spring and fall migration seasons. Light may interfere with sea turtle egg-laying and hatching, because both happen on coasts at nighttime. The behavior of nocturnal animals from

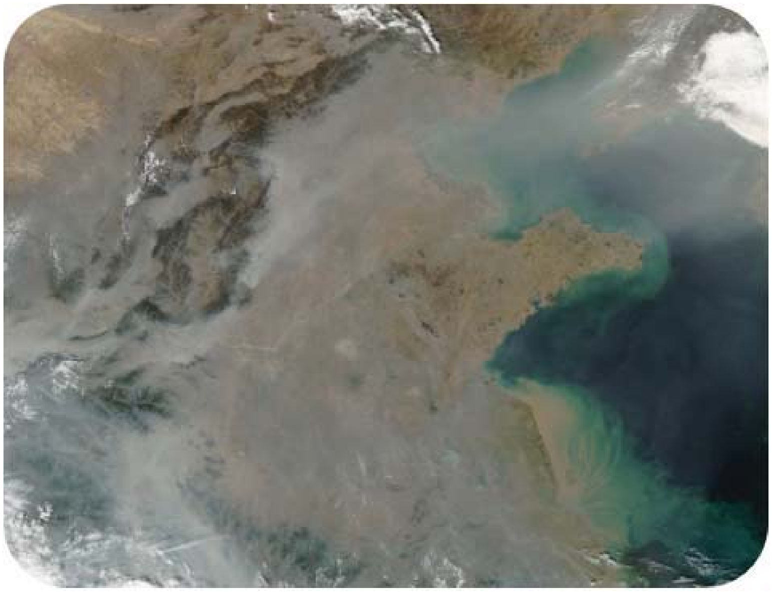

FIGURE 17.38

A cloud of smoke and haze covers this region of China from Beijing (top center) to the Yangtze River (bottom right). At the top right, pollution is blowing eastward toward Korea and the Pacific Ocean. Aerosol pollution with large amounts of soot (carbon particles) is changing precipitation and temperatures over China. Some scientists believe that these changes help to explain increasing floods and droughts.

owls to moths can be changed by light, and night-blooming flowers can be affected directly or through disruption of pollination. Zooplankton normally show daily vertical migration, and some data suggests that changes in this behavior can lead to **algal blooms**.

FIGURE 17.39

When light produced by humans becomes annoying, wasteful, or harmful, it is considered light pollution. This composite satellite image of Earth at night shows that light is concentrated in urban –but not necessarily population –centers. The U.S. interstate highway system, the Trans-Siberian railroad, and the Nile River are visible at higher magnifications.

Solutions to problems caused by light pollution include

- reducing use
- changing fixtures to direct light more efficiently and less harmfully
- changing the spectra of light released
- changing patterns of lighting to increase efficiency and reduce harmful effects

Many cities, especially those near observatories, are switching to low-pressure sodium lamps, because their light is relatively easy to filter.

Acid Rain

Do you remember the pH scale? Its range is 0-14, and 7 is neutral –the pH of pure water. You've probably measured the pH of various liquids such as vinegar and lemon juice, but do you know how important even very small changes in pH are for life? Your body maintains the pH of your blood between 7.35 and 7.45, and death results if blood pH falls below 6.8 or rises above 8.0. All life relies on relatively narrow ranges of pH, because protein structure and function is extremely sensitive to changes in concentrations of hydrogen ions. An important pollution problem which affects the pH of Earth's environments is **Acid Rain** (**Figure** 17.40).

Rain, snow, fog, dew, and even dry particles which have an unusually low pH are commonly considered together as **Acid Rain**, although more accurate terms would be acid precipitation or acid deposition. You will remember that a pH below 7 is acidic, and the range between 7 and 14 is basic. Natural precipitation has a slightly acidic pH, usually about 5, mostly because CO_2, which forms 0.04% of the atmosphere, reacts with water to form carbonic acid:

TABLE 17.4:

CO_2 carbon dioxide	+ H_2O water	$\rightleftharpoons H_2CO_3$ carbonic Acid	$\rightleftharpoons HCO_3{}^-$ bicarbonate	+ H^+ hydrogen ion

This natural chemical reaction is actually quite similar to the formation of acid rain, except that levels of the gases which replace carbon dioxide are not normally significant in the atmosphere. The most common acid-forming pollutant gases are oxides of nitrogen and sulfur released by the burning of fossil fuels. Because burning may result in several different oxides, the gases are often referred to as "NO_x and SO_x." This may sound rather affectionate, but it's more accurate to think of it as obNOXious! Whereas the carbonic acid formed by carbon dioxide is a relatively weak acid, the nitric and sulfuric acids formed by NO_x and SO_x are strong acids, which ionize much more readily and therefore cause more damage. The reactions given below slightly simplify the chemistry (in part because NO_x and SO_x are complex mixtures of gases), but should help you see the acidic results of an atmospheric mixture of water and these gases.

TABLE 17.5:

NO_2 nitrogen dioxide	+ OH^- hydroxide ion (from water)	$\rightarrow HNO_3$ nitric Acid	$\rightleftharpoons NO_3{}^-$ nitrate	+ H^+ hydrogen ion

TABLE 17.6:

SO_3 sulfur trioxide	+ H_2O water	$\rightarrow H_2SO_4$ sulfuric acid	$\rightleftharpoons SO_4{}^{-2}$ sulfate	+ $2H^+$ hydrogen ions

Nitrogen and sulfur oxides have always been produced in nature by volcanoes and wildfires and by biological processes in wetlands, oceans, and even on land. However, these natural levels are either limited in time or amount; they account for the slightly acidic pH of "normal" rain. Levels of these gases have risen dramatically since the Industrial Revolution began; scientists have reported pH levels lower than 2.4 in precipitation in industrialized areas. Generation of electricity by burning coal, industry, and automobile exhaust are the primary sources of NO_x an SO_x. Coal is the primary source of sulfur oxides, and automobile exhaust is a major source of nitrogen oxides.

Because most life requires relatively narrow pH ranges near neutral, the effects of acid rain can be devastating. In soils, lowered pH levels can kill microorganisms directly, altering decomposition rates, nutrient cycles, and soil fertility. A secondary effect of increased acidity is the leaching of nutrients, minerals, and toxic metals such as aluminum and lead from soils and bedrock. Depletion of nutrients and mobilization of toxins weakens trees and

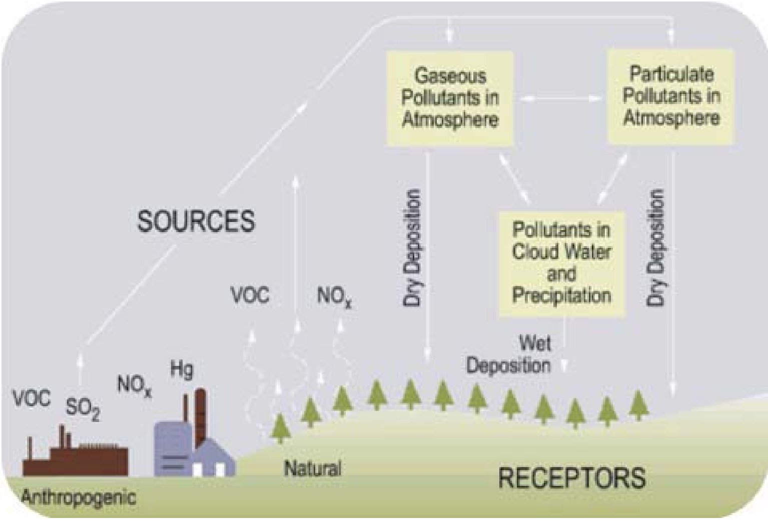

FIGURE 17.40

Acid rain formation begins when nitrogen and sulfur oxides (here NO_x and SO_2) and volatile organic compounds (VOC) from burning fossil fuels escape into the atmosphere. When these gases or particulates combine with water –either in the atmosphere or after reaching the ground –they become acid deposition. The term acid rain commonly refers to all forms of acid deposition.

other plants, especially at higher altitudes where higher precipitation and acid fog damage leaves and needles, as well (**Figure** 17.41).

FIGURE 17.41

A mountain forest in the Czech Republic shows effects attributed to acid rain. At higher altitudes, effects on soils combine with direct effects on foliage of increased precipitation and fog.

The flow of acid rain through watersheds increases acidity, nutrients, and toxins in aquatic ecosystems. Fish and insects are sensitive to changes in pH, although different species can tolerate different levels of acidity (**Figure** 17.42). Food chain disruption can compound even slight changes in pH; for example, acid-sensitive mayflies provide food for less-sensitive frogs. Additional nitrates in aquatic systems can lead to **eutrophication** and **algal blooms**, discussed in the last lesson.

