GREEN TECHNOLOGY

CONSERVATION

Protecting Our Plant Resources

ANNE MACZULAK, PH.D.

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Preface

The first Earth Day took place on April 22, 1970, and occurred mainly because a handful of farsighted people understood the damage being inflicted daily on the environment. They understood also that natural resources do not last forever. An increasing rate of environmental disasters, hazardous waste spills, and wholesale destruction of forests, clean water, and other resources convinced Earth Day's founders that saving the environment would require a determined effort from scientists and nonscientists alike. Environmental science thus traces its birth to the early 1970s.

Environmental scientists at first had a hard time convincing the world of oncoming calamity. Small daily changes to the environment are more difficult to see than single explosive events. As it happened the environment was being assaulted by both small damages and huge disasters. The public and its leaders could not ignore festering waste dumps, illnesses caused by pollution, or stretches of land no longer able to sustain life. Environmental laws began to take shape in the decade following the first Earth Day. With them, environmental science grew from a curiosity to a specialty taught in hundreds of universities.

The condition of the environment is constantly changing, but almost all scientists now agree it is not changing for the good. They agree on one other thing as well: Human activities are the major reason for the incredible harm dealt to the environment in the last 100 years. Some of these changes cannot be reversed. Environmental scientists therefore split their energies in addressing three aspects of ecology: cleaning up the damage already done to the earth, changing current uses of natural resources, and developing new technologies to conserve Earth's remaining natural resources. These objectives are part of the green movement. When new technologies are invented to fulfill the objectives, they can collectively be called green technology. Green Technology is a multivolume set that explores new methods for repairing and restoring the environment. The

set covers a broad range of subjects as indicated by the following titles of each book:

- *Cleaning Up the Environment*
- *Waste Treatment*
- *Biodiversity*
- *Conservation*
- *Pollution*
- *Sustainability*
- *Environmental Engineering*
- *Renewable Energy*

Each volume gives brief historical background on the subject and current technologies. New technologies in environmental science are the focus of the remainder of each volume. Some green technologies are more theoretical than real, and their use is far in the future. Other green technologies have moved into the mainstream of life in this country. Recycling, alternative energies, energy-efficient buildings, and biotechnology are examples of green technologies in use today.

This set of books does not ignore the importance of local efforts by ordinary citizens to preserve the environment. It explains also the role played by large international organizations in getting different countries and cultures to find common ground for using natural resources. Green Technology is therefore part science and part social study. As a biologist, I am encouraged by the innovative science that is directed toward rescuing the environment from further damage. One goal of this set is to explain the scientific opportunities available for students in environmental studies. I am also encouraged by the dedication of environmental organizations, but I recognize the challenges that must still be overcome to halt further destruction of the environment. Readers of this book will also identify many challenges of technology and within society for preserving Earth. Perhaps this book will give students inspiration to put their unique talents toward cleaning up the environment.

Acknowledgments

I would like to thank a group of people who made this book possible. Appreciation goes to Bobbi McCutcheon, who helped turn my unrefined and theoretical ideas into clear, straightforward illustrations, and to photo editor Elizabeth Oakes for her wonderful contributions. My thanks also go to Marilyn Makepeace, who provided support and balance to my writing life, and Jodie Rhodes, who helped me overcome more than one challenge. Finally, I thank Frank K. Darmstadt, executive editor, for his patience and encouragement, and Facts On File, for giving me this opportunity.

Introduction

The Sun's energy drives the activities of virtually every living thing on Earth. Without it, Earth's *biota* in their current form would not exist. Daily on Earth's surface, plant life transfers energy coming from the Sun into a chemical form—sugars—that the plant uses for building new cells and powering its other functions. But plants do not use all the energy they capture and store; much of plant energy fuels animal life. Excluding certain *microbes* that use different means of energy conversion, *ecosystems,* communities, *biomes,* and the entire Earth's biodiversity would be impossible without plants and trees.

Conservation refers to the careful and controlled use of natural resources for the purpose of extending the time these resources are available as well as retaining biodiversity. Conservation does not prevent the loss of plants, trees, land, water, or *habitat;* it simply slows the rate of degradation of these things. As Earth's human population continues to grow, it will be inevitable that forests will come down to make room for more people to find a place to live. The major problem in this scenario comes from two conflicting events. First, more people will put more greenhouse gases into the atmosphere, which will continue to affect global climates. Second, more people cutting down more trees will leave less remaining plant life to remove carbon dioxide—the predominant greenhouse gas—from the atmosphere, and this, too, leads to *global warming.*

Global warming and forest growth affect each other. Global warming influences the patterns of tree growth, especially of trees that require long periods of cold temperatures. Because global warming has increased the average temperature at northern latitudes, the health of northern boreal forests has been compromised. In many cases, trees weakened by the stress of adapting to rising temperatures become vulnerable to more diseases and pest infestation. Meanwhile, a healthy global forest helps

regulate climate by cooling parts of the land surface and by pulling carbon dioxide out of the atmosphere.

This book explores aspects of conservation, particularly the conservation of plant life upon which ecosystems are built. Though students with an interest in ecology assume conservation is a worthwhile endeavor in sustaining the environment, conservation has had a rocky history. Environmentalists and industrialists have held differing opinions on the best uses for the world's natural resources. Forests have been central in this debate.

Naturalist John James Audubon remarked about conservation, "A true conservationist is a man who knows that the world is not given by his fathers but borrowed from his children." Yet industry and government leaders have often held a view that natural resources be saved only after people take what they need to live. To be fair, industry leaders must meet the demand from consumers for ever-increasing amounts of resources, and government leaders must assure that their constituents have a place to live. Conservation becomes vulnerable in the face of these pressures. Mollie Beattie, who was director of the U.S. Fish and Wildlife Service from 1993 to 1996 observed, "What a country chooses to save is what a country chooses to say about itself."

Economist Robert Costanza of the University of Vermont developed a theory in the 1990s to compare the value of nature's resources for consumers against the value of nature as the framework for all ecosystems. Some natural resources simply have no substitute: air, water, soil, and biodiversity. Perhaps these resources hold more value than just a monetary amount, for instance, on their monthly water bill. The science of putting a true value on natural resources that have no substitutes is called *ecological economics*. By contrast *neoclassical economics* is founded on the idea that natural resources are to be used, and when they have been used up, technology will find substitutes. *Environmental economics* proposes the middle road: Some natural resources cannot be replaced once used up, so sustainable practices must be adopted to lengthen the time these resources can support people.

Costanza applied ecological economics to determine the value of forest conservation compared with forest cultivation for profit. His team of scientists determined in 2002 that benefits of forest conservation translate to $4.7 trillion per year; while the economic value from harvesting forests amounts to about $45 billion per year; the value of conservation exceeds

the value of forest depletion by about 100 to 1. Costanza explained in a 2002 article in *Science,* "The environment is not a luxury good. Ecosystem services contribute to human welfare and survival in innumerable ways, both directly and indirectly, and represent the majority of economic value on the planet. . . ." In other words, humans receive value from activities in nature—pollination, nutrient cycling, waste treatment, climate regulation, and water supply are but a few examples—that are unrelated to the price of a wooden board, a diamond, or an animal's fur. In 1997 Costanza explained in *Nature,* "One additional way to think about the value of ecosystem services is to determine what it would cost to replicate them in a technologically produced, artificial biosphere." Though it may seem crass to put a dollar value on nature, this may be a clever way to force society to help save nature as it would save money.

Forest, grassland, and riparian (land next to rivers and streams) conservation represent the ecosystem approach to saving biodiversity. This approach proposes that by sustaining entire ecosystems, rather than concentrating on select threatened species, all of biodiversity can be saved. Saving biodiversity is important because the number and variety of the Earth's species results in a diversity of genes, adaptations, ecosystems, and entire ecological processes. These things all contribute to the welfare of people and the world as a whole in tangible and intangible ways. For example; the biodiversity of plants helps science find new drugs, chemicals, and other materials for the benefit of human life—a tangible benefit. Biodiversity also enriches people's lives in intangible ways by providing places where people can appreciate nature. Forests in particular offer solitude, peace, cleanliness, and an escape from stressful activities. This book covers the ecosystem approach to plant conservation because without plant activity on Earth, animal life would not be possible in its current form, and neither would biodiversity. By learning about the worth of forests, people also learn about the astounding ways Earth's biodiversity developed and why it affects people directly and indirectly.

Chapter 1 describes forests and the *water cycle*. It reviews the economics—neoclassical economics—of forests as natural resources, and addresses today's most pressing issues in global *forest management*. The chapter reviews the relationship between forests and biodiversity and reviews the history of forest conservation.

Chapter 2 discusses current threats to forests of the world and describes the world's current *deforestation*. The chapter details specific

threats from population growth, *invasive* species, industry, and *climate change*. Emphasis is placed on the timber industry and agriculture.

Chapter 3 takes a closer look at the conservation of tropical forests, which cover vast amounts of the Earth but are also under extreme threat of deforestation. This chapter explains the primary and secondary causes of tropical deforestation, activists and action plans to save tropical forests, and the issues involved in restoring tropical forests and converting traditional *forestry* to *sustainable forestry*.

The next chapter details the world status of *temperate* forests and *boreal* forests. It describes timber harvesting, fire management, forest protection laws in the United States, *ecoforestry,* and the goals of forest biotechnology. Special sections discuss the contribution of old-growth ecosystems to the environment and the philosophy of one of this country's earliest conservationists, John Muir.

Chapter 5 covers one of the world's most serious ecosystem threats, *desertification,* and the reason it is expanding. Sections discuss irrigation methods and soil conservation strategies. The chapter also describes sustainable farming and sustainable livestock rearing methods. It reviews the special effects of desertification on impoverished areas in a case study on Africa's Lake Chad.

The following chapter covers the functions and threats in *riparian habitats* along rivers, streams, or lakes. The chapter describes riparian ecosystems as well as the reasons for restoring badly damaged ones, and it explains the approaches to riparian and wetlands *restoration*. This chapter also reviews the effect of dams on the environment and focuses on two landscapes that influence the health of riparian ecosystems: lawns and barrier reefs.

Chapter 7 closes with the entrepreneurial means with which people can reduce the stress on threatened forests by turning to wood alternatives. The chapter explains sustainable wood production, recycled wood, renewable wood resources, and the effect of tree nurseries on the environment. A sidebar devoted to Theodore Roosevelt explains how government can partner with environmentalists to conserve forests and the wildlife that live in them.

Conservation provides an overview of the successes and the failures in the effort to protect living natural resources that predate humans on their home continents. In a sense, forest conservation is the critical first step in saving the environment and its biodiversity.

Forests and the Water Cycle

The Earth contains almost 10 billion acres (400 million km^2) of forest that covers 30 percent of the land's area. Forest is a type of biome dominated by trees but also containing unique plants, animals, microbes, and soils. Forests contain undisturbed areas of various trees and smaller plant life and usually receive moderate to high levels of precipitation. Forests make up one of six land biomes: desert, grassland, taiga, temperate forest, tropical forest, and tundra, and they grow in tropical, temperate, and polar regions. The only places on Earth completely bare of trees are the North and South Poles, some mountains, deserts, and prairies, and the aquatic biome—although even the aquatic biome contains large kelp forests.

Forests contribute to all other forms of life on Earth because they have various environmental roles. They participate in climate regulation; regulate water and other nutrient cycles; offer habitat for the majority of the globe's species; filter pollutants from the air; reduce the rate of global warming by absorbing the greenhouse gas carbon dioxide; reduce soil *erosion* with their root systems; and provide *watersheds* by absorbing rainfall and releasing it slowly into streams. Forests also serve more commercial needs for people and, in many cases, these needs cause the threats forests confront today. People depend on forests for timber and paper products, materials such as rubber, waxes, and fibers, fuel, foods (fruits, nuts, and sap), camphor, and antitumor and anti-inflammatory drugs. This chapter explores the forest biome, its relationship to the biodiversity of other living things, and the contribution of forests to the Earth's water cycle.

EARTH'S MOST THREATENED BIOME

Forests exist on almost every part of the globe's land. Forest complexity causes scientists to classify forests in more than one way, by (1) location, (2) the type of wood they produce, or (3) their age. Sometimes these three classifications interconnect. Ecology uses a forest classification system based on climate, determined by precipitation and temperature. This classification system correlates to where on the globe the forests grow. The following table shows the tropical, temperate, and boreal classifications used in ecology.

Each of the three main classifications contain subcategories based on more detailed climatic conditions: tropical, subtropical, Mediterranean, temperate, coniferous, boreal, and montane (cloud forest). Some of these groups contain additional subtypes.

Forests also belong to categories according to the types of trees that predominate; for example, coniferous, mixed broadleaf, aspen, oak, or

FOREST TYPES

TYPE OF FOREST	FOREST SUBTYPE
tropical	rain forest
	evergreen
	montane cloud
	deciduous
	scrub
	thorn
temperate	deciduous
	evergreen
	rain forest
boreal (taiga)	evergreen coniferous

mangrove forest. Finally, forest age determines characteristics of this habitat, so forests may be identified as immature, secondary, primary, or old-growth.

The World Resources Institute's Global Forest Watch program states on its Web site that the Earth has lost almost 50 percent of its forests in the last 8,000 years, the same time period in which civilization developed. The highest rates of today's forest loss occur in Africa and South America; every five years Africa and South America lose 3.2 and 2.5 percent, respectively. These numbers can be deceptive because in some African nations the combined grassland and forest loss tops a rate of 10 percent annually. Grasslands have in fact undergone more drastic reductions than forests in some places, particularly Africa. If these current disappearance rates continue, many countries will lose all their forests within a few decades.

Forest loss has a devastating impact on biodiversity because forests, especially the tropical rain forests near the equator, make a great contribution to the world's plant and animal diversity. These tropical rain forests account for at least half of all the Earth's biodiversity even though they cover only about 2 percent of the Earth's surface. These forests have also become the most threatened by deforestation.

Deforestation refers to any removal of trees without replacement, and it threatens forests in direct and indirect ways. Direct deforestation comes from four main causes: (1) clearing of tropical forests for crops, livestock, and timber; (2) clearing of temperate *deciduous* forests for timber, crops, and urban development; (3) clearing of evergreen coniferous

The forest biome consists of trees as well as a unique variety of plants, animals, microorganisms, soils, and climates. Although forests are not irreplaceable, they take hundreds of years to return to maturity after being destroyed. This picture shows a deciduous forest in the Blue Ridge Mountains, which stretch from Virginia to North Carolina. *(Carolina Environmental Diversity Explorations)*

forests for timber; and (4) conversion of forests to monoculture (vineyards, commercial tree farms). Illegal *logging* makes up part of the deforestation problem, much as exotic animal poaching decimates protected wildlife populations. Logging is the process of cutting and removing logs from the forest.

Indirect causes affect forests similarly to how they affect animal species. Three important indirect threats to forests are (1) roads, (2) climate change, and (3) habitat fragmentation. Indirectly, off-road vehicles used to build roads damage seedlings and new growth, increase soil erosion, and fragment habitat. Climate change affects environment by shifting the optimal temperature range in habitats. Wildlife can migrate to a different elevation or latitude to find the ideal temperature. Trees, however, do not possess the luxury of moving; entire species can slowly die as a result of continuous temperature changes. Climate change also makes conditions suitable for invasive species to enter a habitat and may additionally open the door to increased incidence of disease or pest infestation. Habitat fragmentation from urban growth or agriculture reduces the ability of tree populations to propagate and lessens their genetic diversity.

All of these effects caused the world to lose 3 percent of its forests in a 15-year period from 1990 to 2005, a rate of 0.2 percent a year. At present, the world's forested areas continue to decrease but the disappearance rate has been slowing; Europe and North America have now reversed centuries of forest loss. The most threatened forests reside in Africa, Latin America, and the Caribbean. Fortunately, national governments in Africa have started cooperative programs for forest conservation, and individual nations have adapted new forest policies and forest laws. New forestry management programs help save forests to some extent, but fires, regional conflicts, and legal and illegal industries have continued the deforestation crisis. The table on the next page provides details on today's major threats to forests and their primary location, though all of these threats can be found to some degree in almost every part of the world.

Many people may assume forest fires pose the greatest threat to forests. In the United States, the Smokey Bear campaign began in the 1940s to remind people of the dangers of forest fires. Illegal campsite fires, arson, and blazes cause damage each year in dry areas of the United States that have dense human populations. But fires in general, natural or human-caused, do not threaten the overall population of forests, and

Major Threats to Forests Worldwide

Activity	Reason	Main Effects	Primary Region
clearing (also clear-cutting)	agriculture, livestock	erosion, degradation of soil quality, wastes, habitat loss, desertification	Africa, Central America, South America
	timber harvesting	erosion, carbon dioxide production, habitat loss, desertification	Russia, China, Mexico
	urban development	pollution, erosion, habitat destruction	global
	mining	pollution, mountain destruction	North America, Africa
conversion to monoculture	commercial tree plantations	loss of native animals, insects	South America
	vineyards	loss of native animals, insects	North America, Europe
	urban tree-planting programs	possible invasive species	North America, Europe
	illegal drug cultivation	pollution, erosion, habitat destruction	South America, North America, Asia
fragmentation	development	habitat degradation	global

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MAJOR THREATS TO FORESTS WORLDWIDE
(continued)

ACTIVITY	REASON	MAIN EFFECTS	PRIMARY REGION
vehicles	recreation, road-building	soil erosion, transmittance of disease	North America, South America, Australia, Asia
invasive species	intentional or accidental release of nonnative plants	ecosystem destruction	global
climate change	vehicles, population growth, industry	pollution, habitat loss, disease and pests, ecosystem destruction, desertification	global

fire management makes up an important sector of overall forest management. Fires actually contribute to the health of forests and plant communities by

- enhancing nutrient recycling
- allowing for small plants to spread
- regulating the succession of new tree growth
- developing new habitat
- reducing *biomass* buildup
- enriching soils
- reducing parasites and disease-causing organisms

In North America and Europe, forestry programs work in conjunction with the government. The success of slowing forest loss in these places varies, however. Forest area stabilized in Canada and the United States in

the mid-2000s, but forest area continues to shrink in Mexico, although fortunately the rate has slowed. In Europe, lands set aside for protected forests have increased slightly in the past five to 10 years. Asia and the Pacific have halted an alarming trend of forest loss that took place during the past 30 years, and in these places forested land may now be increasing in area. However, part of East Asia's statistics may be misleading. China has planted large forest plantations, and while these plantations add to the total amount of land that forests cover, such monocultures do little to improve biodiversity.

Trees in the forest interact with other living things in ecosystems just as plants, animals, and microbes do. An imbalanced ecosystem can therefore harm trees. For example, if a predator were to disappear, other animals may grow to higher population numbers and graze all the young seedlings needed to regenerate the forest in 100 years. An alteration to a plant community in the forest likely alters the birds and reptiles living there, which can affect populations of tree pests and parasites. Trees weakened by a parasite become more vulnerable to infection by disease-causing microbes.

Climate change holds paramount importance in forest health because it affects seasons, normal temperature ranges, and tree reproduction. Climate change has also influenced the world's availability of clean water. Like all living things, trees cannot survive long without water, but equally important, trees play a crucial role in the Earth's water cycle.

THE WATER CYCLE

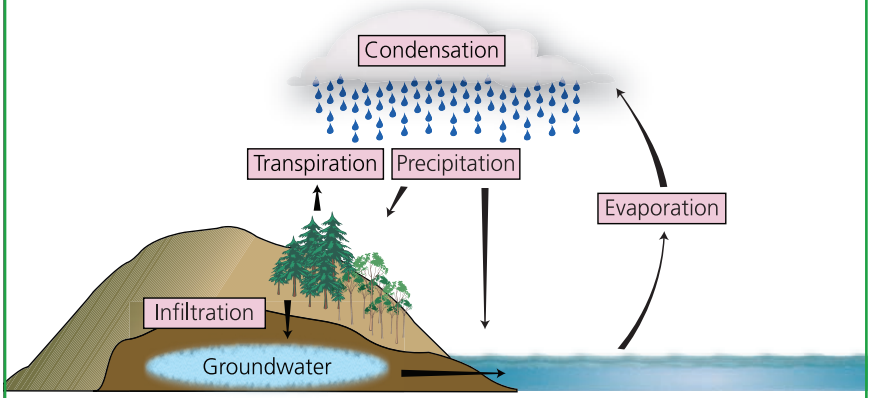
The water cycle, also called the hydrologic cycle, operates similarly to *biogeochemical cycles* in which plant and animal nutrients move through the atmosphere, the earth, and through living things. The water cycle includes water in the forms of solid, liquid, and gas, and the Sun provides the energy needed to power the constant cycle of water among these three forms. The water cycle occurs in oceans, bays, lakes, ponds, rivers, and streams. The ocean covers most of the Earth's surface and so contributes the largest share to the water cycle; more than 85 percent of the water that evaporates from the Earth's surface into the atmosphere does so from the ocean. About 80 percent of the world's precipitation enters oceans.

The water cycle contains five components that transfer moisture either from the Earth's surface to the atmosphere or from the atmosphere back to Earth. These components are the following:

- condensation—conversion of water vapor into droplets of liquid water
- precipitation—water that falls from the atmosphere to land or to surface waters as rain, snow, sleet, or hail
- infiltration—downward movement of liquid water through soil
- evaporation—conversion of liquid water into gas, or water vapor
- transpiration—movement of liquid water from plant roots, upward in vessels, and into the atmosphere from the leaves as water vapor

Forests serve in the water cycle in two critical ways: transpiration and water storage. Both animals and plants transpire water vapor into the air, but animals transpire as part of aerobic respiration when they exhale moisture from their lungs. Plants and trees possess special cells on the underside of their leaves, called guard cells, that release water vapor from the plant into the atmosphere. The transpiration process begins when

The Water Cycle

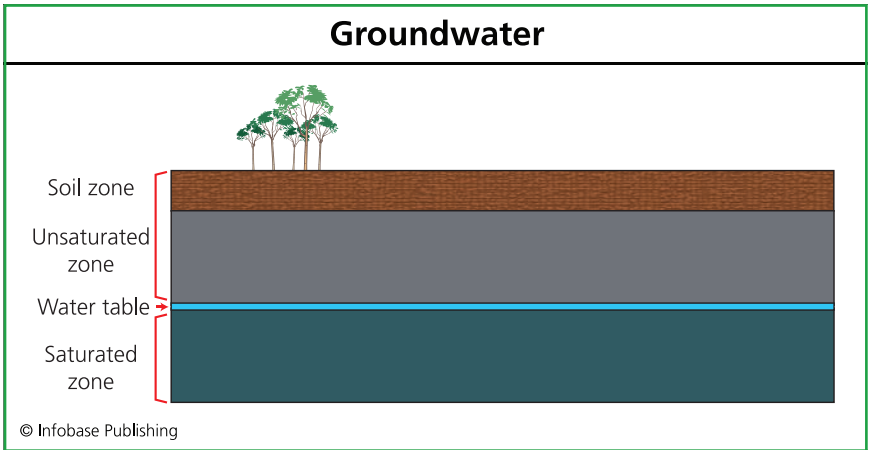


The Sun's energy powers the water cycle, which is critical for conserving Earth's water. Within this cycle, oceans account for more than 80 percent of evaporation, and more than 80 percent of rainfall lands in the oceans.

trees draw water from the soil through their roots and transport it upward in vessels—xylem carries water and nutrients upward, phloem distributes water and nutrients throughout the plant. Trees, depending on size and species, transpire from 5,000 gallons (18,921 l) to almost 50,000 gallons (189,210 l) of water per year, more in warmer weather and less in colder weather. Low relative humidity and increased air movement caused by wind or breezes also increase the transpiration rate. During drought or in the desert where only drought-tolerant plant life lives, a tree's transpiration rate decreases so that it can conserve water. Soil also affects water transpiration. When soil moisture levels are low, as in drought, trees slow their transpiration rate to conserve water. Trees undergoing the normal aging process, called *senescence,* give way to new trees ready to take their place. Prolonged drought, however, puts all trees into a premature senescence, an event that may eventually kill a forest. Global warming has exerted a critical effect on forest health because it increases the incidence and severity of droughts worldwide, and in doing so it accelerates the death of drought-vulnerable trees.

Forests' second major activity involves the capacity of trees to store water. Trees act as a watershed by absorbing water during floods and storing and slowly releasing water in times of low rainfall. Surface waters, *groundwaters* (or aquifers), and plant life comprise the Earth's total watershed. Part of trees' role in the watershed involves regulation of the *water table,* which is the area underground where water has completely filled the spaces between rocks and soil particles. Beneath the water table lies an area of higher density where all the air has been squeezed out to make room for water. This location, called the *zone of saturation,* holds water undisturbed for longer periods than the water table. Therefore, water moves through three layers in the earth: (1) the upper unsaturated zone, where soils hold varying amounts of moisture (also called the *soil zone*); (2) the water table, where water exchanges from the saturated layer below to the unsaturated layer above; and (3) the zone of saturation. Tree roots pull water from either the unsaturated zone or the water table.

Human activities interfere with the water cycle in the three following ways: (1) by drawing large amounts from surface sources and groundwaters, (2) by polluting water, and (3) by removing or damaging the world's forests. Part of the problem of water use by the Earth's human population resides in the fact that water is a very poorly managed resource. Water covers 71 percent of the Earth and makes up at least 60 percent of living cells,



Groundwater serves as a major source of drinking water in most of the world, but high water demand due to growing populations draws down the reserves, lowering the water table. Pollution further threatens groundwater reserves. Metals, pesticides, and organic chemicals have infiltrated many once pristine aquifers.

but only 0.014 percent is available for people's use. Yet humans continue to waste water, pollute it, or otherwise treat it as if it were free. Benjamin Franklin once said, "When the well's dry, we know the worth of water." The world has been progressing toward ever greater water shortages since the acceleration of global warming. Some countries have already entered a dangerous condition known as *water stress,* meaning their water requirements exceed the water they have available.

Since every living thing needs water and cannot exist without it for more than a few days, maintaining a clean supply is paramount to maintaining biodiversity. Forests play a vital role in maintaining a continuous supply of available water, so this represents one way in which forests maintain biodiversity. As the next section and the sidebar "The Forest Canopy" point out, forests add to the world's biodiversity in other immeasurable ways.

FORESTS AND BIODIVERSITY

Forests support biodiversity through indirect means by helping water and soil conservation and climate regulation. Directly, forests provide habitat for about two-thirds of all species on Earth, and by so doing forests may

The Forest Canopy

A forest *canopy* consists of the area above the forest floor where tree *crowns* containing branches and leaves meet. At 200 feet (61 m) or more above the ground, the canopy performs more than 90 percent of a forest's total photosynthesis because it is the portion most exposed to sunlight. For that reason the canopy stores 60 percent or more of the Earth's carbon while supporting a *food web* that is more diverse than any other. Carbohydrates made in photosynthesis provide the foundation for food webs that live solely in the canopy and also for ecosystems that extend to the forest floor.

Tropical, temperate, and boreal forests each have their own unique canopies, but there are basic similarities among them. The canopy's *overstory* contains towering trees spaced closely together so their branches and leaves form a continuous community. The *understory* consists of more widely spaced shorter and juvenile trees. Because forests across the globe receive different amounts of sunlight, water, and wind (or storms), the various canopies affect the organisms living nearer the forest floor differently. For example, the canopy of coniferous forests filters light through narrow leaves, allowing organisms living in the canopy and below to receive small amounts of direct sunlight. Broadleaf tree canopies, by contrast, block the sunlight and provide a dark and moist environment below.

In addition to filtering sunlight and performing photosynthesis, the forest canopy provides five services to the environment: (1) nutrient delivery to the soil in the form of biomass, when leaves and small branches fall to the forest floor; (2) soil erosion reduction by protecting the ground from heavy rainfalls; (3) particle and pollutant removal from the air, rain, and fog; (4) transpiration in the water cycle; and (5) habitat for animal and plant life that exist only in this place. The canopy habitat is so specialized, in fact, that it makes up what is known as a *microhabitat*. A microhabitat is an area within a larger habitat that has unique characteristics found nowhere else in the environment.

Plants that live only in the forest canopy are *epiphytic* plants, meaning they receive physical support from the canopy and not by putting roots into soil, and they draw water and nutrients directly from the

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atmosphere. Epiphytes contain about 30,000 species, including Spanish moss, lichens, liverworts, ferns, cacti, vines, and up to 70 percent of all orchids.

The canopy's animal life is also unusual because the canopy includes species that rarely if ever visit the ground. A wide variety of flying and crawling insects, including bark-eating and wood-boring insects and spiders, mites, centipedes, and millipedes, live in the canopy. Invertebrates such as worms, snails, and slugs also live as either carnivores or herbivores in addition to the reptiles and amphibians that are found there. Songbirds and woodpeckers spend entire lifetimes in the canopy, and raptors such as hawks and owls hunt from the canopy. Some 90 percent of all tropical rain forest organisms stay in the canopy their entire lives.

Warm-blooded life in the canopies of the world, especially in tropical rain forests, is the most diverse on Earth. Monkeys and lemurs have prehensile tails that enable them to grab branches, while other animals evolved as gliders to travel through the forest's upper reaches. Flying squirrels, colugos, Draco lizards, and flying frogs possess a body form that catches the air and helps them glide from branch to branch. The slow-moving sloth also lives exclusively in the tropical rain forest canopy by clinging to tree trunks with sharp claws.

Urban areas have started taking a cue from nature by planting trees in treeless neighborhoods, partly because of the benefits of the canopy. Urban tree canopies help reduce city carbon dioxide levels and pollutants, absorb storm water, provide shade to decrease the use of air conditioners, and reduce traffic noise. Very often, trees in the city increase property values. Said Kelly Quirke, head of Friends of the Urban Forest in San Francisco, California, "As more of us live in cities and as we lose more open space, people are getting more and more of their experience in nature in their urban environment. That means the urban forest becomes ever more critical." An urban forest can never replace the unbroken expanses of forestland that existed before towns grew up, but they make their own contribution to returning some habitat to large metropolitan centers.

be the single most important constituent in maintaining the Earth's biodiversity. Forests support not only diverse animal species, small plants, and microbes, but forests also contain diverse mixtures of different trees that grow and recycle nutrients at different rates and provide biomass of varying compositions when the trees die.

In the United States, land designated as protected national forest covers 192 million acres (78 million km^2). These forests contain almost every habitat in the country: tropical and temperate rain forests, coasts, rivers and lakes, grasslands, mountain and alpine areas, deciduous forests, conifer and mixed forests, old-growth forests, arctic tundra, deserts, and *wetlands*. National forestland gives habitat to at least one-third of all wildlife on the endangered species list. Rich biodiversity within any forest serves as an indicator of the health of that forest; the greater the diversity of plants, animals, and microbes, the healthier the forest.