The sensitivity of lakes, streams, and soils to damage from acid rain depends on the nature of the soils and bedrocks. Watersheds containing limestone, which can buffer (partially neutralize) the acid, are less severely affected. In addition, northern regions with long winters suffer "acid shock" when spring thaws dump months of accumulated acid precipitation into streams and rivers. In the US, lakes and streams in the Appalachians, northern Minnesota and upper New York, and Western mountains have been more severely impacted by acid rain. According to the EPA, the

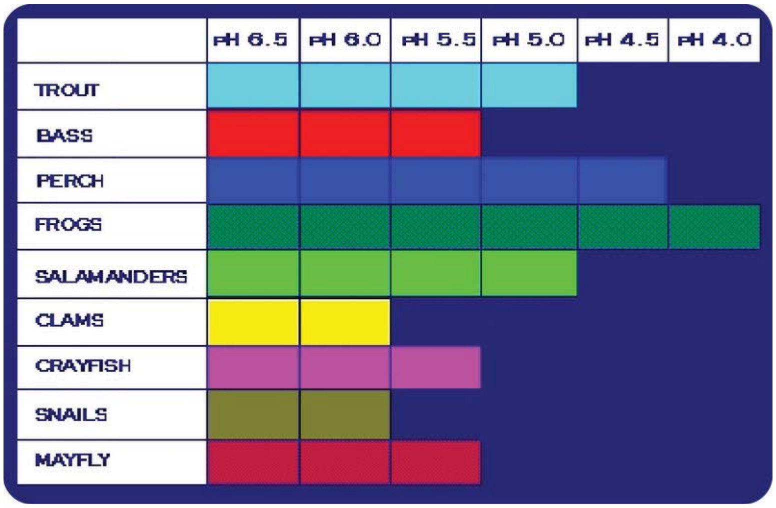

FIGURE 17.42
Aquatic species show varying sensitivity to pH levels. Colored bars show survival ranges. Trout are more sensitive to increasing acidity than frogs, but mayflies, which frogs consume, are even more sensitive. Consequently, changes in a lake's acidity may affect ecosystems more severely than simple species sensitivity charts would indicate.

pH of Little Echo Pond in New York state, 4.2, is one of the lowest in the U.S.

Another class of victims of acid rain is entirely within the realm of human culture and history. Acid's ability to corrode metal, paints, limestone, and marble has accelerated erosion of buildings, bridges, statues, monuments, tombstones, and automobiles (**Figure** 17.43).

FIGURE 17.43
Acid rain accelerates erosion of statues, monuments, buildings, tombstones, bridges, and motor vehicles.

Attempts to solve the problem of acid rain began with building taller smokestacks. These only sent the polluting gases higher into the atmosphere, relieving local problems temporarily, but sending the damage to areas far from their industrial sources. Today in the U.S. and other western nations, smokestacks increasingly use "scrubbers" which remove as much as 95% of SO_x from exhausts; the resulting sulfates "scrubbed" from the smokestacks can sometimes be sold as gypsum (used in drywall, plaster, fertilizer and more), but may also be landfilled. Catalytic converters and other emission control technologies remove NO_x from motor vehicle exhaust. However, population growth and development throughout the world is increasing pressures to use more fossil fuels and high-sulfur coal, often without these expensive technologies.

Ozone Depletion

Many people confuse the "hole in the ozone" with "global warming." Although the two are related in part, they are separate problems with separate effects and only partially overlapping causes, so they require separate solutions.

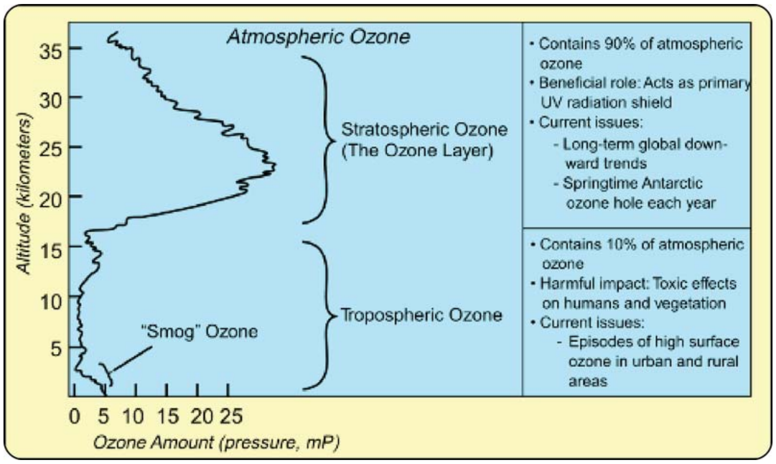

FIGURE 17.44
At altitudes less than 5 kilometers, respiratory irritant "smog" ozone forms when sunlight reacts with pollutants. The Ozone Layer, at altitudes between 15 and 35 kilometers, forms when UV radiation interacts with oxygen, and shields life on Earth from 97-99% of the Sun's damaging UV radiation.

Ozone is both a threat and a gift (**Figure** 17.45). As a ground-level product of the interaction between sunlight and pollutants, it is considered a pollutant which is toxic to animals' respiratory systems. However, as a component of the upper atmosphere, it has shielded us and all life from as much as 97-99% of the sun's lethal UV radiation for as long as 2 billion years. The "hole" in the ozone develops in this thin upper **Ozone Layer**. How long will that protection continue? Let's explore the problem of ozone depletion.

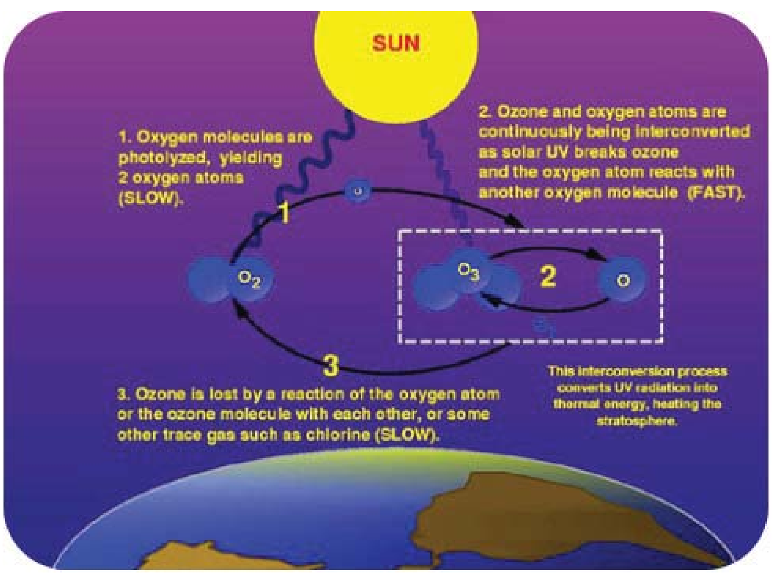

FIGURE 17.45
The ozone cycle involves the conversion of oxygen molecules to ozone (1 and 2) a slower reconversion of ozone molecules to oxygen (3). Interactions among ozone molecules or the presence of other reactive gases trigger the loss of ozone.

The Ozone (O_3) Layer forms when UV radiation strikes oxygen molecules (O_2) in the stratosphere, between 15 and 35 kilometers above the Earth's surface. Even the highest concentrations of ozone are only about 8 parts per million, but ever since photosynthesis oxygenated the Earth's atmosphere, allowing ozone-forming chemical reactions, this thin Ozone Layer has shielded life from the mutagenic effects of ultraviolet radiation –especially the more damaging UV-B and UV-C wavelengths (**Figure** 17.44).

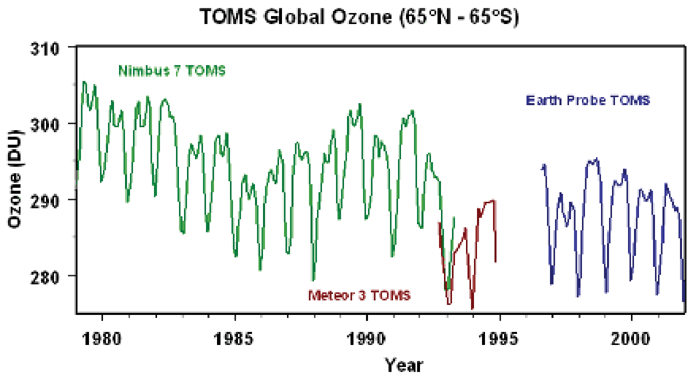

FIGURE 17.46

Total global monthly ozone levels measured by three successive spectrometers (TOMS) show both seasonal variations and a general decline.

The thickness of the Ozone Layer varies seasonally and across the Earth –thicker in Spring than in Autumn, and at the Poles compared to near the Equator. **Ozone depletion** describes two related declines in stratispheric ozone. One is loss in the total amount of ozone in the Earth's stratosphere –about 4% per year from 1980 to 2001 (**Figure** 17.47). The second, much larger loss refers to the **ozone hole** –a seasonal decline over Antarctica (**Figures** 17.48 and 14), which has now lost as much as 70% of pre-1975 ozone levels. A much smaller "dimple" overt the North Pole has also shown a 30% decline. The Antarctic ozone hole occasionally affects nearby Australia and New Zealand after annual breakup. A secondary effect is the decline in stratosphere temperatures, because when ozone absorbs UV radiation, it is transformed into heat energy.