Forests support biodiversity in a horizontal fashion as well as a vertical fashion. Horizontal forest growth refers to the forested land across continents, which provide different climates and terrain. This is the core

Forests hold an enormous amount of the world's plant and animal biodiversity. (a) This boreal chickadee lives in cold northern or high-altitude forests. *(Jeremy Yancey, courtesy of Audubon)* (b) The Borneo fan palm is one of thousands of tropical forest species. *(World Wildlife Organization)*

reason why tropical rain forests at the Earth's equator bear little resemblance to evergreen forests in Canada. Each forest possesses its unique biodiversity, and this diversity contributes hundreds of different types of

CASE STUDY: CONSERVATION IN COSTA RICA

Since the 1990s, Costa Rica has been the site of one of the world's most ambitious ecological restoration projects. Ecological restoration is the act of altering a habitat in order to return as much of it as possible to its original state. In the 1990s Costa Rica's Tropical Forestry Initiative purchased 350 acres (1.4 km^2) of land that had been cleared and used for ranching for the next 50 years. The initiative sought to restore a tropical wet forest (one receiving more than 100 inches [254 cm] of rainfall yearly) on the abandoned pastureland by planting 40,000 seedlings of a mix of 35 native tree species. One such preserve, named Los Arboles, will require from 100 to 800 years for the forest to mature, so the experiment remains in its earliest stages. Ecological restoration usually cannot restore all the native species by reintroducing them to an area, so in Los Arboles the best hopes are centered on a plan to nurture the planted seedlings and accelerate the growth of as many native species as possible. In order for restoration like Los Arboles to succeed, four important steps must occur: (1) growth of the seedlings; (2) dispersal of new seeds; (3) germination of seeds; and (4) avoidance of predation. Soil depleted of nutrients or areas with little available water increase the difficulty of restoring any forest.

A variety of techniques have been used in Costa Rica to assist natural processes in forest recovery. Forest restoration depends on seed dispersal by insects, rodents, and birds that eat seeds and eliminate undigested seeds in their waste in a new location. Restoration teams now help this process in two ways: (1) by growing a healthy shrub understory and (2) by providing perches for birds. Shrub understories provide habitat to attract birds, rodents, and insects, replenish soil, and keep aggressive grasses from hindering the growth of seedlings. Costa Rica's young seedling trees needed time to reach a size suitable for perching of seed-dispersing birds, so workers built artificial perches. Other methods serve the same purpose as man-made perches. For instance, workers can plant young woody trees on the restoration's perimeter to give birds a place to find shelter and roost. On restored rangelands, ranchers often leave a few stands of trees to provide shade for their cattle. These well-established trees already house insect and bird populations acclimated to the area, so they, too, aid the restoration.

In the northern part of Costa Rica, the biologist Daniel Janzen of the University of Pennsylvania has led a second restoration project in the tropical dry forest (which contains a distinct dry season) in Guanacaste National Park. Janzen and his students developed seedlings of the area's

habitats for animals, plants, and microbes. Vertical biodiversity in forests resides from the upper part of the tree line, the canopy, to the roots in the earth. From top to bottom, a single forest can house ecosystems

native trees in his laboratory, then organized field trips from the United States to sow the seeds and plant seedlings. From the start Janzen included local students and farmers so that they could learn the restoration techniques. Since the local people participate in the recovery of their own natural resources for their long-term benefit, Guanacaste presents an example of *biocultural restoration.* This means both the environment and the local population receive some sort of recovery. In the community's case, the residents received greater opportunity for earning higher income. Eventually, Costa Ricans will run the park with no outside influence.

Ecologists measure the progress of restoration by monitoring increases in number and diversity of species moving into the new habitat. Within the first decade of new growth in Costa Rica, woody plants and a diverse mixture of mammals, birds, and invertebrates began building populations. The Tropical Forestry Initiative recorded tree growth and species, finding that many trees grew 7.2 feet (2.2 m) per year and a canopy developed five years after planting seedlings. In addition, researchers counted more than 350 plant species that had become established in the new forest.

Restoration ecology would probably not be successful if left entirely to humans or entirely to nature, but the projects in Costa Rica prove they can work in tandem. Janzen described it this way in an essay he wrote for *Science* in 1998: "Why can't the wild tropical species be left 'out in the wild' to fend for themselves? Because the wild is at humanity's mercy. Humanity now owns life on Earth. . . . Until the Pleistocene, not more than a few thousandths of 1 percent of the Earth's surface was ours. Today it all is. If we place those species anywhere other than in a human safe zone, they will continue in their downward spiral as grist in the human mill, just as they have for the past 10,000 years." Though restoration ecology manipulates nature, it profits nature in the long term.

The Los Arboles project also relies on the success of its biocultural restoration activities. In 1997, David Knowles and A. Carl Leopold of the Tropical Forestry Initiative said in an ecology presentation, "A crucial part of this effort will be to spark interest among the local landowners. We are working with local landowners to encourage reforestation by providing them with seedlings, by participation in a local forestry association, and by interacting with local schools." More than decade later, both of these forest restoration projects have engaged the local communities in the areas of restoration, ecotourism, and environmental education.

containing raptors, seed- or insect-eating birds, tree-dwelling mammals, insects and snakes that live lower on trees, small rodents and plants on the ground, and invertebrates and microbes digesting biomass within the soil. This model describes merely a general look at the forest ecosystem; forest food webs contain many more complex animal-plant-microbe relationships within each different type of forest.

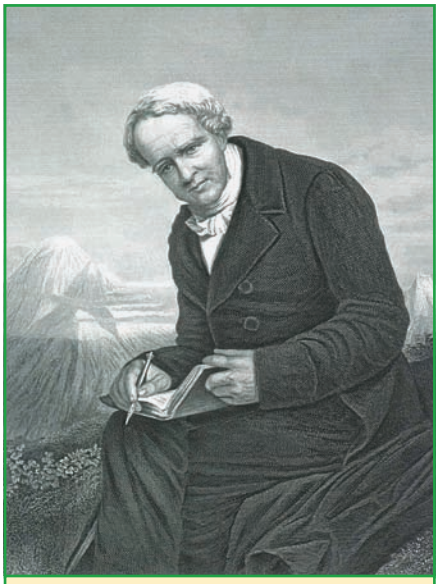
The world's biodiversity concentrates in tropical rain forests, which cover only 7 percent of the Earth's land, but hold at least 50 percent of all the Earth's species. For this reason the tropical rain forests in many parts of the world have been designated *biodiversity hot spots* by Conservation International. Environmental expert Norman Myers first proposed the concept of biodiversity hotspots in 1988 to describe places that contain a high degree of biodiversity and are simultaneously under a high threat of being destroyed. In that year Myers wrote an essay titled "Tropical Forests and Their Species" stating, "Extinction has been a fact of life since the emergence of species almost four billion years ago. . . . Whereas past extinctions have occurred by virtue of natural processes, today the virtually exclusive cause is *Homo sapiens,* who eliminates entire habitats and complete communities of species in super-short order. It is all happening in the twinkling of an evolutionary eye." Though Myers spent his career addressing both plant and animal diversity, his words can certainly be applied to the plight of forest loss taking place today.

Deforestation refers to any removal of trees from a forested area without adequate replanting, and it represents the biggest threat to tropical rain forests and the species dependent on them. Many of these forests are in areas with high population growth rates compared with the rest of the world. In general, a large area of the world's tropical rain forests have fallen victim to population growth, poverty, and inadequate government protection. These are not simple matters to overcome when trying to design plans for protecting trees. The case study "Conservation in Costa Rica" provides a look into one ambitious forest recovery program.

HISTORY OF FOREST CONSERVATION

The conservation movement in the United States began to blossom in the early 19th century with the writings of James Fenimore Cooper, Ralph

Waldo Emerson, Alexander von Humboldt, and Henry David Thoreau. Each shared a deep love and respect for nature and connected the conservation of nature with living a better life. One of the forest's strongest advocates, John Muir, built upon the ideas of those writers and others when he developed his views on nature, forests, and their spiritual value to people. Muir wrote in 1916, "Why should man value himself as more than a small part of the one great unit of creation?" Muir's philosophy was to become known as the *preservationist ethic,* which valued nature for its *intrinsic* qualities. That is, nature has value whether humankind can derive a direct benefit from it or not.



The German naturalist Alexander von Humboldt (1769–1859) possessed an interest in many sciences and sought connections between the principles of zoology, botany, geography, astronomy, and the physical sciences. His major work, the 33-volume *American Journey,* relayed his observations on nature accrued during a single six-week visit to the United States. *(Dibner Library of the History of Science and Technology)*

Another key figure in the conservation movement was Gifford Pinchot, who became the first director of the U.S. Forest Service in 1905. Pinchot became interested in conservation as a young adult, but his education had relied on his father's income from the timber industry. At about the same time that Muir formulated his theories on conservation, Pinchot proposed his own theory called the *resource conservation ethic,* which proposes that people view nature as a natural resource for their use. He stressed that this theory could work only if people used natural resources prudently to provide "the greatest good of the greatest number [of people] for the longest time." Though Pinchot advocated making nature a commodity, he also made clear that natural resource management must serve not just the present but also future generations, so resources should be conserved and not wasted. In this way Gifford Pinchot may be said to have invented sustainable natural resource management.

The resource conservation ethic served the country well as it grew into a strong nation, despite the Great Depression in the early 1930s. Naturalist Aldo Leopold had agreed with Pinchot's theory during his early education, but after graduating from Yale University in 1909, Leopold held less faith in the idea that nature existed only for man's needs. In 1939 Leopold wrote in his essay "A Biotic View of the Land," ". . . with one hand he [the biologist] points out the accumulated findings of his search for utility, or lack of utility, in this or that species; with the other he lifts the veil from a biota so complex, so conditioned by interwoven cooperations and competitions, that no man can say where utility begins or ends." In his way, Leopold had described ecosystems and the intricate relationships among ecosystem members.

Aldo Leopold combined the early philosophies on nature with the resource conservation theory to develop the evolutionary-ecological land ethic, or simply the *land ethic*. The land ethic proposed that humans should be involved in land management but in a way that does not exploit the land or use up its resources. Leopold further envisioned conservationists making small improvements to nature to help biodiversity flourish. To this purpose, in 1935 Leopold teamed with two other environmentalists, Robert Marshall and Benton Mackaye, to form the Wilderness Society. The Wilderness Society today acts to protect unspoiled land while carrying out education, advocacy for the environment, and scientific studies.

Also in the 1930s, Franklin D. Roosevelt followed in the footsteps of his second cousin, Theodore Roosevelt. During Theodore Roosevelt's two terms as president of the United States (1901–09) he led a strong push to make conservation a national priority. Theodore Roosevelt focused most of his conservation efforts on forests and wildlife, using the Forest Reserve Act of 1891 to set aside millions of acres of undisturbed land as wilderness. Almost all of the land Roosevelt protected was forest, mainly in the West and in Alaska. Franklin D. Roosevelt became president of the United States in 1933 after serving in the New York legislature as chairman of the Senate Committee on Forest, Fish, and Game. On the forests' health at the time, he wrote, ". . . we are consuming five times as much timber as being grown. We plant in a year an area about equal to what is cut over in less than five days." Two of Franklin Roosevelt's landmark contributions to conservation were the Civilian Conservation Corps (CCC) and the Soil Conservation Service. History has shown that many of the proj-

ects conducted by the CCC led to environmental harm years later, but the notion of forests as important ecosystems was still a new idea. Roosevelt's intentions were meaningful because they urged the American public to be responsible when managing the country's natural resources.

Today conservation biology emphasizes forests and forest ecosystems. In addition to the Wilderness Society, other organizations raise funds or awareness in the public on the immediate need to halt further destruction of forests or have put concerted efforts into purchasing forest land to take it out of the hands of the timber and mining industries. The main organizations involved in protecting forests are listed in the appendix.

Though many people in the world understand that forests are threatened, factors in society sometimes override conservation. Economics represents a dangerous direct and indirect threat to forests. Subsistence communities need to find fuel, income, and food, and they often find these things in the jungle or forest. At the same time, industries want to continually grow and to do so they need ever-increasing amounts of natural resources. Along the way, the philosophy and the politics of forest conservation have taken some interesting turns. Two U.S. presidents in the past century demonstrate how divergent the world has become toward a simple tree.

"A grove of giant redwoods or sequoias should be kept just as we keep a great or beautiful cathedral." Theodore Roosevelt made this statement in 1919 during a time in history when the country had not yet grown into a world leader in manufacturing. Horses pulled equipment over farmlands and carried logs out of the forest. Of course, U.S. commerce would emerge in the next 40 years, and presidents increasingly depended on backing from industrialists to win elections and make economic policy. President Ronald Reagan demonstrated a great shift in how nature could be viewed, particularly if preserving nature ran counter to making products and profits. In 1966 Reagan said in a speech to the Western Wood Producers Association, "I think, too, that we've got to recognize that where the preservation of a natural resource like the redwoods is concerned, that there is a common sense limit. I mean, if you looked at a hundred thousand acres or so of trees—you know, a tree is a tree, how many more do you need to look at?" Then as now, savvy politicians learned that keeping businesses happy might be just as important as keeping environmentalists happy. When leaders' decisions regarding the environment are based on economics, however, the chances increase that natural resources will lose.

FOREST ECONOMICS

Forests serve people and animals as safe places of solitude and habitat far from the intrusion of urban life. Forests have long supported recreational activities such as hiking, horseback riding, camping, and swimming, while providing an important natural resource: wood fibers. For generations people have depended on wood for construction, furniture, paper, and heating fuel. The logging industry grew first on the East Coast of the United States as the population grew from the original colonies. Logging supplied the raw materials needed for the population's westward expansion, especially in the hurried rush west after gold was discovered.

Today only 36 percent of the world's forests are *primary forests,* forests that have never been disturbed by human activities on a large scale. In the United States, the U.S. Forest Service predicts that forest destruction will continue to increase to serve the country's increased demand for wood and paper because of three factors: growing population, rising income levels, and upward economic activity. The U.S. Forest Service has estimated the country's increased consumption of wood products based on 1986 figures through the year 2040, shown in the table on the next page. These figures take into account recycling programs, substitute materials, and efforts by the timber industry to enhance its efficiency.

The timber industry employs forest economics to determine the most inexpensive way to select, cut, and transport wood to the nearest mill. Today the timber industry must include plans for making harvests as efficient as possible in order to spare trees and to reduce wood waste.

Forest economics includes aspects of forestry that support sustainability in forest harvesting and regrowth. Some of the areas covered by forest economics target increased profitability of the timber business, and other areas focus on the development of sustainable forests. The main activities that contribute to forest economics are:

- managing fire and storm losses
- protecting against invasive species
- managing native pests, parasites, and diseases
- engaging in methods for replanting harvested areas
- sustaining a wildlife population
- managing the effects of air pollution

World Timber Consumption and Production	
Major Consumers of Forest Products	
Product	**Country (percent of global consumption)**
roundwood (hardwood for poles, posts, fence stakes, etc.)	United States (23)
	Canada (11)
	China (8)
sawnwood (tropical hardwoods)	United States (26)
	China (9)
	Brazil, Canada, and Germany (5 each)
wood panels	United States (23)
	China (21)
	Germany (6)
pulp for paper	United States (26)
	China (14)
	Japan and Canada (6 each)
paper and paperboard (cardboard)	United States (23)
	China (21)
	Japan (8)
Major Producers of Forest Products	
Product	**Country (percent of global production)**
roundwood	United States (23)
	Canada (11)
	Russian Federation (10)

(continues)

WORLD TIMBER CONSUMPTION AND PRODUCTION *(continued)*

MAJOR PRODUCERS OF FOREST PRODUCTS	
PRODUCT	**COUNTRY (PERCENT OF GLOBAL CONSUMPTION)**
sawnwood	United States (20)
	Canada (12)
	China (7)
wood panels	China (27)
	United States (15)
	Germany (7)
pulp for paper	United States (26)
	Canada (11)
	China (10)
paper and paperboard	United States (22)
	China (20)
	Japan (8)
wood fuel	India (16)
	China (11)
	Brazil (7)

Source: Food and Agriculture Organization (FAO) of the United Nations, 2007

- removing biomass
- enacting policies toward extreme environmentalism

Forest economics is a component of two different aspects of conservation: forest management and forestry. Both of these disciplines strive to maintain healthy forests, but each has different goals.