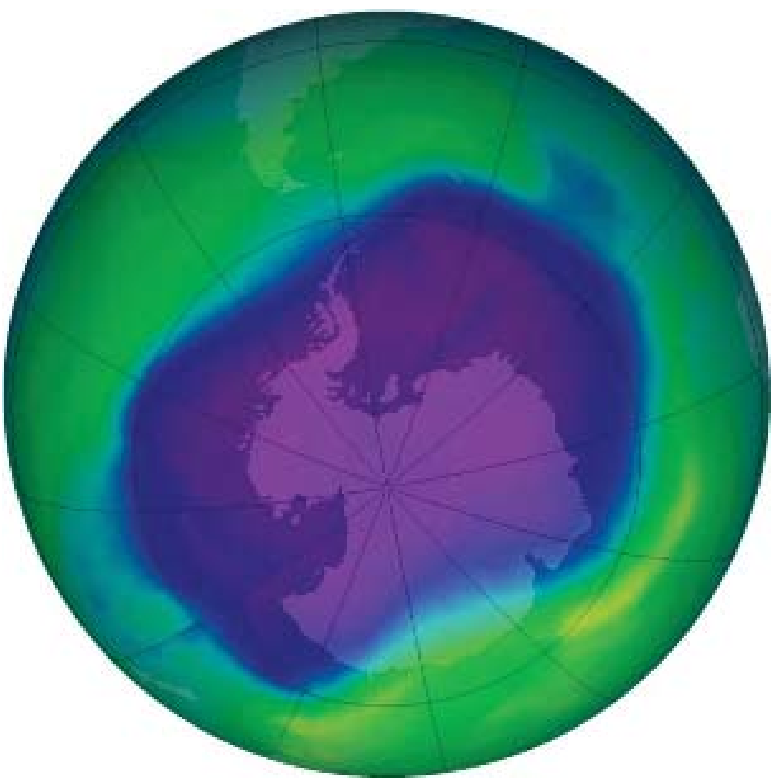

FIGURE 17.47

On September 24, 2006 the seasonal ozone hole over the Antarctic covered a record daily area (29.5 million square kilometres or 11.4 million square miles). Blue and purple areas show the lowest ozone levels, and green, yellow, and red indicate successively higher levels.

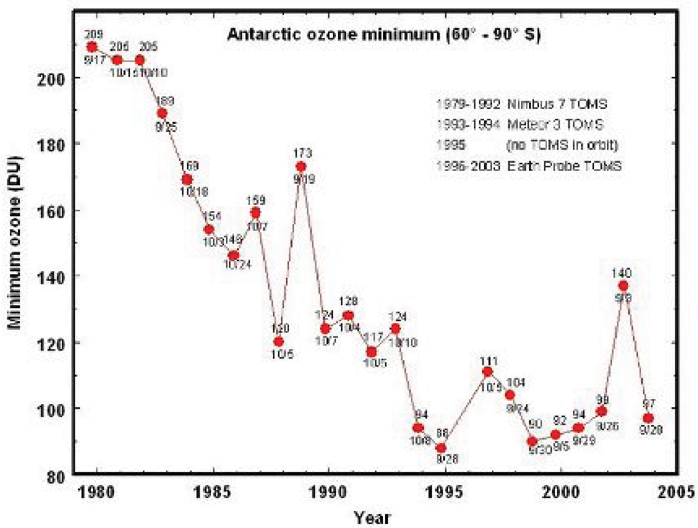

FIGURE 17.48

Lowest annual values of ozone in the ozone hole decreased dramatically between 1980 and 1995. Before 1980, values less than 200 Dobson units were rare, but in recent years, values near 100 units are common. Unusually high temperatures in the Antarctic stratosphere may have caused the high reading in 2002.

The causes of ozone depletion are gases which unbalance the ozone cycle (**Figure** 17.46) toward the breakdown of ozone. Chlorine and bromine gases have increased due to the use of *chlorfluorocarbons* (CFCs) for aerosol sprays, refrigerants (Freon), cleaning solvents, and fire extinguishers. These ozone-depleting substances (ODS) escape into the stratosphere, and when UV radiation frees chlorine and bromine atoms, these unstable atoms break down ozone. Scientists estimate that CFCs take 15 years to reach the stratosphere, and can remain active for 100 years. Each chlorine atom can catalyze thousands of ozone breakdown reactions.

Ozone depletion and the resulting increase in levels of UV radiation reaching earth could have some or all of the following consequences:

- effects on human health
- increase in skin cancers, including melanomas
- increased incidence of cataracts
- decreased levels of vitamin A
- possible increase in levels of vitamin D produced by the skin
- reduced abundance of UV-sensitive nitrogen-fixing bacteria
- loss of crops dependent on these bacteria
- disruption of nitrogen cycles
- loss of plankton (supported by a supernova-related extinction event 2 million years ago)
- disruption of ocean food chains

Most of these effects are based on the ability of UV radiation to alter DNA sequences. It is this potential which has made the Ozone Layer such a gift to life ever since photosynthesis provided the oxygen to fuel its production. Its total loss would undoubtedly be devastating to nearly all life.

In 1987, 43 nations agreed in the Montreal Protocol to freeze and gradually reduce production and use of CFCs. In 1990, the protocol was strengthened to seek elimination of CFCs for all but a few essential uses. Today, Hydrochlorofluorocarbons (HCFCs –similar compounds which replace one chlorine with a hydrogen) have replaced CFCs, with only 10% of their ozone-depleting activity levels. Unfortunately, HCFCs are greenhouse gases (see next lesson), so their role as alternatives is a mixed blessing. HFCs (hydrofluorocarbons) are another substitute; because these contain no chlorine, they have no ozone-depleting activity, and their **greenhouse effect** is less than HCFCs (though still significant). One HFC is currently used in automobile air conditioners in the U.S.

If ozone-depleting substances have been virtually eliminated, is ozone depletion no longer a problem?

Unfortunately, we have not yet reached that point. Levels of CFCs in the atmosphere are beginning to decline, and ozone levels appear to be stabilizing (**Figures** 17.47 and 14) for years after 2000). Scientists predict that ozone levels could recover by the second half of this century; the delay is due to the long half-life of CFCs in the stratosphere. However, recovery could be limited or delayed by two unknowns:

1. Developing countries outside the Montreal Protocol could increase their use of CFCs.
2. According to scientists, global warming would cool the stratosphere and increase ozone depletion because cooler temperatures favor ozone decomposition.

Preventing Air Pollution

Throughout this lesson, we have discussed solutions to specific problems for our atmosphere. A quick recap of ways to maintain our atmosphere and its ecosystem services from this chapter includes:

- Reducing use of fossil fuels
- Switching to cleaner fuels, such as nuclear power
- Switching to renewable energy sources
- Increasing fuel efficiencies
- Supporting legislation for fuel efficiencies
- Supporting national and international agreements to limit emissions
- Utilizing pollution control technologies: e.g., scrubbers on smokestacks and catalytic converters for motor vehicles
- Creating and supporting urban planning strategies

As always, costs are high and tradeoffs must be considered. The classic example is nuclear power, whose effects on the atmosphere are less than those of fossil fuels. Unfortunately, it has high potential for health damage and high costs –both economic and environmental –for storage and transport of nuclear waste.

Because fossil fuel use is the cause of so many atmospheric as well as water and soil pollutants, the solutions mentioned in the last two lessons apply here, as well. The final lesson on Climate Change relates directly to both fossil fuel combustion and atmospheric change, so more pollution solutions, specific to climate change, will be presented. You should also review the individual responses at the end of the lesson on **biodiversity**, because that list focuses on ways you can change your own life to help protect the environment.

Lesson Summary

- Earth's atmosphere, as we understand it today, provides ideal conditions and essential raw materials for life.
- Throughout Earth's history, the atmosphere has changed dramatically, and life caused some of the changes.
- Within human history, the atmosphere had been in a dynamic equilibrium: balancing photosynthesis, respiration, evaporation, and precipitation.
- Primary pollutants are directly added to the atmosphere by processes such as fires or combustion of fossil fuels. Secondary pollutants are formed when primary pollutants interact with sunlight, air, or each other.
- The majority of air pollutants can be traced to the burning of fossil fuels for heat, electricity, industry, transportation, and waste disposal.
- Worldwide, air pollution causes as many as 2.4 million deaths each year.
- Aerosols (particulates and liquid droplets) cab cause global dimming, or reduction in sunlight reaching the Earth.