FOREST MANAGEMENT WORLDWIDE

Forest management comprises the use of science, economics, and social principles to maintain healthy forests. While forest management used to be an arm of the timber industry, today it includes other aspects for the purpose of conserving forests: creating sustainability in forests; multiple uses for individual forests, which conserves total forested land; fire management; and conservation of biodiversity. Forestry includes conservation methods also, but forestry's objectives strive for the best ways to use trees as a natural resource for making products. Quite a bit of controversy has emerged when the two fields' different objectives are not compatible. In a general sense, forest conservation can be divided into those who seek to protect the world's remaining forests from any further destruction for any reason versus those who seek to find the most efficient ways of harvesting forests to meet the population's growing needs for wood products. Even the most committed activist for saving trees must realize that forests represent the raw materials of business. The American Forest and Paper Association in a 2006 press release quoted Steve Rogel, head of the Weyerhaeuser pulp and paper company: "In the midst of tumultuous change, some things remain constant: Timberlands are the nucleus of this company, and our commitment to enhancing value for shareholders is as strong as ever." But that same year, the nature advocate Ted Williams countered in *Audubon* magazine, "National forest timber has never been a major or (for the public at least) even a profitable resource. But 80 percent of the nation's rivers originate in national forests, and 60 million Americans depend on national forest water." Both Rogel and Williams expressed correct views: Forests supply a large portion of raw materials, but they also house a tremendous amount of biodiversity and nature as yet unspoiled by human activities.

A compromise on sustainable forest management that benefits both business and nature has yet to be found. Sustainable management decreases the rate of wood harvesting through various measures so that harvests can occur without decreasing the total forested land area. In some cases sustainable methods may even increase forest area. Agreement between environmentalists and the timber industry has grown slowly, with much work still ahead.

The World Resources Institute, based in Washington, D.C., has stated that analyzing the health of forests is complicated by four main factors.

First, genetic diversity mapping is incomplete. Second, many tree species remain unknown. Third, science lacks a historical database on trends of forest growth and decline. Fourth, detailed monitoring is costly and time-consuming. A 2007 report titled *State of the World's Forests,* published by the United Nations Food and Agriculture Organization (FAO), stated, "The biggest limitation for evaluating [conservation] progress is weak data. Relatively few countries have had recent or comprehensive forest inventories." Therefore, lack of data hampers both staunch forest conservationists and forest harvesters when they try to meet their objectives.

In the United States, the U.S. Department of Agriculture's (USDA's) U.S. Forest Service serves as the federal agency in charge of overseeing the nation's forest land. The Forest Service holds the dual responsibilities of conserving the land while at the same time serving people and industries that desire forests for recreation and profit, respectively. The Forest Service carries out the five following responsibilities: (1) manage the nation's 155 national forests and 20 protected grasslands; (2) conduct scientific research; (3) reach out to state and private forests to coordinate fire management, disease control, and protections; (4) educate the public and schools on issues in forestry and forest conservation; and (5) develop cooperation with international agencies to formulate policies on forest management and protection. Forest Service Chief Abigail Kimbell said in 2008, "Kids must understand why forests are so valuable so they will grow into citizens who support conservation. Building on the Forest Service tradition of conservation education, we will work with partners to ensure that American children have the opportunity to experience the great outdoors, whether it is a remote mountain wilderness or a spot of nature in the heart of a city." Like many aspects of environmental science, education of a new generation of conservationists will be critical for preserving the forests.

The Forest Service conducts research at experiment stations located in its nine regions and at the Forest Products Laboratory in Madison, Wisconsin. The experiment stations focus on disease, invasive species, soils, fire, native wildlife, forest monitoring methods, and the design of sustainable forests. The Forest Products Laboratory also specializes in research on the properties of wood and new directions for wood composite materials.

Many other national agencies and international organizations conduct activities similar to those at the U.S. Forest Service. The FAO compiles

reports every three to four years that summarize the worldwide losses or gains in forests and the current conservation programs. One key factor that FAO monitors in regions of the world and globally is carbon stocks in biomass, which is the total organic matter produced by plants. The FAO's *State of the World's Forests 2007* reported that from 1990 through 2005 carbon stocks rose slightly in North America and Europe, but plunged in tropical areas. Some areas increased their forest area, but most experienced

Summary of International Agreements Concerning Forest Conservation, as of 2007

Name, Date Signed	Major Emphasis	Signed by the U.S.
Convention on Biological Diversity (CBD), 1992	biodiversity protection	no
Convention to Combat Desertification (CCD), 1977	halting of worldwide loss of fertile land to desertification	yes
Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES), 1973	prohibits international trade in endangered plant or animal species or products derived from them	yes
Kyoto Protocol, 1997	sets national targets for reducing greenhouse gases	no
Ramsar Convention, 1971	halting of worldwide loss of wetlands	yes
United Nations Framework Convention on Climate Change (UNFCCC), 1994	data sharing on climate change	yes
World Heritage Convention, 1972	protection of both natural and cultural heritage	yes

decrease. Overall, therefore, forest management worldwide has not conserved forestland, and the global carbon stock decreased in those years 5.5 percent and lost 3 percent of its total forest area.

Seven current international agreements have a component for forest conservation, summarized in the table on page 25. Most of these agreements have been signed by the majority of the world's countries.

Worldwide the FAO describes the success of forest management programs as "uneven." Most countries must manage their forests for multiple uses. This means that certain countries with the best intentions of conserving their remaining forests, preserving biodiversity, and maintaining clean air, water, and soil believe they must destroy a portion of their forests to survive. Overall the world loses about 0.2 percent of forest every year. World forest management has yet to find a balance between attaining sustainable forest management and meeting the economic needs of all countries.

CONCLUSION

Forests make up a large portion of the Earth's surface and contribute a critical role in maintaining healthy air, water, and soil for the world's biota. Forests in fact constitute a biome of their own on the Earth. Three major types of forest fulfill important roles in the environment: tropical, temperate, and boreal. Forests also hold economic value because they serve as the source of raw materials for the timber industry and the pulp and paper industry. Two of the numerous important roles played by forests are participating in the water cycle and providing a variety of habitats for wildlife. The water cycle comprises the continual movement of water from the earth, through plants, to the atmosphere as water vapor, and back to the earth as precipitation.

Forest habitat depends on this water cycle, as do humans. Forests provides a myriad of habitats, depending on the type of forest, from tropical equatorial regions to frigid northern woods. Forests also contain many different specialized habitats, called microhabitats, within them. These habitats begin at the uppermost forest canopy and occur with their unique characteristics all the way to the soil of the forest floor.

Forest conservation began with the writings of naturalists who appreciated the forest for its intangible gifts, including solitude, cleanliness, quiet, and communion with other species in their natural habitat. Con-

servation programs grew in the 1800s and became a priority of the federal government under President Theodore Roosevelt. During the same period, however, the United States underwent a spurt in population growth that put increasing demand on forests to supply needed construction materials. Forest destruction proceeded at a rapid pace from that time in the United States and Canada until the 2000s, when it finally slowed. North America overall now enjoys a stabilized rate of forest destruction and forest conservation, but Mexico still loses some forest area each year. Internationally, Europe has added a small amount of protected forest to its land, but the rest of the world suffers from dangerous rates of forest removal. Forests have become most threatened in Africa, Latin America, and parts of Asia.

Saving the forests requires a mix of conservation actions, new sustainable practices, and legal protections. But even the best planning will not work unless people move quickly to alter their use of wood-based products and avoid illegal destruction of forests. Forest conservation requires a good deal of voluntary participation by all people in the world regardless of whether the trees have been protected by laws or not. Poverty, commerce, and climate change have, however, made forest conservation a very difficult goal for the long-term future.

Analyzing Threats to Forests

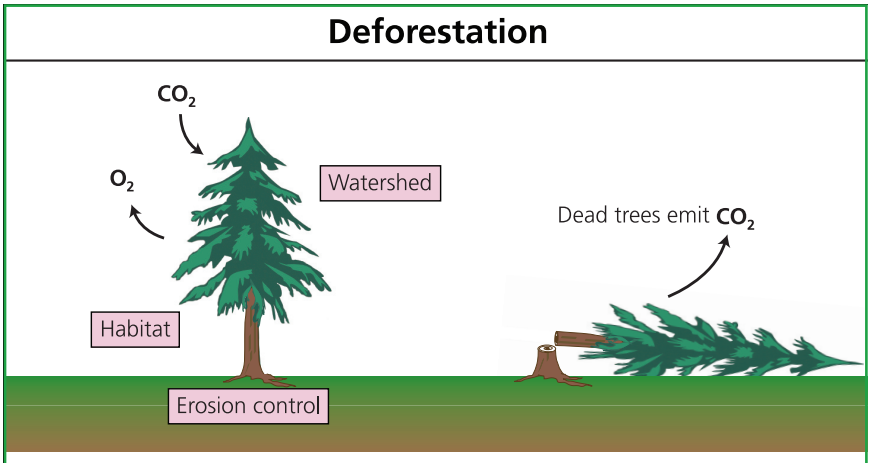
One of the largest obstacles to overcome in conserving forests has been a lack of awareness regarding their importance as a limited resource. Much of the forest loss in the last two centuries began in the late 1800s and continued through the 1970s. In the late 1800s to early 1900s, forests produced wood needed for helping cities grow, building new towns with the nation's westward expansion, and laying railroads. A small group of visionaries realized the American forests would not stand forever at the rate they were being decimated. Though the idea of sustainability had not yet become part of the language, President Theodore Roosevelt saw the urgent need to set aside forestland for protection from development.

John Muir held perhaps a more spiritual approach than Roosevelt in his love for the land. Muir appreciated the land for itself without the desire to harvest its natural resources. In his travels and writings in the late 1800s, Muir hoped people would see the merit of forests and understand the need to save them, not for future exploitation, but for the innate values forests offer. In Muir's book *Our National Parks,* he wrote, "I have done the best I could to show forth the beauty, grandeur and all-embracing usefulness of our wild mountain forest reservations and parks, with a view to inciting the people to come and enjoy them and get them into their hearts. . . ." Muir and Roosevelt allied with each other in their efforts to protect forests and encourage the public to see the virtues of undisturbed land. Despite the efforts of these two visionaries, forests came down as the population increased.

THE RATE OF DEFORESTATION

Since Theodore Roosevelt's administration, ballooning populations in the United States and in other parts of the world continued to level timber for their needs. By 1920 almost all of the old growth in the United States was gone. In fact, millions of acres of forested land from the polar regions to the equator have disappeared in the 8,000 years since humans arrived, and the World Resources Institute estimates that about 50 percent of the planet's original forests have been destroyed.

Deforestation refers to the complete or partial removal of trees from an area of land. The Earth's forests represent a renewable resource, but unless removal equals the rate of new tree regrowth, deforestation will continue to chip away at the world's remaining forest. The Earth holds less than 10 billion acres (400 million km^2) of forest covering 30 percent of its land, far less than the amount of forest that dominated the landscape before humans arrived. John Muir's Wilderness Society tries to help people picture what forests looked like before human interference. Included in its vision statement is a plea to "Imagine American forests as they should be. Forests that adorn our country's mountains and valleys



Deforestation causes the extinction of thousands of plant and animal species by robbing them of habitat. Destruction of forests also makes soil vulnerable to erosion and loss of nutrients, eliminates one of the Earth's main water stores, and disrupts carbon cycling.

with large, stately trees. Forests that firmly hold and replenish the soil while reaching high overhead. Forests graced with clean, sparkling streams and lakes, and filled with abundant fish and wildlife populations. Forests that inspire awe and humility." The Wilderness Society and other environmental groups conveyed the value of forests to nature and to people, but as world commerce grew, these organizations held little power to stop deforestation.

Deforestation results from four main human activities: agriculture; cattle ranching and other livestock production; removal for wood products and heating fuel; and *mountaintop mining.* Agriculture reduces forests at the fastest rate, especially in Latin America and Africa. Africa holds about 55 percent of the world's forested land but has been losing forest at a yearly rate of almost 10 percent. Central America, South America, and parts of Southeast Asia combined hold about 25 percent of the world's forests and they, too, have high deforestation rates.

Agriculture and ranching both deplete nutrients from soils. This leaves the deforested land unable to support regrowth; sometimes the land

Tree farms containing no more than one or two species spoil the environment because they fill the land with a homogeneous planting that bears little resemblance to natural habitat, but tree farms help by sparing old-growth forests from deforestation. *(Natural Resources Conservation Service)*

Clear-cutting is the most injurious type of tree harvesting to the environment. The Amazon rain forests such as the one pictured here have become the most vulnerable to clear-cutting of all the world's forests. In 2004 Brazil clear-cut 10,400 square miles (27,000 km^2) of its forests, and by 2008 the deforestation rate across the Amazon region had accelerated. *(Rhett A. Butler/Mongabay.com)*

becomes unfit for additional crops, so people cut down more trees. Tropical forests contain poor quality soil that does not support many agricultural crops in the first place. In a conservation tragedy, these nutrient-poor conditions only accelerate the deforestation on land that will continue to produce poor crop growth.

Reforestation involves planting seeds or seedlings in deforested areas for the purpose of growing a new forest. Reforestation takes place naturally in cleared forest areas and abandoned cropland by a process called *ecological succession,* in which plant and animal communities emerge and are replaced over time by more complex plants and animals. Reforestation may also occur when a forest has been replanted with one type of the same species. This is called a *tree plantation* or forest plantation, which may provide a fast way to replace forest and income for a local community, but these plantations support little biodiversity. Plantations do not promote biodiversity because they are monocultures, or plantings made up of only one variety of plant. Monocultures restrict the types of insects, birds, and other animal

life that can live in them, so full ecosystems containing prey, predators, and interrelationships among these groups cannot occur. In addition, because all the trees in the monoculture are about the same age, they deplete soil nutrients, water, and pesticides quickly. They are labor-intense because all their produce must be harvested in a short period of time, and they require extra fertilization and weeding. Reforestation therefore requires a compromise between long-term regrowth under natural conditions and fast, but environmentally harmful monoculture. The following table describes important phases of tree growth during reforestation.

TYPES OF DISTURBED AND UNDISTURBED FORESTS

TYPE OF FOREST	DEFINITION
primary forest (virgin forest)	original forest arising from natural ecological succession and which has never been logged or disturbed by other human activities
secondary forest	regrowing through natural processes after having significant damage done by human activities; will develop a canopy different from primary forests
disturbed forest	contains significant damage from human activities, such as clearing, burning, and road construction
frontier forest	large, intact primary or old-growth forests that have received little or no disturbance and support the area's full natural biodiversity
forest plantation (tree plantation)	trees established by planting seeds or seedlings of either native species or nonnative species
old-growth forest	either primary or secondary forest containing trees that are hundreds or thousands of years old

POPULATION ENCROACHMENT

Forests perform their functions best when they grow in large contiguous swaths with healthy riparian systems and periodic fires started by natural causes. Even when urbanization grows to the doorstep of a forest, but leaves the forested land undisturbed, trees still feel the presence of humanity.

The most important threat from urbanization originates in the land's *carrying capacity,* which is the number of individuals of a species—humans in this case—that the land can sustain indefinitely. Large urban areas that overshoot their carrying capacity must increase the amount of goods they import from outside their region just to sustain daily life. Considering this circumstance, a nearby forest falls under extreme threat of deforestation to provide more room for homes, buildings, roads, farms, and parks, not to mention timber for construction materials and paper. The United States now imports most of its wood-derived products, mainly for economic reasons and partially as part of forest protection. That means that countries supplying wood products that conserve U.S. forests are likely decimating their own forests.

Population encroachment takes area away from forests—trees come down, buildings go up. Other direct effects of population growth are the following: roads that fragment habitat; hunting that potentially imbalances ecosystems; elimination of natural predators; interference with nutrient and water cycles; and global warming. Important harmful effects that come from population encroachment on forest ecosystems are the following:

- draining of the watershed
- pollution or destruction of riparian corridors
- air pollution and acid rain
- excess noise and light disturbing wildlife
- imbalanced ecosystems in the urban area that affect forest ecosystems
- roads that fragment the forest and introduce pollution
- camping and off-road vehicle use
- accidental fires and arson

- illegal drug cultivation
- invasive species of plants or animals
- transmission of new plant diseases

Nature rebounds surprisingly well after it has been injured, but it needs time to do this and it must be left undisturbed. Some of the factors listed above can affect a forest even if the city limit does not encroach

CASE STUDY: CONSERVING NATURE'S PHARMACY

The timber industry has a logical need to cut down forests in order to get the raw material it requires for making wood products. But leaving forests intact gives a different industry, the pharmaceutical industry, an opportunity to explore for new products. At least 120 different chemicals used in medicines today derive from plants or trees, especially from the jungles and rain forests of the Tropics, the very places that contain the fastest deforestation rates. Therefore, a science called *ethnobotany* has developed to learn more about plant-derived drugs before the plants disappear and to find ways of gathering drug-producing plants in a sustainable manner.

Ethnobotany is the study of relationships between native cultures and the plant life indigenous (native) to the area where the plants live. Tropical societies have long used plant- or tree-derived medicines as part of their culture, and now some pharmaceutical companies have followed that lead and established screening programs to find as many medicinal chemicals from plants as possible, as quickly as possible. Ethnobotanists take a multifaceted approach that serves the needs of large corporations and small local communities. Ethnobotany stresses two objectives that must be met together, not separately: (1) gaining knowledge on the traditional medicines of indigenous tribes of tropical forests and (2) conserving the forests. These two objectives set ethnobotany apart from commercial *bioprospecting*, in which company scientists enter the forest for the sole purpose of finding and removing useful biological products.

Ethnobotanists visit local tribes to learn their customs and methods of healing, and usually the community's shaman, or healer, shows the study team the types of trees and plants that have produced various cures since ancient times. Some medicines come only from particular leaves, or bark, or even from insects that live only on a specific plant. Mark J. Plotkin was an early advocate of ethnobotany for the purpose of learning the medicinal practices of rain forest communities. He described for the *New York Times* in 1999 one of his first experiences in the forest, which turned out to be a revelation for him. On a visit to South America, Plotkin introduced himself to a sha-

on the forest. For example, noise, light, air pollution, invasive plants (see the sidebar "Kudzu"), and overdraw of the watershed originate outside the forest's boundaries but continue to cause damage. As an example, the National Park Service's Web site describes present conditions in the Blue Ridge Mountains that run through several eastern states as follows: "There has always been some pollution affecting the views in the Southern Appalachians. In fact the Blue Ridge Mountain's name originated because

man of the Sikiyana-Chikena tribe. *Times* reporter John Christensen described the meeting: "He [Plotkin] then followed the shaman into the forest and watched him pick a trailside herb, peel long strips of bark from a towering tree and drain sap from a twisted vine. Back at the village, he boiled all the ingredients together in a clay pot over a wood fire. That night, the shaman gave the thick reddish-brown liquid to a young Indian woman with a nearly fatal case of diabetes. The next morning her blood sugar level was almost normal. Within a few days she was well enough to work in her garden again." A small number of scientists took note of the opportunities hidden in the jungle; some wished to work with local communities in a cooperative way, but undoubtedly others sought only to exploit the resources.

Plotkin has criticized bioprospecting and has urged his scientific teams to work with the local people, rather than take knowledge and chemicals to the United States without giving something back to the local community. In an interview with *ActionBioscience.org*, Plotkin explained, "I think the whole concept of intellectual property rights boils down to a question of good manners. If you're going to compensate local or indigenous people, you want to do so in a culturally sensitive way. But you cannot say, 'okay—we'll be back in twelve years and, if we have a cure for AIDS, you'll be in the money.' These people have real needs now." Plotkin now heads the Amazon Conservation Team, which sets up medical clinics and implements apprentice programs with local tribes so they may learn forest conservation principles and computer skills.

In the long term, ethnobotanists help support the biological and cultural diversity of the places they visit. Similar conservation projects now take place all over the world, including projects in the United States with Native American tribes, who already have followed sustainable practices for generations. In addition to sharing information on health and medicine, ethnobotanists try to ensure that the end result of their studies is to support local communities and preserve their forested environment.

Kudzu

Kudzu (*Pueraria lobata* or *P. montana*) is a vine that is part of the pea family, *Fabaceae,* introduced to the United States from Asia in the late 1800s. Farmers in the southeastern states planted the vine because of its fast growth with a plan to reduce soil erosion and possibly use it as animal feed. The vine also belongs to the legume family, which includes plants that capture nitrogen at the plant root and make it available for the plant's use; this process is called *nitrogen fixation*. Kudzu, however, does not control erosion. Instead it bursts into growth so prolific that it engulfs every stationary thing in its path. Those early farmers probably soon discovered that without constant cutting, the vine overgrew yards, gardens, trees, orchards, stream banks, hillsides, and even abandoned houses and farm equipment. In 2005 Georgia farmer Jason Millsaps told *National Geographic*, "I've measured a foot a day [of kudzu growth]. It's a never-ending battle to keep it back." Kudzu remains a very big problem in U.S. agriculture, and universities have set up project teams to work solely on the task of solving the kudzu problem.

Kudzu is one example of an aggressive invasive plant, nonnative to the United States. The vine has spread from its origins to the rest of the southeastern states, from Florida north to Maryland and west to Texas. Some farmers have nicknamed it "the vine that ate the South." At the current rate of global warming, scientists predict kudzu will spread to Michigan in about 30 years. The University of Arkansas agricultural research station offers on its Web site the following: "The joke goes that you should fertilize kudzu in a dry year with motor oil because lubricating the undersides of the leaves reduces the chance of sparks as it races across the ground." This fast growth explains why many invasive plants threaten the surroundings they enter; nature simply cannot adapt fast enough to repel them.

Aggressive plants may be the most harmful of all invasive species because they disrupt the foundation of ecosystems. Aggressive invaders kill or dislodge native photosynthetic plants that support a community of herbivores, carnivores, and predators in addition to microbes and inver-

of the bluish haze caused by hydrocarbons released by trees into the atmosphere. However, over the last 50 years the visibility in the Southern Appalachians has decreased 40 percent in the winter and 80 percent in the summer because of man-made pollutants. Most of the pollution is caused by power plants, industry, and automobiles . . . often traveling hundreds of miles." The National Park Service also discusses the unseen pollution from ozone, acid rain, and nitrogen and sulfur saturation of the soil, all from population encroachment.

tebrates. Kudzu also blocks sunlight from reaching soil organisms, overwhelms tree trunks and leaves, and can literally choke any woodland it overruns.

Kudzu removal is difficult for the following five reasons: (1) it creates deep and extensive root systems; (2) it grows back within days of cutting; (3) kudzu has no natural enemies outside Asia; (4) its seeds disperse easily, carried by wind, water, and animals; and (5) the herbicides active against kudzu also kill many native plants. Entomologist David Orr of North Carolina State University told the *New York Times* in 1998, "It takes a 55-gallon [208 l] drum of herbicide to kill just one acre, and even then you don't really kill it." Protection against kudzu invasion may require a combination of new technologies and a certain amount of cleverness.

New techniques meant to save pristine forests from kudzu attack may soon employ caterpillars called soybean loopers, which have been engineered in laboratories to devour kudzu leaves as they do soybean plants. Though this research has been conducted since the mid-1990s, research has yet to find the right approach for looper-destruction of the thousands of square miles of kudzu infestation. Another approach under study involves a fungus named *Colletotrichum gloeosporioides*, which causes a deadly infection in kudzu after the fungus has been grown and strengthened in a laboratory. These and other biological means of fighting kudzu must come onto the scene quickly in order to help agriculture threatened by invasion.

Meanwhile, research into kudzu's valuable properties has taken shape. Perhaps kudzu can be made into a food source or serve as a sustainable answer to deforestation. Botanists have explored kudzu's use in pulp and papermaking, for example. University of Toronto botanist Rowan Gage told CBC News in Canada in 2007, "If you can develop it as a commodity, kudzu can pay for its own control." Kudzu's commercial use may be a long way off, but the fact that kudzu has caught the attention of people in Canada attests to the vine's ability to grow and invade. Solutions from any sector of research will be helpful.

AGRICULTURE, LOGGING, AND INDUSTRY

Agriculture, the logging industry, and other industries such as mining have threatened the world's three main forest types—tropical, temperate, and boreal—since the 1800s. Parts of the world have made progress toward slowing the destruction of forests for industrial activities. For instance, North America's forest area has stabilized in Canada and the United States so that the total area is no longer decreasing as rapidly as it

was throughout the 1900s. Mexico, however, continues to lose forests at a rate of about 0.5 percent of the total area per year.

Parts of South America, Central America, Africa, and Asia have greatly threatened their forests due to clearing for agriculture, which includes crop cultivation, grazing, or ranching. The land in these parts of the world also contains the greatest stress from population growth and water shortages. Cattle ranching and the conversion of forests into cropland cause a number of damaging effects on the local ecosystems and in the world as a whole. First, wholesale clearing of trees leaves the land vulnerable to landslide and erosion and thus makes the soils less and less suitable for agriculture. Second, as crops become harder to grow, the land may undergo desertification, meaning the soil has been depleted to the point in which agricultural yields drop more than 10 percent. Some areas that have succumbed to desertification no longer contain growth of any kind. Third, agriculture involves road-building, which further destroys the crop or grazing land and contributes to erosion. Roads also interfere with the migrations of mammals, reptiles, and amphibians. Fourth, the deforestation of forests for agriculture or any other enterprise destroys habitat and so destroys the natural ecosystems that depend on forested areas. Finally, each loss of trees represents a loss of the Earth's capacity to reduce carbon dioxide levels in the atmosphere, so that global warming continues.

The Amazon region of South America has been especially hard hit by cattle ranching and soybean farming. *National Geographic* reported in 2007 that during the past 40 years, 20 percent of the Amazon rain forests have been deforested for agriculture. The National Spacer Research Institute's satellite images furthermore have shown that in a single year, from 2007 to 2008, Brazil's Amazon region lost an area of jungle twice the size of Delaware. This is more forest loss than took place in all of the previous 450 years since Europeans began settling those areas. In Brazil the government allows farmers to clear 20 percent of their land for crops provided they leave the other 80 percent untouched. But hunger and poverty continues here and in many other parts of the world, driving families into the forests to clear land for cultivation or ranching. Stephan Schwartzman of the Environmental Defense Fund explained to *National Geographic*, "Satellite imagery shows that in many frontier zones there is near zero compliance [to Brazil's 20 percent quota]. People have to believe breaking the law has consequences." Schwartzman's stance may be correct, but unless nations address poverty at the same time they establish forest protections,

Strip clear-cutting allows large-scale logging while making an attempt to conserve habitat and reduce erosion. Loggers leave the cut strip alone for several years while young trees reemerge. Meanwhile they cut strips from other parts of the forest. The first two to five years on a pine plantation such as this one are the most critical because young trees need room to grow without competition from one another or from weeds and grasses. *(Natural Resources Conservation Service)*

the trees will continue to fall legally or illegally. Poverty has now been identified by many biodiversity experts as a major underlying cause of species loss. The future of forests is therefore linked to the progress society makes toward alleviating hunger and poverty.

Commercial logging in all parts of the world represents another major threat to forests. The forestry industry classifies forests into three different types: old-growth, second-growth, and tree plantation or tree farm. Old-growth forests have never been cut or disturbed by human activities, so they hold a vast collection of natural ecosystems. Second-growth forests refers to forests that are in the second phase of ecological succession, meaning they have returned after being cut down by people or destroyed by natural occurrences such as fire. Tree plantations are managed tracts of land that contain one or more species of planted trees on land that has been cleared of natural forest.

Today in the United States and Canada, old-growth forests receive protections either from government agencies or from purchases by organizations that take the forests out of industry's reach. Even so, only about

3 to 4 percent of the old-growth forests that covered the United States still remain. Timber companies now work principally in second-growth forests and tree plantations to supply their customers with pulp for the paper industry and wood for the wood products industry. Companies manage these forests in one of two ways: even-aged growth or uneven-aged growth. In even-aged growth, all the trees grow from seedlings that were planted at the same time, so the trees are almost identical in age and size. Uneven-aged stands contain trees of many different ages and sizes. Uneven-aged stands create extra work for loggers during harvesting, but varied stages of tree growth also support natural ecosystems better than even-aged trees.

Two different styles of logging can greatly affect the condition of the logged land. The first type, *clear-cutting,* removes all trees in an area in a single cutting operation. The second method, called *selective cutting,* removes only the older trees, which are cut down individually while other trees remain standing. The timber industry for many years preferred efficient and fast clear-cutting, and this method remains in use in parts of the world today. A healthy environment demands that forests be only minimally disturbed if they must be disturbed at all. So for now, logging has become lodged in the middle of two critical needs: the world's paper consumption and environmentalists' wishes to spare forests from further destruction.