- Light pollution can interfere with bird migrations, sea turtle reproduction, nocturnal animal behavior, and human activity.
- Rain, snow, fog, dew, and even dry particles which have an unusually low pH are commonly considered together as Acid Rain.
- Normal rain has a pH of about 5, due in part to formation of a weak (carbonic) acid from CO_2.
- Burning fossil fuels adds NO_x and SO_x gases to the atmosphere; these form strong acids (nitric and sulfuric) and change the pH of rain to as low as 2.4.
- Acid rain leaches nutrients and toxins from soils, weakening forests and killing aquatic animals.
- Limestone in bedrock or watersheds buffers the effects of acid rain for certain lakes.
- The development of taller smokestacks only sent pollution elsewhere, but scrubbers in smokestacks and catalytic converters in motor vehicles help to reduce emissions.
- The Ozone Layer in the stratosphere –formed from O_2 –protects Earth's life from mutagenic UV radiation.
- Ground-level ozone –formed from automobile exhaust and industry –is a component of smog, which irritates eyes and respiratory membranes.
- Ozone depletion is a global reduction in the thickness of the ozone layer, caused by chlorine and bromine atoms which reach the stratosphere.
- The ozone hole is a seasonal thinning of ozone above the Antarctic.
- CFCs in aerosol sprays, refrigerants (Freon), cleaning solvents, and fire extinguishers are the primary ozone-depleting substances (ODSs).
- The 1987 Montreal Protocol has reduced the use of CFCs and ozone depletion.
- Chemical substitutes, though less harmful, still cause damage, and countries outside the Protocol may still add ODS to the atmosphere.
- Global warming would cool the stratosphere and increase ozone depletion, because cooler temperatures favor ozone decomposition.
- Because fossil fuels are the source of many air pollutants, reducing their use is the key to solving air pollution problems.
- Technology can help by developing alternative energy sources, increasing fuel efficiencies, and improving pollution control.
- Governments can help by legislating fuel efficiencies and pollution control, urban planning, and forging agreements with other governments.

Review Questions

1. Summarize the importance of the gaseous "life support system" which Earth's atmosphere provides, and the dynamic equilibrium which characterizes the natural atmosphere.
2. Describe the ecosystem services provided by Earth's atmosphere.
3. Distinguish between primary and secondary pollutants, and give an example of each.
4. Define acid rain and trace the steps in its formation.
5. Why is rain with a pH of 5 not considered acid rain?
6. Analyze the effects of acid rain on soils, water resources, vegetation, animals, and humans.
7. Define ozone depletion and explain its causes.
8. Explain the consequences of ozone depletion.
9. Chart the air pollution problems discussed in this chapter together with a primary cause and an important prevention practice for each.

TABLE 17.7:

Problem	Major Cause	Major Prevention Practice
Global Dimming	Dust from erosion	Contour plowing, conservation tillage, cover crops

TABLE 17.7: (continued)

Problem	Major Cause	Major Prevention Practice
Light Pollution	Urbanization, artificial lights	Alteration of spectra and design of lights
Smog	Automobile exhaust	Catalytic converters, emissions control
Acid Rain	Generation of electricity from coal	Reduce use, scrubbers
Ozone Depletion	CFC emission	Eliminate use, find substitutes

10.
11. Why are international treaties, such as the Montreal Protocol and the Kyoto Treaty, so important in solving air pollution problems?

Further Reading / Supplemental Links

- US Environmental Protection Agency, *Effects of Acid Rain - Surface Waters and Aquatic Animals,* ACID RAIN, US EPA website, last updated 8 June 2007. Available online at:
- http://www.epa.gov/acidrain/effects/surface_water.html
- http://www.anr.state.vt.us/site/html/reflect/April5.htm
- http://www.epa.gov/acidrain/
- http://www.atm.ch.cam.ac.uk/tour/
- http://www.epa.gov/ozone/
- http://www.pbs.org/wgbh/nova/sun/
- http://www.documentary-film.net/search/sample.php
- http://www.skyandtelescope.com/resources/darksky
- http://www.wellesley.edu/Biology/Faculty/Mmoore/Content/Moore_2000.pdf
- http://en.wikipedia.org

Vocabulary

acid rain
Precipitation in any form which has an unusually low pH.

aerosols
Airborne solid particles or liquid droplets.

air pollution
Alteration of the Earth's atmosphere by chemical, particulate, or biological materials.

algal bloom
A rapid increase in the growth of algae, often due to a similar increase in nutrients.

anthropogenic sources
Sources of pollution related to human activities.

biodiversity
Variation in life –at all levels of organization: genes, species, and ecosystems.

ecosystem
A functional unit comprised of living things interacting with their nonliving environment.

eutrophication
An increase in nutrient levels in a body of water, often followed by an increase in plant or algae production.

global dimming
A reduction in the amount of radiation reaching the Earth's surface.

global warming
The recent increase in the Earth's average near-surface and ocean temperatures.

greenhouse effect
The trapping by the atmosphere of heat energy radiated from the Earth's surface.

light pollution
Production of light by humans in amounts which are annoying, wasteful, or harmful.

nonpoint source pollution
Runoff of nutrients, toxins, or wastes from agricultural, mining, construction, or developed lands.

ozone depletion
Reduction in the stratospheric concentration of ozone molecules, which shield life from damaging ultraviolet radiation.

ozone hole
A seasonal reduction in ozone levels over Antarctica.

ozone layer
A concentration of ozone molecules located between 15 and 35 kilometers above Earth's surface in the stratosphere.

point source pollution
Single site sources of nutrients, toxins, or waste, such as industrial or municipal effluent or sewer overflow.

pollution
Release into the environment of chemicals, noise, heat or even light beyond the capacity of the environment to absorb them without harmful effects on life.

primary pollutants
Substances released directly into the air by processes such as fire or combustion of fossil fuel.

secondary pollutants
Substances formed when primary pollutants interact with sunlight, air, or each other.

sustainable use
Use of resources at a rate which meets the needs of the present without impairing the ability of future generations to meet their needs.

Points to Consider

- What are the major ecosystem services provided by our atmosphere?
- Could you now explain to a friend or family member the difference between the “hole in the ozone” and “global warming"?
- In what ways have we already begun to add the costs of atmospheric changes to our economic system?
- Can you think of additional ways in which we could build in these costs?
- How can we gain support for adding environmental costs to economic costs?

17.4 Climate Change

Lesson Objectives

- Explain the mechanism of the greenhouse effect.
- Recognize that the greenhouse effect maintains an equilibrium.
- Compare greenhouse conditions on Earth to those on Mars and Venus.
- Explain the extent of current increases in the Earth's temperature.
- Review past changes in the Earth's temperatures.
- Summarize the evidence and support for greenhouse gases as the cause of recent global warming.
- Discuss the significance of global warming for Earth's ecosystems.
- Relate global warming to current global stability.
- List the atmospheric gases that absorb the Earth's thermal radiation, and their sources.
- Evaluate possible solutions to the problem of global climate change.
- Recognize the tradeoffs required by nuclear power plants: reduced emissions vs. radioactive fuels and waste

Introduction

On December 10, 2007, the Intergovernmental Panel on Climate Change (IPCC) and former US Vice President Al Gore received the Nobel Peace Prize "for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change." The Peace Prize is designated "to the person who shall have done the most or the best work for *fraternity between the nations, for the abolition or reduction of standing armies and for the holding and promotion of peace congresses*." A high honor, the award also announced to the world that climate change (**Figure** 17.49) is a critical issues for the future of the Earth and its people. What is climate change? What are its causes? How do its effects relate to world peace? What are "the foundations for the measures that are needed to counteract such change"? Can individuals like us help? These are the questions we will explore in this last lesson about human ecology.

What is the Greenhouse Effect?

The Greenhouse Effect is a natural feature of Earth's atmosphere –yet another ecosystem service. Without the Greenhouse Effect, Earth's surface temperature would average -18^{o}C (0^{o}F) –a temperature far too cold to support life as we know it. With the Greenhouse Effect, Earth's surface temperature averages 15^{o}C (59^{o}F), and it is this temperature range to which today's diversity of life has adapted.

How does this ecosystem service work? The Greenhouse Effect is summarized in **Figure** 17.50. Of the solar radiation which reaches the Earth's surface, as much as 30% is reflected back into space. About 70% is absorbed as heat, warming the land, waters, and atmosphere (you may recall that only about 1% is converted to chemical energy by photosynthesis). If there were no atmosphere, most of the heat would radiate back out into space as infrared radiation. Earth's atmosphere, however, contains molecules of water (H_2O), carbon dioxide (CO_2), methane (CH_4), and ozone (O_3), which absorb some of the infrared radiation. Some of this absorbed radiation further warms the

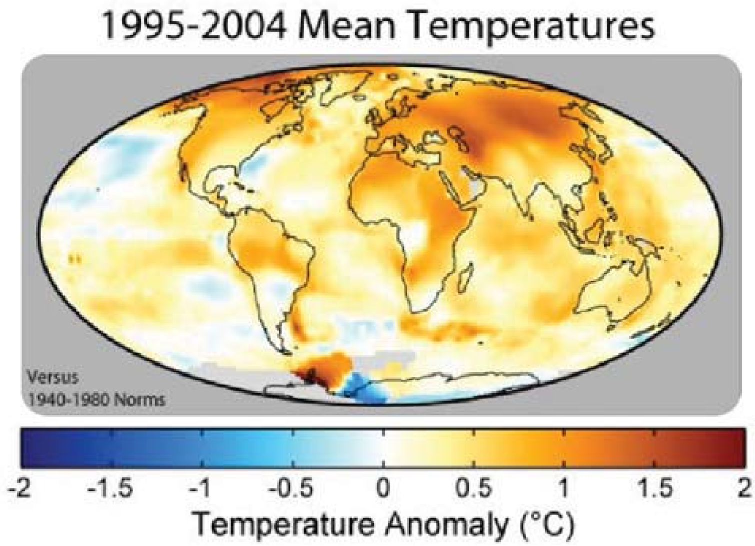

FIGURE 17.49
Temperature variations from 1940-1980 averages show that most of the Earth warmed significantly in just a single decade. The average temperature change across the entire globe for this period is 0.42^{o}C (0.76 ^{o}F). Over the past 100 years, surface air temperatures have risen 0.74 ± 0.18 ℃ (1.33 ± 0.32 ℉).

atmosphere, and some is emitted, radiating back down to the Earth's surface or out into space. A balance between the heat which is absorbed and the heat which is radiated out into space results in an equilibrium which maintains a constant average temperature for the Earth and its life.