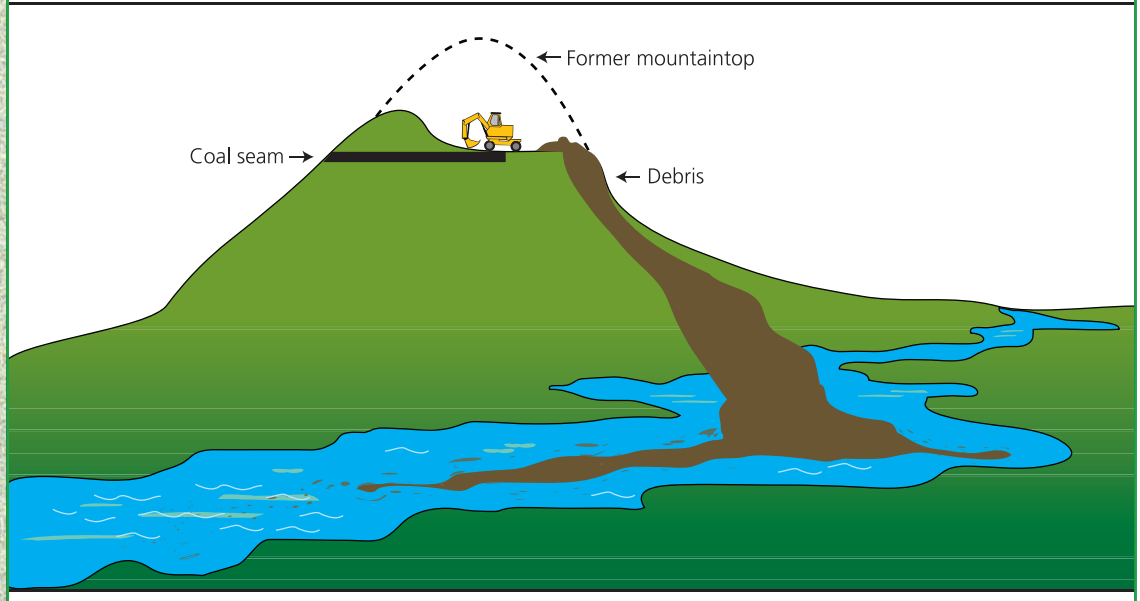
Clearing land for agriculture and logging destroys forests even before the planting or logging begins. Road-building, entry of large equipment, and blasting with explosives all endanger forest ecosystems.

After agriculture and timber, mining may cause the next greatest harm to forests, and two different types of mining each cause different problems. First, *shaft mining* refers to the creation of a narrow tunnel from the ground's surface to the ore or coal below, perhaps as far as a mile (1.6 km) beneath the surface. It disrupts the land around it with roadways, noise, dirt, dust, and pollution from toxic *mine tailings.* Second, *strip mining* involves the removal of a large piece of the land, rather than digging shafts, in order to gain easier access to the coal. Strip mining has angered environmentalists and local communities because of the dramatic changes it causes to the landscape, often in pristine woods that had never before seen any human activities. Mining companies restore the land as best they can after the mines have been exhausted, but even this attempt at restoration meets stern criticism. Many environmentalists believe that ecosys-

tems cannot recover their original vitality on restored strip mine sites. The biology professor Frank Gilliam of Marshall University in West Virginia described his view on such restoration in 1992 in *Audubon* magazine: "It's like taking apart someone's clock, then 'restoring' it by stuffing some of the parts into a box." Strip mining has slowly given way to other forms of mining, but one method called mountaintop mining may have even worse consequences.

Mountaintop mining is a type of coal strip mining—in existence for about 30 years—in which mining companies remove the topmost portion of a mountain and level it to gain easier access to the coal. Mountaintop mining causes two potentially serious changes to the environment: (1) removal of an entire mountaintop eliminates habitat and (2) the excess material, known as spoil or overburden, must be dumped somewhere; this dumping has the potential to pollute streams and destroy the dump area's

Mountaintop Mining



Mountaintop mining begins with clear-cutting trees and using explosives to loosen soil and rock. Large equipment then digs through the earth to expose the coal. Coal companies are expected to restore the land after it has been mined, but native trees have trouble growing on the altered soil and landscape. As a result, mountain habitats are destroyed, and streams that receive runoff from the mine suffer for many years.

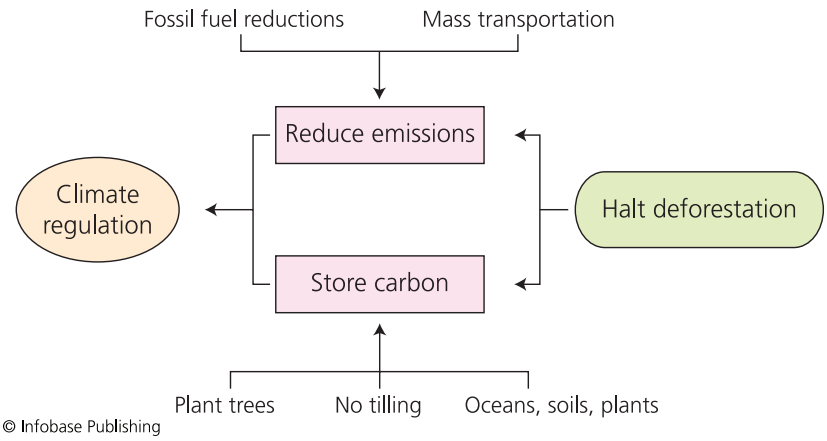
ecosystems. A government scientist told the *Washington Post* in 2004, "A huge percentage of the watershed is being filled in and mined out [in West Virginia], and we have no idea what the downstream impacts will be. All we know is that nothing on this scale has ever happened before." An official from the U.S. Interior Department's Office of Surface Mining explained his dilemma to the *New York Times* in 2007: "There's really no place to put the material except in the upper reaches of hollows. If you can't put anything in a stream, there's really no way to even underground mine." Mining therefore produces hazardous wastes at the same time it creates serious potential threats to habitats.

Strip mining and mountaintop mining now take center stage in a heated debate between the mining industry and environmentalists, particularly since the need for energy sources such as coal continues to increase. Bo Webb is a West Virginia resident who lived near a site that began mountaintop mining several years ago. He told the *Washington Post,* "I've been coming up through these mountains since I was five years old. Now the place looks like an asteroid hit it." The U.S. Environmental Protection Agency (EPA) has estimated that by the year 2010 at least 2,300 square miles (5,957 km^2) of forest will have been lost to strip and mountaintop mining in Appalachia alone. An EPA briefing to President George W. Bush as early as 2002 warned of the hazards of mountaintop mining. "The Appalachian Highlands is characterized by some of the best forest habitat in the world," the briefing stated. "Current [mining] reclamation practices are converting these forests into grasslands, which may significantly impact neotropical bird populations and other sensitive species if left unchanged." Mining companies meanwhile counter that they leave mountains in better condition than before the mining started. "People have used these sites to build high schools and golf courses," argued Jack Gerard of the National Mining Association. "Some of the sites are so beautifully reclaimed, many people can't tell the difference." Mining may continue to be a point of contention between its industry and environmentalists for a long time.

CLIMATE CHANGE

Forests take in the greenhouse gas carbon dioxide (CO_2) and produce large amounts of oxygen. Forests also provide habitat, cool the landscape, filter pollutants from air and water, and soak up excess water to reduce flooding

Deforestation and Climate



Deforestation of large landmasses reduces Earth's ability to regulate its climate. New tree plantings help reduce atmospheric carbon dioxide and serve as carbon storage—oceans and soils, especially non-tilled soils, also store carbon. A halt to deforestation meanwhile helps reduce emissions by reducing the carbon dioxide released into the atmosphere when trees are cut down. Reduced carbon dioxide emissions and increased carbon storage in organic compounds work in unison to regulate Earth's climate.

and erosion. Of all of these services, the contribution of forests in solving the climate change problem may be the most critical. Trees help reduce warming of the atmosphere by withdrawing carbon dioxide, which is one of five gases that trap heat as a greenhouse traps warmth by reflecting heat energy. The other greenhouse gases are water vapor, ozone, nitrous oxide (N_2O), and methane (CH_4).

Deforestation adds to global warming in two ways that act simultaneously. First, fewer live trees means less carbon dioxide removed from the atmosphere. Second, deforested areas produce large amounts of biomass that releases more carbon dioxide into the air as the biomass decays. Eventually deforested areas warm up because the cooling effect of trees has been removed and a deforested region grows hotter and drier, often leading to desertification. Desertification in turn decreases soil fertility, causes erosion, and further damages any healthy habitat remaining.

Deforestation therefore contributes to climate change, and the continued warming of the atmosphere affects the remaining forests. Global

warming is expected to cause the following events, some of which have already begun:

- increased pests and infections
- advance of invasive species
- extinction of certain trees at lower altitudes
- accelerated aging
- decreased growth and productivity
- abnormal growth due to a shift in insect, mammal, and bird populations
- flooding of low-lying areas

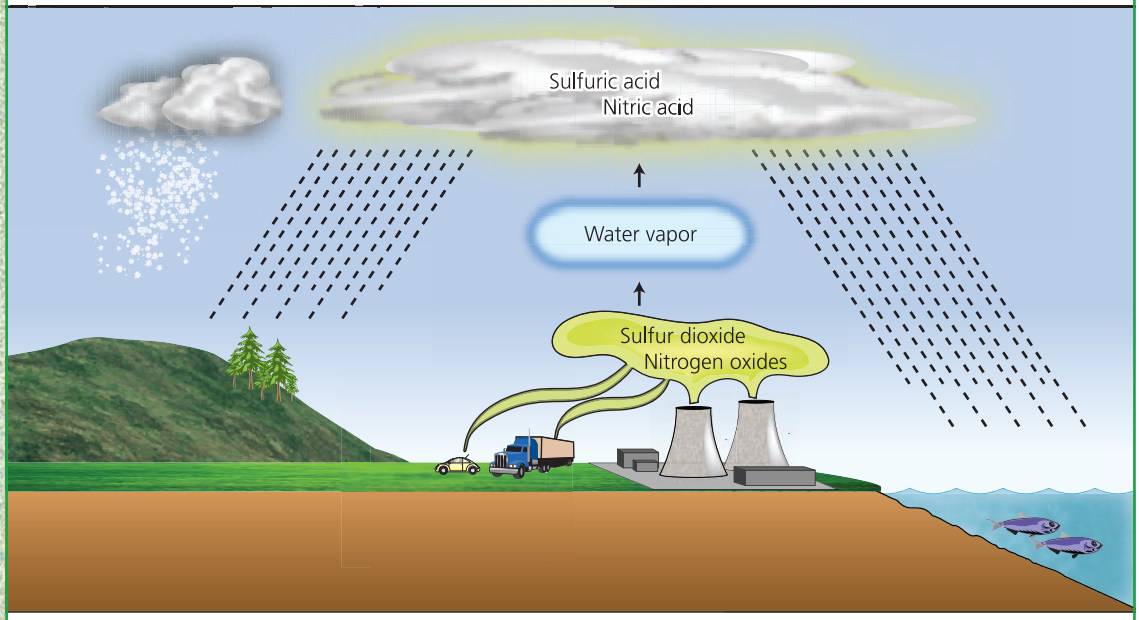
"Planet Earth is always more complicated than you think," said the geographer Heiko Baltzer of Great Britain's University of Leicester to *Science Daily* in 2007. "The lengthening of the growing season that has been described in the scientific literature is a non-linear phenomenon. It is influenced by feedbacks between the atmosphere and the forest, which responds to rising greenhouse gas levels and higher temperatures." The relationships between climate and forests, climate change and deforestation present ecologists with one of society's biggest challenges.

POLLUTION AND PESTS

Four types of pollution damage forests: acid rain, other air pollution, ozone, and runoff containing excess nitrogen fertilizers. Acid rain consists of industrial emissions containing sulfur dioxides and nitrogen oxides from fossil fuel combustion. In addition to rain, fog, snow, smog, dirt, dust, and smoke carry these compounds; all of these materials can be grouped into the general category of acid rain. Acid rain harms leaves and also makes soils more acidic. Acidic soils display different chemistry than normal soils and this affects nutrient uptake by roots. Acidification of soil also leads to a leaching of nutrients with rainwater. As a result, areas in the soil undergo *eutrophication,* which is the depletion of oxygen by microbes due to a sudden influx of nutrients, often nitrogen or phosphorus compounds.

Particles carried in smoke and smog change ecosystems indirectly by decreasing rainfall, and they may injure lichens, mosses, and insects

Acid Rain



Acid rain is a general term for a mixture of wet and dry matter having low pH and which falls to Earth with precipitation. The EPA has declared that in the United States about two-thirds of all sulfuric acid and one-fourth of all nitric acid in acid rain come from coal-burning electricity-producing power plants.

in particular. The meteorologist Daniel Rosenfeld of the Hebrew University of Jerusalem explained the process to Cable News Network in 2000: "The smoke and pollution particles, when going into the clouds, distribute water into many small droplets. They are so small that they are very slow in combining into raindrops and other icy precipitation particles." The consequence is lowered rainfall or even drought.

Trees behave in the same way as humans when they become vulnerable due to aging, poor nutrient supply, or a stress such as dehydration: They become more susceptible to injury. Climate change makes trees vulnerability to infection in two ways: first, by putting physical stress on trees that increases the likelihood of infection, and second, by expanding the normal range of pests, including invasive species. With global warming, the range of many tree pests and *pathogens* will grow larger and affect trees that had previously been free of disease. Infection then attacks trees already stressed by environmental changes. Pests have another advantage

over trees: They can adapt to changing environmental conditions faster than trees.

A greater proportion of stressed trees also gives invasive plants an opening into the forest habitat. These invaders may be nonnative trees, but they are also likely to be plants, insects, microbes, or animals. Not all invasive species kill ecosystems, but many do, and these invaders can take over a forest in a matter of days.

CONSEQUENCES OF DEFORESTATION

As the world's forested area contracts, the carbon-storage capacity of the planet also decreases. Between 1990 and 2005, for example, the planet's carbon-storage capacity declined because more than 5 percent of forests disappeared during that time. By the end of 2005, the Coalition for Rainforest Nations proposed that nations be paid to leave their forests standing because the worth of the stored carbon exceeded the worth of timber from the same trees. Kevin Conrad, a resident of Papua New Guinea (where forests are critically threatened), spoke to the United Nations in 2007 on the topic of deforestation, emissions, and global warming. "I think collectively we as humanity have become more mature in this climate battle, and we understood collectively that we've got to turn off all the emission sources in order to win," Conrad said. "The climate doesn't know whether it came from a factory or from Papua New Guinea's deforestation. If we can deliver sustainable revenues to communities living in rural areas of tropical countries that are deforesting simply to exist, then we have sort of a win-win proposition." Halting deforestation may be the cheapest way to slow global warming.

In 2007 the U.S. government's Climate Change Science Program released "The North American Carbon Budget and Implications for the Global Carbon Cycle" report, which concluded that the remaining North American forests could no longer remove the amount of carbon emissions produced each year. According to the report, the North American continent accounts for 27 percent of all carbon dioxide emissions in the world, and the disparity between emissions and forests' capacity to reduce the carbon is getting larger. The report's authors stated, "Carbon absorption by vegetation, primarily in the form of forest growth, is expected to decline as maturing forests grow more slowly and take up less carbon dioxide from the atmosphere." Christopher B. Field of the Carnegie Institution's

Department of Global Ecology added, "By burning fossil fuel and clearing forests, human beings have significantly altered the global carbon cycle." People cannot ignore the connections that nature has established between forests, the cycling of elements, and the planet's climate.

People in forested regions of the world that are also beset by poverty need compensation if they agree to save trees. As noted earlier in this chapter, even making deforestation illegal may not completely solve the problem. Desperate loggers may leave their land alone but sneak into other areas to continue harvesting wood. Rachmat Witoelar, Indonesia's Minister of Environment, told the Associated Press in 2007 that heavily forested countries such as his own, Brazil, and Costa Rica must receive compensation for avoiding the deforestation of their lands, or else any plan to slow carbon emissions would not work. "Our view is that we can combat climate change by maintaining the health of our forests and for that we need funding. This is a matter of justice." Carbon payments to farmers might need official monitoring to ensure that farmers who receive payments refrain from logging forests anyway. In the deep Amazon and Congo basins, monitoring would not be an easy matter, and this highlights the challenges that come with protecting the forest biome.