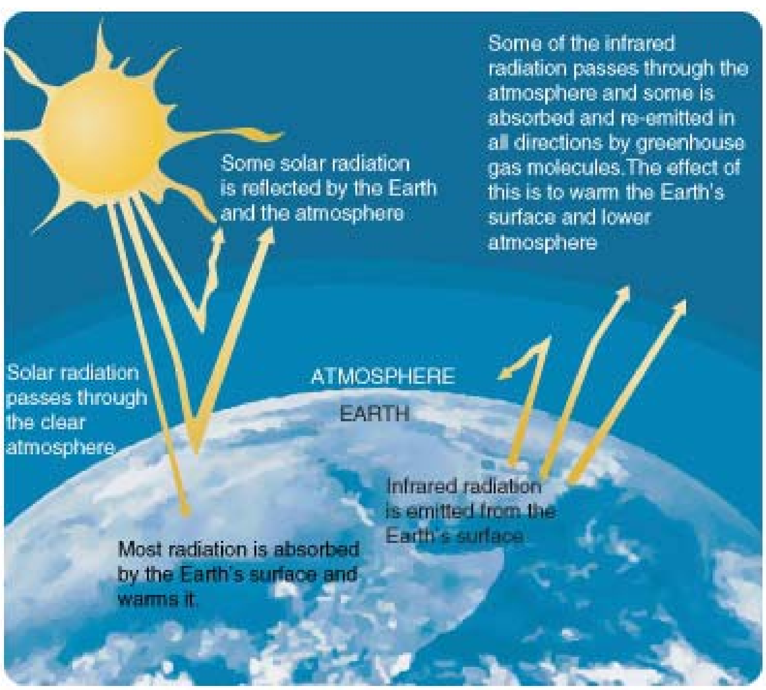

FIGURE 17.50
Without greenhouse gases, most of the sun's energy (transformed to heat) would be radiated back out into space. Greenhouse gases in the atmosphere absorb and reflect back to the surface much of the heat which would otherwise be radiated.

If we compare Earth's atmosphere to the atmospheres which surround Mars and Venus (**Figure** 17.51), we can better understand the precision and value of Earth's thermal equilibrium. Mars' atmosphere is very thin, exerting less than 1% of the surface pressure of our own. As you might expect, the thin atmosphere cannot hold heat from the sun, and the average surface temperature is -55^{o}C (-67^{o}F) –even though that atmosphere is 95% CO_2 and contains a great deal of dust. Daily variations in temperature are extreme, because the atmosphere cannot hold heat.

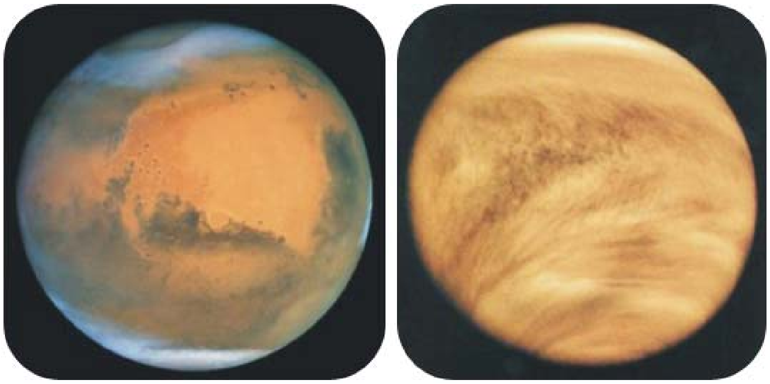

FIGURE 17.51
The thickness of a planet's atmosphere strongly influences its temperature through the Greenhouse Effect. Mars (left) has an extremely thin atmosphere, and an average temperature near -55^{o}C. Venus (right) has a far more dense atmosphere than Earth, and surface temperatures reach 500^{o}C.

In contrast, Venus' atmosphere is much thicker than Earth's, exerting 92 times the surface pressure of our own. Moreover, 96% of the atmosphere is CO_2, so a strong Greenhouse Effect heats the surface temperature of Venus as high as 500^{o}C, hottest of any planet in our solar system. The thick atmosphere prevents heat from escaping at night, so daily variations are minimal. Venus' atmosphere has many layers which vary in composition, and scientists have identified a layer about 50 km from the surface which could harbor liquid water and perhaps even life; some scientists propose that this would be a reasonable location for a space station. Near this altitude, pressure is similar to the Earth's sea level pressure, and temperatures range from 20^{o}C to 37^{o}C. Nitrogen, though only 3.5% of Venus' atmosphere, is present in the same overall amounts as on Earth (because the density on Venus is so much greater); oxygen, however, is absent, and sulfuric acid would present challenges.

Considering the extremes of Greenhouse Effects on Mars and Venus, we can better appreciate the precise balance which allows our own atmosphere to provide temperatures hospitable to liquid water and life. Inevitably, we must also ask this chapter's repeating query: how have human activities affected this equilibrium? This leads us back to the 2007 Nobel Peace Prize, and an evolving consensus that our species is responsible for significant global warming.

Global Warming

Global warming refers to the recent increase in the Earth's average near-surface and ocean temperatures (**Figure** 17.52). During the past 100 years, surface air temperatures have risen 0.74 ± 0.18 °C (1.33 ± 0.32 °F). Multiple sources agree that the two warmest years since the introduction of reliable instrumentation in the 1800s were 1998 and 2005.

This recent increase contrasts with relatively stable temperatures shown by scientific data for the previous two millennia. Multiple sets of temperature data inferred from tree rings, coral growth, and ice core samples are compiled in **Figure** 17.53. Warmly debated exceptions to the stability include a warm period during the Middle Ages and a "Little Ice Age," attributed to decreased solar activity and increased volcanism.

According to paleoclimatologists, on a scale of millions of years Earth's temperatures have varied almost regularly (over time intervals of roughly 140 million years) from those which support global tropics to continental glaciations (**Figure** 17.54). Scientists estimate the global average temperature difference between an entirely glaciated Earth and an ice-free Earth to be 10^{o}C.

The causes of Ice Ages are not completely understood, but greenhouse gases, especially CO_2 levels, often correlate with temperature changes (**Figure** 17.55). Rapid buildup of greenhouse gases in the Jurassic Period 180 million years ago correlates with a rise in temperature of 5^{o}C (9^{o}F). Similar changes have been hypothesized as causes for the dramatic Permian Extinction 250 million years ago and the Paleocene-Eocene Thermal Maximum (one of the most rapid and extreme global warming events recorded in geologic history) 55 million years ago. Paleoclimatologist

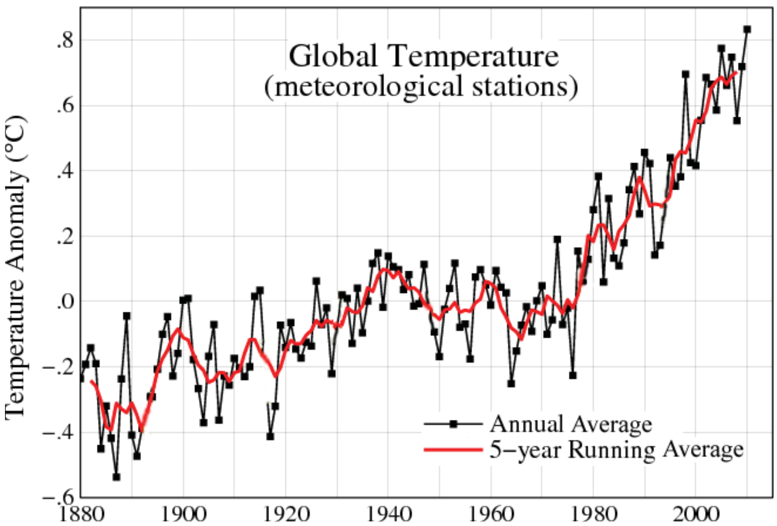

FIGURE 17.52
Global warming refers to the increase in Earth's average near-surface temperatures over the past 100 years. "Anomalies" measure deviation from 1961-1990 averages.

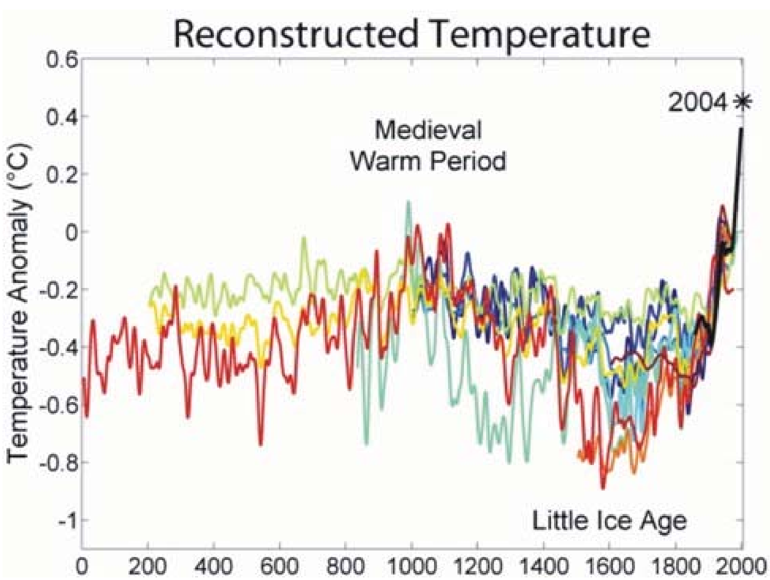

FIGURE 17.53
Global temperatures compiled from tree ring, coral growth, ice core analysis, and historical records, show relative stability over the last 2,000 years before about 1850, interrupted by a debatable Medieval warming and a more recent cooling termed the "Little Ice Age." Colored lines indicate different published data sources. For more detail on the increase since 1850, refer to Figure 3.

William Ruddiman proposes that human activities began to affect global CO_2 levels as long ago as 8,000 years, when agriculture and deforestation began. Ruddiman argues that without this early contribution to greenhouse gases, cycles indicate the Earth would already have entered another Ice Age.

Others dispute Ruddiman's "overdue-glaciation" theory, but most scientists today agree that recent global warming since 1850 is caused by an unprecedented rise in atmospheric CO_2 (**Figure** 17.56) which resulted from human activities –primarily burning of fossil fuels, but also continuing deforestation and changes in land use. Fossil fuels burn organic compounds in the same way your cells burn glucose to make ATP: a product of both reactions is CO_2. Deforestation and other land use changes contributes to the CO_2 levels from the opposite direction –a decrease in photosynthesis, which would have removed CO_2 from the atmosphere. Slash-and-burn destruction of tropical forests combines the worst of both worlds; burning adds CO_2 to the atmosphere, and the loss of layers of vegetation decreases CO_2 use.

Two additional greenhouse gases having anthropogenic (human activity) sources are methane (CH_4) and nitrous oxide (NO). Agriculture adds both of these to the atmosphere; cattle production is responsible for much of the

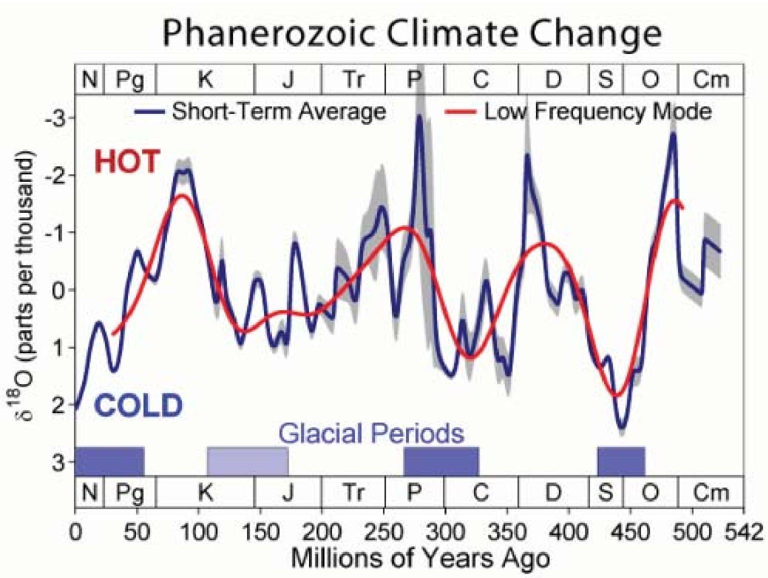

FIGURE 17.54
Paleoclimatological measures of global temperatures show dramatic fluctuations in temperature. Graphs should be read from right (past) to left (present). Ice core data for temperature is recorded in oxygen isotope units rather than ^{o}C.

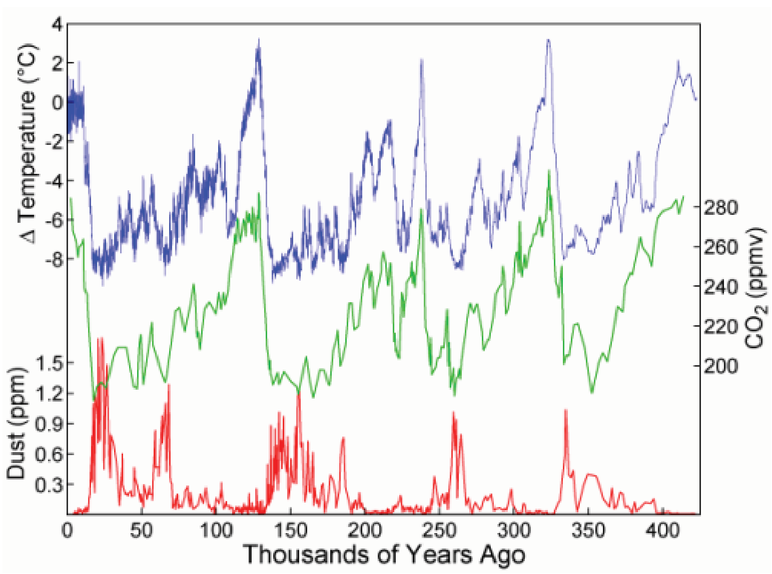

FIGURE 17.55
Over the past 450,000 years, temperature changes (blue) correlate closely with changes in atmospheric CO_2 (green) and dust levels (red).

methane, a powerful greenhouse gas. Land use changes, waste processing, and fossil fuel production, which we've already implicated in CO_2 increases, are other **anthropogenic** (human-caused) sources. A last but important contributing factor is secondary to these primary causes; triggers of "runaway greenhouse effects" will be discussed below.

Although the causal connections between fossil fuel combustion, deforestation, greenhouse gases, the greenhouse effect, and global warming have been strongly debated in the past, the majority of the world's scientific organizations now support these relationships, and many use the term "consensus." (See "Scientific Opinion about Climate Change" in Further Reading.) The awarding of the Nobel Peace Prize to the organization which focuses most directly on climate change, the IPCC, highlights this consensus. Alternative hypotheses include variation in solar activity; several references are included in Further Reading. The IPCC projects future temperature increases ranging from 1.1 °C to 6.4 °C (2.0 °F to 11.5 °F) between 1990 and 2100. Predictions from multiple models which

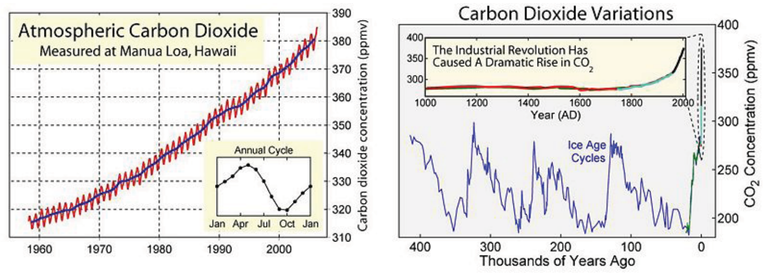

FIGURE 17.56

Since the Industrial Revolution began, the burning of fossil fuels has dramatically increased atmospheric concentrations of CO_2 to levels unprecedented in the last 400 thousand years. The graph on the right integrates recent measurements with paleoclimatologic data.

incorporate connections between greenhouse emissions and global warming are summarized in **Figure** 17.57; all show significant rises in temperature by 2100.