CONCLUSION

The rate of deforestation varies in different parts of the world, but overall the world is losing its forests. Human activities threaten forests in numerous ways, but population growth has been shown to be the main threat. Two main types of threats have endangered the world's forests: large commercial logging operations and small subsistence farmers that take small but steady pieces out of local forests. The timber industry has harvested so much of the unprotected primary or old-growth forests that it now relies mostly on secondary forests for its income. Fortunately, governments have greater control over large timber companies and, if the government chooses, can work with industry to protect forests. Small logging operations that occur in hidden parts of forests present a more difficult challenge for two reasons. First, these operations are difficult to find and so to control. Second, much of the world's logging in poor communities offers the only means people have of earning an income and getting fuel for heating and cooking. As poverty increases in densely forested areas,

the forests fall under increased threat of destruction. Protecting forests therefore requires the cooperation of industry and government to alleviate the poverty that threatens forests and their ecosystems. Ridding the world of poverty has been a goal of society for thousands of years, yet people have made very little headway on this problem. The world's forests—trees, ecosystems, and exotic animal life—have all become endangered either directly or indirectly by this aspect of society.

Technology offers a few windows of opportunity in forest conservation. New methods for restoring forests, such as reseeding, have been successful, but a large amount of work must still be done to protect forests from encroachment by people, their industries, or by invasive species. Environmental scientists have also been hampered by a lack of data on the current and future conditions of the Earth's forests. Though this biome has been threatened, forests still cover almost one-third of the world's land and remote places have been difficult to study. Even without a complete picture of today's forest health, biologists know that global warming will damage the forests as it damages many other biomes and ecosystems. Stopping and reversing global warming presents another very big obstacle to conserving the health of the environment.

The threats to forests are therefore not small problems that are easily solved; they are global problems that require international cooperation. While governments and organizations such as the United Nations continue to work on lessening poverty and putting a halt to global warming, forests need additional help for the more immediate future. Forests require strong legal protections that will stop both small-scale and large-scale destruction. The timber industry has tools at its disposal to harvest forests in more sustainable ways and, to their credit, many representatives of the timber industry seem interested in taking a more careful approach to logging. The mining industry must also explore options for decreasing the damage done to the land during ore excavation. Both industries must work hard to find the best methods of returning the land to a state that can support forests again in the future. Some technologies already exist that will help. New technologies in replanting forests, harvesting timber, and fighting invasive species are almost ready to join these efforts in forest protection.

Tropical Forest Preservation

Any discussion on plant and animal conservation usually begins with tropical forests because these forests contain at least two-thirds of the world's organisms, at least 3 million species. They may contain many more species that are simply undiscovered. Tropical forests today cover about 6 percent of the Earth's land area, which is half of what they covered as late as the 1950s. Current satellite scanning technology combined with on-the-ground surveys indicate that the fastest destruction of tropical forests is taking place in Central and South America (especially Brazil), equatorial Africa, and parts of Asia. The forests in these regions of the world also include tropical rain forests—meaning they are dense, heavily wooded forests that grow in areas of high precipitation, receiving 55–160 inches (150–400 cm) of rain per year. Other characteristics of tropical forests are the following: a high amount of plant, tree, and animal diversity; more than 380 tree species per square mile (100 per km^2); dense, continuous canopy that lets little light reach below; temperature averages of 68–77°F (20–25°C) that vary little throughout the year; evenly distributed precipitation; and nutrient-poor soil. The largest rain forests with these characteristics occur in Brazil in South America, Zaire in Africa, and Indonesia in Southeast Asia.

A challenge to quantifying diversity loss in the tropical forests arises from the fact that many of the species living there have not yet been identified or named. Peter H. Raven, the director of the Missouri Botanical Garden, once wrote, "Regardless of whether there are 2.5 million or 25 million, the task facing us is enormous. In light of the rapid destruction of tropical

forests, it is an especially urgent matter to catalog the organisms in those regions. . . ." Despite those cautions, more than 20 years later the plight of tropical forests remains as precarious as ever, if not more so. The Worldwatch Institute has estimated from high-resolution satellite images that, since 2003, South America lost 2.5 percent of its forest, Central America and the Caribbean lost 3.9 percent, and Africa lost 3.2 percent. More alarming, it may be accelerating in some places. Brazil engineered a plan within the past decade to slow its deforestation rate, and by 2008 the government assured environmental groups that the country had reined in deforestation. Though the rate had slowed, Brazil's Amazon Basin continues to undergo a frightening rate of deforestation: 1,250 square miles (3,235 km^2) lost in one five-month period in 2007 alone. Tim Hirsch, a writer on environmental topics, said in 2008, "What matters most to people is whether deforestation is coming under control, or whether this magnificent ecosystem is doomed to relentless decline, with all the implications for the millions of unique species it harbors, for the survival of precarious indigenous cultures, and for the global climate." Environmentalists such as Hirsch find it understandably hard to trust that forests will be saved if governments send falsely assuring messages.

Deforestation in the tropical Amazon basin has been devastating to biodiversity. Thousands, perhaps hundreds of thousands, of species such as this yellow-crowned parrot live almost exclusively in this region. *(iStockPhoto.com)*

Remote sensing surveys and field studies can be difficult for assessing the exact status of forests. Parts of South America are inhospitable to survey teams due to terrain and to armed political groups that operate in certain regions. Tropical deforestation also does not take place evenly; some areas fall much faster than others. These factors complicate the process of counting forest species and determining their rate of loss or gain. In parts of Ecuador, Brazil, and Madagascar, for instance, the biodiversity expert Norman Myers estimated "there

are at least ten to thirty animal species for every one plant species." Saving the forests means saving all of biodiversity.

The world's tropical forests make up a major portion of the total biodiversity hot spots. This chapter discusses the reasons for tropical forest loss today, the methods being used for halting tropical deforestation, and new technologies for meeting the needs of trees and the people that depend on them.

TROPICAL FOREST LOSS

Measuring forest loss has always been a difficult task in ecology because satellite imagery cannot discern detailed ground conditions in dense forests, and field studies require intrepid researchers willing to work in remote places. Tropical forests often present an added challenge due to local political circumstances. Two additional factors make all types of forest assessments difficult. First, deforestation means different things to different people. Governments and environmental organizations use various definitions for deforestation, forest degradation, and even for the term *forest*. (In this book, a forest is a biome that receives an annual precipitation adequate to support the growth of a mixture of tree and plant species). Second, some countries' conservation programs hinge on the policies of other countries with which they trade. Therefore, unscrupulous leaders may be tempted to hide deforestation rates or even to exaggerate them. By concealing the true rate of forest loss, governments might remain in good standing with the rest of the world. Conversely, by exaggerating the loss rate, countries may become eligible to receive monetary aid for national programs that spare forests.

Tropical forest loss comes about by two types of human incursion into pristine forests: large-scale urban expansion and small-scale agriculture. Large swaths of forests have always been vulnerable when human populations grow and devour more space and more construction materials. In Central and South America and Africa, rural families take additional small pieces out of forests and use them for growing crops for their own use and for sale. A small bit of forest removal probably does not seem as if it could harm an entire vast ecosystem of thousands of square miles. This little-by-little deforestation has had a devastating effect on tropical forests of the Amazon Basin and equatorial Africa. Though small-level deforestation has taken place for centuries, it accelerated in the past half-century when populations boomed and industrialization entered the Tropics on a major scale,

transferring jobs that had previously been available in rural areas to large cities and forcing small communities to rely more on the local forest to support them.

Tropical forests now serve as resources for various types of industries dealing in timber, plant life, exotic animals, medicinal herbs, and dietary supplements. The table on the next page lists the main resources sought in tropical forests today.

In 1997 more than 150 nations signed a treaty called the Kyoto Accord for the purpose of putting into action plans for reducing global warming. The protocol omitted, however, any meaningful attention to deforestation. Since the treaty's signing, nongovernment environmental groups have led the way in buying forests with the objective of protecting them from further destruction. Conservation International, the Nature Conservancy, and the World Wildlife Fund are three organizations that try to save the world's forests from harvesting. Governments in Australia and Europe have recently joined these efforts by setting aside funds for forest protection. In Brazil, the home of some of the world's richest biodiversity, deforestation rates declined for three straight encouraging years until 2007, when deforestation rates again increased.

Indigenous societies in Brazil have now asked to help turn the tide so that their way of life will not disappear with the last tree. In April 2008 several forest tribes from the Amazon Basin met in a conference to discuss with the government plans for greater input in climate change programs. Stephan Schwartzman of the Environmental Defense Fund attended the meeting and told the *New York Times,* "There is a real sense that this potentially represents a huge opportunity for forest peoples to influence climate change negotiations and create larger scale incentives to stop deforestation and improve their living conditions." Unfortunately, finding a fair means of compensating poor villages for not destroying their forests has been a hurdle. In the meanwhile, government agents roam central Brazilian forest roads in sport-utility vehicles to catch illegal loggers in a program called Arc of Fire. Only 70 armed agents patrol 1.3 million square miles (3.4 million km^2) of forested land, so the chances of this program succeeding remain questionable. Brazil loses an average of 270 square miles (670 km^2) of forest every month. One Arc of Fire agent admitted to the *Times* in 2008, "I am playing a game we are fated to lose. The game is 12 to 1 against us and there are two minutes to turn it around." Though the Arc

Tropical Forest Resources			
Type of Tropical Forest	Main Characteristics	Main Woods with Commercial Value	Other Plant Resources
rain	warm, moist, dense, along the equator	mahogany, Brazilian walnut, Brazilian cherry, ipê, Malaysian hardwood, bamboo, palm, rattan	fruits, vegetables, nuts, coffee, chocolate, beans, oils, flavorings, medicines, rubber, ornamental plants
evergreen and semievergreen	no dry season	tamarind, bamboo, rattan, oak, chestnut, mangrove, tropical pine	fruits, vegetables, nuts, beans, coffee, honey, oils, medicines, ornamental plants, dyes
montane cloud (fog forest)	Tropics dominated by clouds and mists at tree level	oak	beans, coffee, fruits, herbs, orchids, tropical ferns, medicines
deciduous	contains dry and rainy seasons	teak, rosewood, palm, light hardwoods (example: mersawa), medium hardwoods (kapur), heavy hardwoods (giam)	oils, balsams, resins
scrub	contains leafless dry season	scrub oak, manzanita, eucalyptus	grapes, olives, figs
thorn	contains leafless dry season, thorny vegetation predominates	limited	legumes, plants, shrubs

The worldwide trade in exotic species presents a serious threat to forests and to forest ecosystems. Traders disturb sensitive habitat as they search for rare birds, reptiles, amphibians, and plants that they sell on the black market. Many threatened or endangered orchids, such as the *Diuris drummondii* shown here, have been nearing extinction because of illegal picking and smuggling. *(Bernd Haynold)*

of Fire agent spoke in hyperbole, he certainly relayed the dire situation of the tropical forests.

Countries outside South America that contain tropical forests confront a different task from Brazil's in stopping deforestation. In Brazil and in other locations in South America, native populations have strong legal claims to their land and may therefore make earnest attempts to protect

their trees for future generations. Other parts of the world do not have similar systems and so decrease the chance that someone will take responsibility for protecting the trees.

PRIMARY CAUSES OF TROPICAL FOREST LOSS

Deforestation of the world's tropical forests today arises from a mix of primary and secondary causes that often relate to one another. Primary causes, also called basic causes, refer to general conditions within a region's economics and politics that lead to deforestation. Secondary causes exert more specific, direct actions on trees.

The underlying factors of tropical forest loss connect to local population lifestyles. Therefore, primary causes of tropical deforestation may be different from one continent to the next. In general, however, tropical forest degradation comes from the following primary causes:

- poverty
- overpopulation
- historical factors
- government policies
- exports to the international market

Poverty and overpopulation throughout the world force people to deforest their land; consequently plant and animal biodiversity declines, pollution increases, and climate change upsets ecosystems. Regional history also puts pressure on forested lands, especially in relation to the region's poverty levels. Tropical forests exist mostly in developing countries, other than the forests of Hawaii and Australia. The history of these developing countries include a period of colonialism in which Great Britain, France, Spain, or Portugal took land away from native people who had managed it for generations. Over time, colonial management of the land's resources tended to exploit those resources more than private owners would likely exploit their own land.

Financially poor countries additionally hold large international debt—money owed to other countries. In order to repay debt with high interest rates, developing countries may be tempted to harvest their natural resources

This cattle ranch in the Pantanal, Brazil, illustrates the potential environmental problems caused by ranching. A swath of forest has been removed to make room for grazing. Grazing also uses large volumes of water, destroys topsoil, produces enormous amounts of solid waste, and the cattle belch methane gas due to normal digestion of grass. Cattle-produced methane accounts for almost 20 percent of the methane in the atmosphere. *(Christopher Reiger)*

for income. Government policies on debt repayment, natural resource management, and exports contribute to degradation of tropical forests. Exports help to pay off debt, but there exists another reason why developing countries have high amounts of exports: overconsumption in the industrialized world. High export levels from tropical regions may be attributed to the following four factors: overconsumption, excess waste, rampant development, and specialized markets in tropical woods, plants, birds, animals, and minerals. This problem has been described in a variety of ways; one term for the problem is the *throwaway society*. The International Food Policy Research Institute has gathered data on the world's resources relative to world population, and many environmental scientists have summed up the results with the following phrase: "Twenty percent of the world's population is using 80 percent of the world's resources." Said another way, consumerism threatens forests.

SECONDARY CAUSES OF TROPICAL FOREST LOSS

Secondary causes of tropical deforestation relate to the activities that have immediate negative effects on forests. The major secondary causes are the following:

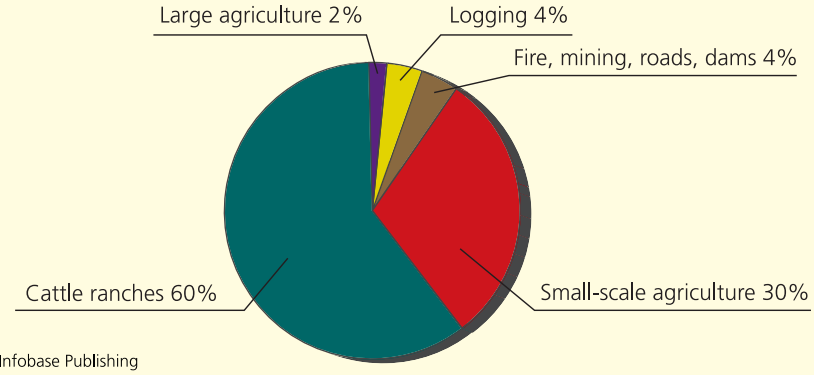
- logging and logging roads
- cattle ranching

- cash crops, small-scale cultivation, and fuel wood
- mining and oil drilling
- large dams
- tourism
- new roadways

These causes can be grouped in various ways. For instance, logging roads create much the same problem as public highways by removing trees, causing erosion, and fragmenting habitat, while cattle ranching resembles mining because it requires large tracts of cleared forest.