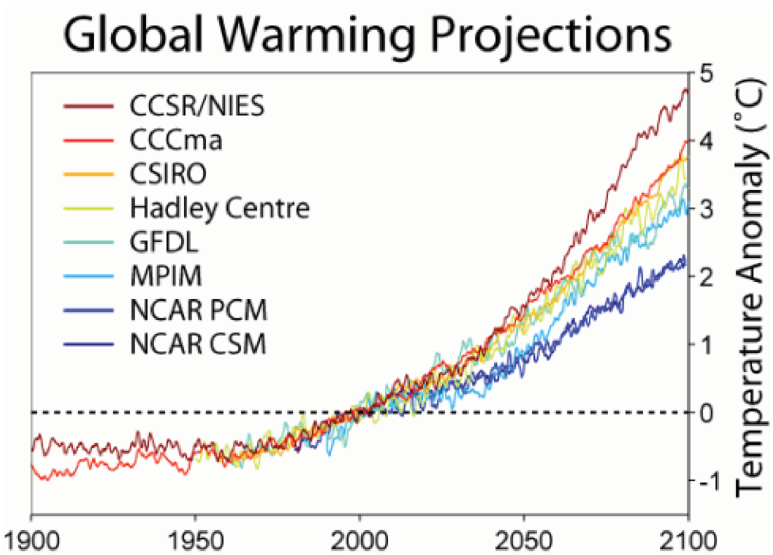

FIGURE 17.57

Various models of climate change which include "business-as-usual" increases in greenhouse gas emissions predict continuing increases in global temperature; this graph compares the projected increases to temperatures during the year 2000.

Once again, then, we "have met the enemy" and "he is us." What have we done? What are the environmental and socioeconomic consequences of this human disruption in atmospheric equilibrium?

A partial list of effects of climate change includes:

Direct Physical Effects

- Melting of glaciers and a consequent rise in sea level, already documented (**Figure** 17.58)
- Sea level rise of 18-59 cm predicted by 2100
- River flooding followed by drought
- Coastal flooding and shoreline erosion

- Melting permafrost, leading to release of bog methane (CH_4) increasing warming via positive feedback*
- Changing patterns of precipitation
- Regional drought
- Regional flooding

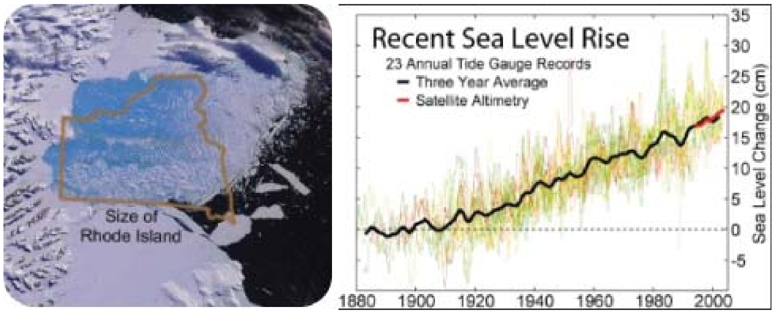

FIGURE 17.58

Glacial melting (left) and a rise in sea level (right) are two consequences of global warming. The left image shows the Larsen Ice Shelf B, which broke up during February of 2002 after bordering Antarctica for as long as 12,000 years. Excluding polar ice caps, 50% of glacial areas have disappeared since the turn of the century. Although sea levels have risen since the end of the last Ice Age, rates increased by a factor of 10 beginning about 1900.

- Ocean warming, leading to increased evaporation
- Increasing rainfall
- Increasing erosion, deforestation, and desertification
- Release of sedimentary deposits of methane (CH_4) hydrates –positive feedback*
- Ocean acidification: 0.1 pH unit drop already documented; 0.5 more predicted by 2100
- Loss of corals
- Loss of plankton and fish
- Temperature extremes
- Increasing severity of storms such as tropical cyclones, already documented (**Figure** 17.59)
- Further reductions in the Ozone Layer (due to cooling of the stratosphere)

FIGURE 17.59

The proportion of hurricanes reaching category 4 or 5 increased from 20% in the 1970s to 35% in the 1990s. The EPA and the World Meteorological Organization connect this increase to global warming, and NOAA scientists predict a continuing increase in frequency of category 5 storms as greenhouse gases rise.

Ecosystem Effects

- Contributions to the Sixth Extinction reaching as much as 35% of existing plant and animal species

- Decline in cold-adapted species such as polar bears and trout
- Increase in forest pests and fires
- Change in seasonal species, already documented
- Potential increase in photosynthesis, and consequent changes in plant species
- Loss of carbon to the atmosphere due to
- Increasing fires, which together with deforestation lead to positive feedback
- Increasing decomposition of organic matter in soils and litter

Socioeconomic Threats Result From Some of the Above Changes

These include:

- Crop losses due to climate and pest changes and desertification
- Increasing ranges for disease vectors (e.g., mosquitoes –malaria and dengue fever)
- Losses of buildings and development in coastal areas due to flooding
- Interactions between drought, desertification, and overpopulation leading to increasing conflicts (**Figure** 17.60)

FIGURE 17.60

A camp in Sudan houses refugees from the far western province of Darfur, who fled from genocide intensified by severe drought. The Darfur conflict echoes predictions that global warming may increase drought and desertification in overpopulated regions and result in more such tragedies.

- Costs to the insurance industry as weather-related disasters increase
- Increased costs of maintaining transportation infrastructure
- Interference with economic development in poorer nations
- Water scarcity, including pollution of groundwater
- Heat-related health problems

Threats to Political Stability

- Migrations due to poverty, starvation, and coastal flooding
- Competition for resources

Note that at least three(*) of the direct physical effects –melting permafrost, ocean warming, and forest fires/deforestation - can potentially accelerate global warming, because temperature increases result in release of more greenhouse gases, which increase temperatures, which result in more greenhouse gases –a positive feedback system aptly termed a " **runaway greenhouse effect**." Here's how it could work: rising temperatures are warming the oceans and thawing permafrost. Both oceans and permafrost currently trap huge quantities of methane –beneath sediments and surface –which would undergo massive releases if temperatures reach a critical point. Recall that methane is one of the most powerful greenhouse gases, so the next step would be further increase in temperatures. Warmer oceans and more thawed permafrost would release more quantities of methane –and so on. These compounding effects are perhaps the most convincing arguments to take action to reduce greenhouse gas emission and global warming.

What measures have been considered?

Preventing Climate Change

Basically, greenhouse gases are products of fossil fuel combustion; according to the EPA, more than 90% of U.S. greenhouse gas emissions come from burning oil, coal, and natural gas. Therefore, energy use is the primary target for attempts to reduce future global warming. In **Figure** 17.61 you can see the sources of emission for three major greenhouse gases in 2000, when CO_2 was 72% of the total, CH_4 18%, and NO 9%. Chlorofluorocarbons (CFCs, HCFCs, and HFCs) are also greenhouse gases; refer to the lesson on The Atmosphere for more information about them.

Knowing the causes of climate change allows us to develop potential solutions. Direct causes include combustion of fossil fuels, deforestation and other land use changes, cattle production, agriculture, and use of chlorofluorocarbons. Runaway effects can result from temperature-dependent release of methane from permafrost and ocean sediments, and forest fires or intentional burning. Unfortunately, the best way to avoid runaway effects is to prevent temperature increases. Prevention, then, should address as many of these causes as possible. A partial list of solutions being considered and adopted follows.

1. Reduce energy use.
2. Switch to cleaner "alternative" energy sources, such as hydrogen, solar, wind, geothermal, waste methane, and/or biomass.
3. Increase fuel efficiencies of vehicles, buildings, power plants, and more.
4. Increase **carbon (CO_2) sinks**, which absorb CO_2 - e.g., by planting forests.
5. **Cap emissions** release, through national and/or international legislation, alone or in combination with carbon offset options (see below).
6. Sell or trade **carbon offsets or carbon credits**. Credits or offsets exchange reductions in CO_2 or greenhouse emissions (tree-planting, investment in alternative energy sources, methane capture technologies) for rights to increase CO_2 (personally, as for air travel, or industry-wide).
7. Key urban planning to energy use, e.g., efficient public transportation.
8. Develop **planetary engineering**: radical changes in technology (such as building solar shades of dust, sulfates, or microballoons in the stratosphere), culture (population control), or the biosphere (e.g. iron-seeding of the oceans to produce more phytoplankton to absorb more CO_2).
9. Legislate Action: International agreements such as the 2005 Kyoto Protocol (which the US has not yet ratified), or national carbon taxes or caps on emissions. Interestingly, in the U.S., some States and groups of States are taking the lead here.
10. Set goals of carbon neutrality: in 2007, the Vatican announced plans to become the first **carbon-neutral** state.
11. Support developing nations in their efforts to industrialize and increase standards of living without adding to greenhouse gas production.

Every potential solution has costs and benefits which must be carefully considered. Human health, cultural diversity, socioeconomics, and political impacts must be considered and kept in balance. For example, nuclear power involves

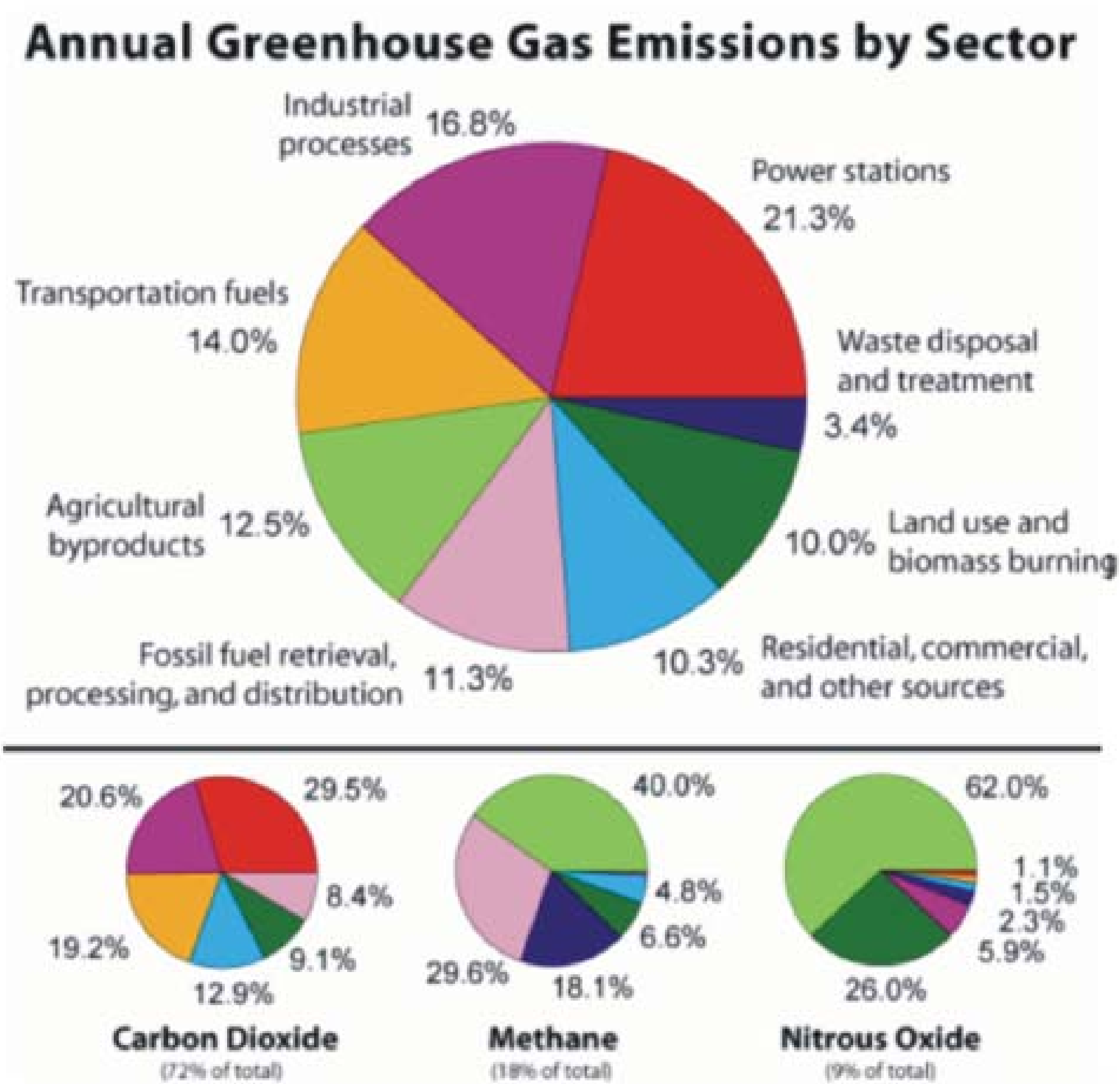

FIGURE 17.61

Global greenhouse emissions during 2002 show sources for each of the three major greenhouse gases. Knowing the causes makes finding solutions clear, but not necessarily easy!

fewer greenhouse gas emissions, but adds the new problems of longterm radioactive waste transport and storage, danger of radiation exposure to humans and the environment, centralization of power production, and limited supplies of "clean" uranium fuels. Studies of costs and benefits can result in solutions which make effective tradeoffs and therefore progress toward the goal of lowering greenhouse gases and minimizing future global warming.

We have reached the point where we understand how and the extent to which our activities have destabilized the Earth's atmosphere and reduced and threatened its ecosystem services. Now we need to move one step further, and put our knowledge to work in the form of action.

What will you do to help?

Lesson Summary

- The awarding of the 2007 Nobel Peace Prize to the Intergovernmental Panel on Climate Change (IPCC) and former US Vice President Al Gore recognizes the potential impact of global warming on the economic, social, and political welfare of the world.

- The greenhouse effect is an ecosystem service which warms the Earth to temperatures which support life.
- The greenhouse effect involves water, carbon dioxide, methane, and ozone, which absorb heat that would otherwise be radiated out into space.
- Earth's atmosphere maintains an equilibrium between heat added by sunlight and heat lost by radiation.
- The atmosphere of Mars is too thin to hold heat, and that of Venus is so thick that temperatures reach 500^{o}C.
- In 2000, the major greenhouse gases were CO_2, CH_4, and NO; CFCs and H_2O contribute, as well.
- Global warming refers to an increase in the Earth's temperature of 0.74°C (1.33°F) within the past 100 years.

- Paleoclimatologists document changes in the Earth's temperature over millions of years which cycle between tropical and ice age extremes –a variation of 10^{o}C.
- Greenhouse gases, especially CO_2 levels, often correlate with temperature changes.
- Deforestation and agriculture –by reducing levels of CO_2 uptake –may have initiated warming 8,000 years ago.
- Most scientists today agree that fossil fuel combustion, deforestation, and agriculture contribute to greenhouse gases and the greenhouse effect.
- Global warming can cause physical changes for the Earth: melting of glaciers and permafrost, changes in precipitation patterns, temperature extremes, warming and acidification of the oceans, and ozone depletion.
- Melting of oceans and permafrost can release methane, resulting in a "runaway greenhouse effect."
- Ecological effects may include loss of biodiversity and addition of still more CO_2 to the atmosphere.
- Socioeconomic threats include crop losses, increased disease, water scarcity, and coastal flooding.
- Population growth and socioeconomic factors (especially interference with third world development) can combine to produce political instability and conflict.

- Most greenhouse gases are products of fossil fuel combustion, so reduced use, increased efficiency, and alternative fuel development are primary means of prevention of climate change.
- CO_2 uptake can be increased by eliminating deforestation, reforestation, and green roofs technology.
- Legislation from local to international levels can cap emissions and develop carbon offset trading.
- Careful urban planning can increase the efficiency of transportation and energy use.
- Planetary engineering could enact radical changes in technology, culture, or the biosphere.
- Support of third world efforts to develop without adding greenhouse gases could improve global stability.
- Every potential solution has costs and benefits which must be carefully considered; tradeoffs are necessary.

Review Questions

1. Explain the mechanism of the greenhouse effect.
2. Compare the effects of the greenhouse effect on Mars and Venus to that on Earth.
3. Define and quantify global warming.
4. Describe paleoclimatic changes over the course of Earth's history. How are these data collected, when no one was around to measure temperatures?

5. Summarize the evidence for greenhouse gases as the cause of recent global warming.
6. Discuss the significance of global warming for Earth's ecosystems.
7. Relate global warming to current global stability.
8. Connect the atmospheric gases that absorb the Earth's thermal radiation to their sources.
9. Combustion of fossil fuels is a common denominator for many problems related to Atmospheric and Water Resources. Clarify the connections for as many problems as you are able.
10. Distinguish between and describe the importance to global warming prevention of carbon sequestration, carbon sinks, carbon offsets, emission caps, emissions trading, and carbon neutrality.

Further Reading / Supplemental Links

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Vocabulary

anthropogenic sources
Sources of pollution related to human activities.

carbon (CO_2) sink
A reservoir which increases absorption of CO_2 –e.g. a forest plantation.

carbon offsetting
Mitigating or reducing greenhouse gas emissions, often as a trade-off from one location to another.

carbon sequestration
Process which removes CO_2 from the atmosphere.

carbon-neutral
Describes an individual, activity, industry, or a political unit which balances CO_2 release with activities which sequester carbon.

emissions cap
Upper limit on CO_2 (or other pollutant) release; may be tradable or sellable.

emissions trading
Reducing greenhouse emissions by purchasing or exchanging means of reducing CO_2 in exchange for rights to release CO_2 .

global warming
The recent increase in the Earth's average near-surface and ocean temperatures.

greenhouse effect
The trapping by the atmosphere of heat energy radiated from the Earth's surface.

greenhouse gas
Atmospheric substance which transmits solar radiation but absorbs infrared radiation: CO_2, CH_4 and NO, for example.

planetary engineering
Radical, often global changes in technology, culture, or the biosphere management.

runaway greenhouse effect
A positive feedback loop in which increasing temperature triggers the release of more greenhouse gases, which further increase temperature, which releases more gases.

Points to Consider

- Do you think global warming is a good example of an "ecosystem service" –or perhaps a " biosphere service?" Explain your reasoning.
- How is the Greenhouse Effect both positive and negative?
- Which of the suggestions for preventing climate change do you think are most realistic for you?
- How might you, as an individual, contribute to national and international solutions to climate change?
- How might we do a better job of building the costs of global warming into the economics of fossil fuel use, deforestation, agriculture, and cattle production?

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