The upheaval in the Amazon Basin provides an example of how human activities kill a forest over time. In the first phase, logging operations remove the best timber from a region, after which timber companies sell the land to cattle ranchers for their animals to graze, beginning the second phase of the land's use. Ranchers may leave a few trees standing for shade, but after the land has been overgrazed, the ranches move to other places and families buy the land at discounted prices. These families cultivate small gardens and perhaps cut down more trees for cash crops or fuel and hunt the native animals. Eventually, the small

Deforestation in the Amazon



The forests of South America's Amazon River basin are among the most threatened ecosystems in the world due to human activities, primarily ranching and small family-owned farms.

farms deplete the nutrients from the soil so that it supports little new plant growth. The farmers move on to cleared land they can cultivate or they remove more forest. Meanwhile, other parts of the forest disappear as mining operations and oil drilling companies burn the already damaged patches of forest because burning is easier and quicker than cutting and hauling out the logs. The succession of human activities in the Amazon Basin described above is unsustainable. After a few decades, maybe less, the forested land turns into a bleak landscape that cannot support substantial human, animal, or plant life. The results of such

CHICO MENDES—ACTIVIST FOR THE BRAZILIAN RAIN FOREST

Chico Mendes was born into extreme poverty in 1944 in the Acre state of western Brazil. Mendes's people earned their living as *seringeiros,* or rubber tappers, workers who gather rubber from the forest's seringeira trees owned by private owners. After World War II ended in 1945, the need for massive amounts of rubber slowed and rubber prices plunged. Landowners forced the *seringeiros* to sell their harvest for pennies. At the same time, ranchers squeezed the villagers into smaller pieces of viable land by slashing and burning the forests for conversion to cattle ranches. Stephan Schwartzman of the Environmental Defense Fund said, "For their part, the rubber tappers had no inkling that the forest had values and meanings in the outside world, beyond its rubber and Brazil nuts." Within a decade of the conversion from rubber production to ranches, almost half of the rubber tapper communities died from malnutrition or lack of medical care.

Chico Mendes watched the smoke fill his homeland's sky year after year. Into the 1970s, ancient forests burned and new ranches and farms took their place. Swindlers with counterfeit deeds took land from the few fortunate tappers who had owned their property for generations. Tappers who refused to sign over their land were killed at the hands of the scam artists. Mendes's frustration grew as he watched his people fall deeper into trouble. "Don't you sign anything," he urged. "This land is ours. When you change it into money, you are losing the possibility of surviving. Land is life!" Still, the land burned, rain filled pools in the rutted ground and mosquitoes bred; malaria soon plagued the already suffering villages.

Between 1980 and 1983, a gold rush hit Brazil and highways carved through the remaining forests. Miners refined the gold with mercury, and tons of this metal began entering the ecosystem, as well as the native people's bodies. Chico Mendes had few political skills but nevertheless led a workers' union and fought on behalf of his people against illegal logging, the poisoning of

actions are detailed in the sidebar "Chico Mendes—Activist for the Brazilian Forest."

Ranchers and large farms have learned to reduce soil degradation by clearing the forest in a method called *slash and burn*. Slash and burn is a process of cutting down large tracts of forest, letting the downed trees dry, then burning them in place to release nutrients into the soil. Soils in tropical forests tend to be nutrient-poor due to the dense vegetation they support. Slash-and-burn methods fortify the soil for grazing or agriculture, but eventually the added nutrients also diminish and the

forest ecosystems, and conditions that led to the villagers' illness and threatened livelihoods. He taught them the value of the intact forest and at the same time informed environmentalists in other countries about the rubber tappers, a culture that most of the world never knew existed. Mendes persevered in alerting the world to the devastation that the Brazilian government and businesses had done to the Amazon Basin. International environmental groups listened; British film director Adrian Cowell released *The Decade of Destruction,* filmed in the Amazon, to show the world how the forests were being annihilated.

Mendes and other natives of the Amazon advocated the sensible use of tropical forests. They tried to convince leaders that part of the forests could be conserved even while industries claimed other portions. For a half-century the *seringeiros* and ranchers continued a fierce battle over how the forests were to be used. Through the 1980s Mendes rallied the *seringeiros* into a national organization, found people in government willing to accept the idea of conservation, and helped environmentalists understand that the Brazilian forests had become an environmental emergency. The ranchers, however, did not easily retire from the forests. At the close of 1988, a rancher and his son shot Mendes to death at his home in the town where he had been born. After his death, the Brazilian government set up extractive reserves, or *reserva extratìvìstas,* which were forest preserves that Mendes had long advocated. The reserves now protect the *seringeiros'* culture and the forest and its ecosystems. Schwartzman said, "What I wanted them [the press, policy makers, and the public] to know was that environmentalism in the Amazon . . . was what Chico was doing; that contrary to the received wisdom and common sense of the time, there were people in the forest interested in alternatives for the future—theirs and that of the forest." Chico Mendes's work may provide a lesson for the present and the future; local communities might hold the greatest power of anyone to save forests that are also part of their culture.

ranches and farms move to another part of the forest to begin the process again. This constant using up of land and moving on to healthier sites is called *shifting cultivation.* Abandoned land that has been treated this way can again support a healthy mixture of growth through ecological succession in the succeeding decades. By the time the vegetation has returned, however, the shifting cultivation may also return as it progresses through a region.

RESTORATION AND SUSTAINABLE HARVESTING

Years of burning the Amazon Basin forests have created dry conditions that increase the chance of more fires and makes restoration more difficult. Restoration and sustainable forest management are possible in all of the world's tropical forests, but time is running out. Success in restoration and sustainable harvesting will come about only if both rural villages and national governments agree to the same plan.

Restoration involves activities that enable a degraded forest to recover its health and return to normal growth. Restoration methods make up a science called *restoration ecology,* which is the transformation of land back to its original state, or close to its original state, after being damaged by human activities. Restoration of tropical forests consists of three main techniques: reforestation, rehabilitation of degraded forests, and conversion of damaged areas to sustainable forestry.

The United States and many other countries have used reforestation to restore land that had been cleared of its forests. Reforestation involves the planting of hundreds of seedlings containing a mixed population of native trees, followed by the return of forest in the seeded areas to near their original condition within 100 to 500 years, depending on the type of trees.

In 1977 environmentalist Wangari Muta Maathai began the women's Green Belt Movement in her native Kenya for the purpose of restoring the country's tropical forests. Maathai inspired the group to build nurseries, raise seedlings, and plant new trees. Maathai described her country in her 2006 book, *Unbowed*: "At the time of my birth [1940], the land around Ihithe was still lush, green, and fertile . . . We lived in a land abundant with shrubs, creepers, ferns, and trees, like the *mitundu, mukeu,* and *migumo,* some of which produced berries and nuts. Because rain fell regularly and

reliably, clean drinking water was everywhere. There were large, well-watered fields of maize, beans, wheat, and vegetables. Hunger was virtually unknown. The soil was rich, dark red-brown, and moist." By the time Maathai finished *Unbowed,* the situation in Kenya had undergone a drastic change. "The [European] missionaries were followed [in the 1800s] by traders and administrators who introduced new methods of exploiting our rich natural resources: logging, clear-cutting native forests, establishing plantations of imported trees, hunting wildlife, and undertaking expansive commercial agriculture. Hallowed landscapes lost their sacredness; local people became insensitive to the destruction, accepting it as a sign of

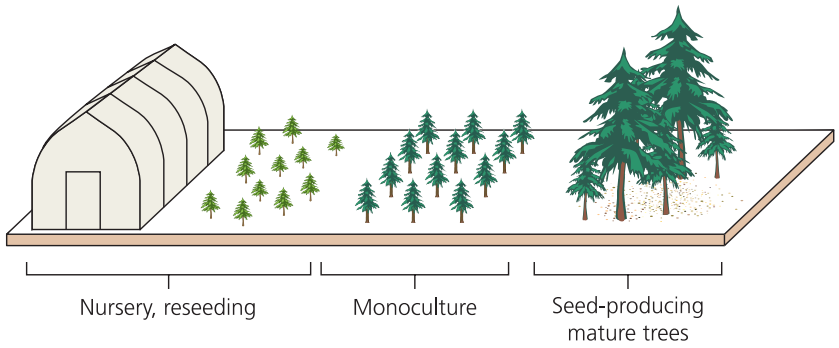
Cloud forests, also called fog forests, occur in mountainous tropical and subtropical regions. Moisture forms in the canopy creating still, humid conditions below. This Malaysian cloud forest grows abundant mosses, ferns, and epiphytes. Epiphytes are plants that grow only in the forest canopy and pull nutrients out of the atmosphere. *(Kenneth McIntosh)*

progress." Maathai's Green Belt Movement had by 2004 planted a seedling for each citizen of Kenya—more than 30 million trees—that received legal protections from the government. Wangari Maathai was awarded the 2004 Nobel Peace Prize for her restoration program, which became a model for other countries in tropical Africa.

Rehabilitation consists of a variety of techniques like those used by the Green Belt Movement to restore partially degraded forests. Depending on the tropical forest's condition, rehabilitation may include restoration of soil nutrients, selection of new plantings for fire or disease resistance, or selection of species for erosion control. Small clearings of tropical forest recover faster than large swaths of cut areas, especially when healthy forest surrounds them. Rehabilitated areas produce secondary forest, which contains less plant diversity than old-growth or primary forests, but over the long term these forests build good plant and animal diversity.

In addition to restoration of damaged land and rehabilitation of damaged forest, a third option involves sustainable harvesting, also called sustainable forestry. Sustainable harvesting relies on the concept that forests must be managed as a nonrenewable resource. Though tropical forests renew themselves over a span of years, the current rate

Reforestation Methods



Three different reforestation methods restore forests. First, forest biologists nurture tiny seedlings in a nursery and then plant the young trees in an area to be restored. Second, monocultures may be planted on a cleared area, which will lead to a restored forest containing one type of tree. Third, forests can be selectively cut so that seed-producing mature trees left behind give rise to a new generation of trees.

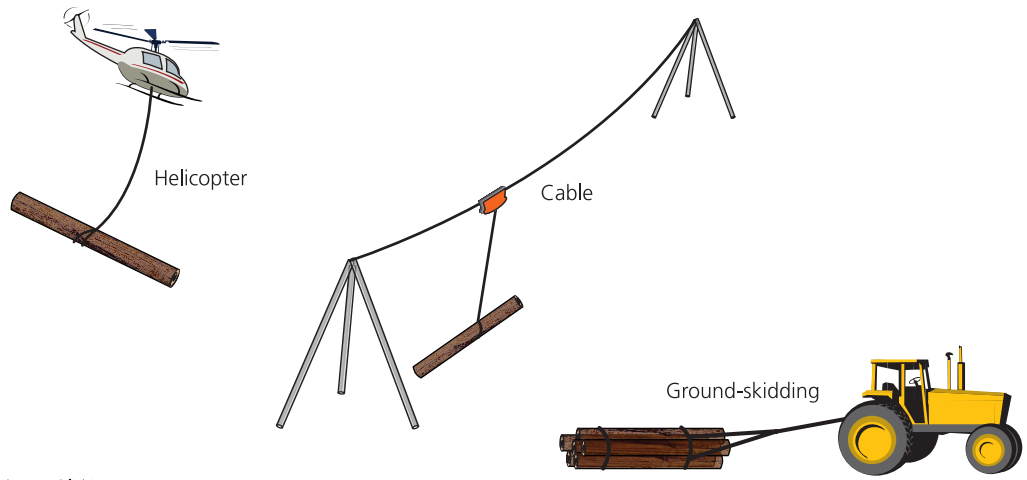
of destruction—0.2 percent per year—will eliminate them faster than they can rebound.

Sustainable harvesting methods allow loggers to remove the timber they need while reducing damage to untouched trees. Sustainable harvesting rejects the use of clear-cutting or slash-and-burn methods. Instead, timber companies use techniques that are gentler on the forest ecosystem, called *reduced impact logging* techniques. The following list provides the main reduced impact techniques that could help conserve tropical forests:

- preharvest mapping and selecting trees of commercial value
- cutting canopy vines before felling trees to prevent damage to the surrounding canopy
- building narrow roads or trails through the forest to reach cuttings, rather than clear-cutting for major roads
- employing directional tree felling to reduce damage to standing trees
- reduction of wood waste by cutting stumps low to the ground
- protecting watersheds with stream buffer zones
- use of low-impact *yarding* systems—methods for hauling timber from forests to trucks
- incorporating restoration and rehabilitation methods in logging areas
- preventing illegal logging
- developing tree plantations on severely degraded land to prevent erosion and desertification
- performing post-harvest assessments to develop constant improvements

In countries where the government owns and controls most of the tropical forest, economics determine the decisions on traditional versus sustainable forestry. In good economic times, developing countries have a greater willingness to follow environmentally sound forestry. In depressed economic times, however, the government may begin selling timber at below-market value, and subsistence farmers may cut down

Types of Yarding



Tree yarding can be done in different ways. Ground-skidding is the oldest method and began with oxen-pulled log sleds. This method also causes damage because it digs up topsoil and requires extensive forest roads.

more trees for cultivation or fuel. This means that big business must also accept a philosophy of conservation in order to save the forests. In 2008 Brazil's Blairo Maggi, governor of a state with high soybean production, declared to *Folha de São Paulo* newspaper, "With the worsening of the global food crisis, the time is coming when it will be inevitable to discuss whether we preserve the environment or produce more food. There is no way to produce more food without occupying more land and taking down more trees." The forest biome therefore remains very vulnerable to human needs.

ACTION PLANS FOR TROPICAL FORESTS

More than 6 billion people on Earth use wood products every day to construct buildings, produce paper, make furniture, and heat their homes. Forests will never be free of some level of destruction, but action plans can help by encouraging people to think of forests as a nonrenewable resource that needs diligent protection. In reality, forests are renewable resources because they return if allowed a long enough period of time.

Tropical forest conservation may be divided into five general action plans that are all geared toward immediate relief of the stress on tropical forests, rather than long-term solutions. Groups such as the Rainforest Action Network, Friends of the Earth, and the National Resources Defense Council urge members to follow these plans listed here by either encouraging community action or demanding the ear of government officials. The first action plan involves the certification of wood products to assure businesses and the public that their purchases come from woods produced in a sustainable manner. Second, citizens can offer assistance to companies that want to adopt more sustainable methods. Third, grassroots programs can help make quick progress by avoiding the red tape found in bureaucracies. The Rainforest Action Network, for example, established in 1993 the Protect-an-Acre Program in Brazil to give small grants to local communities for purchasing sustainable use forest. The program currently works in Acre, activist Chico Mendes's home state, to protect land from proposed oil drilling. A fourth approach involves activism in which the public demands an end to needless destruction due to oil drilling, mining, and agriculture, and to encourage banks not to fund destructive industries but instead fund only sustainable industries. In 2004 the Rainforest Action Network persuaded Citigroup, the world's largest bank at the time, to reorganize its lending practices with more emphasis on sustainable industries. The fifth action plan encourages people to inform the public about companies that currently destroy old-growth forests with no desire for sustainable practices, perhaps embarrassing these companies into adopting better methods.

Any of the action plans described here work much better if they receive cooperation from government. For instance, Papua New Guinea is one of the world's most heavily forested countries, yet its rate of deforestation will destroy all of its accessible forests by the year 2021 if leaders look the other way. Phil Shearman is director of the University of Papua New Guinea's satellite imagery project for monitoring the country's forests. He told the *New Zealand Herald* in 2008, "Forests in Papua New Guinea are being logged repeatedly and wastefully with little regard for the environmental consequences and with at least the passive complicity of government authorities." Local and national governments hold the key to successful forest conservation, explaining why groups such as the Rainforest Action Network put considerable effort into getting government leaders on their side. The case study, "Ecotourism in Belize's Rain Forests," describes a project with just such cooperation.

Case Study: Ecotourism in Belize's Rain Forests

The Central American country Belize borders Mexico, Guatemala, and the Caribbean Sea. Almost 13 percent of Belize contains protected forests, and of this area old-growth forests make up a large portion. Overall, forests and woodlands cover almost 92 percent of Belize. Rather than build an economy based on lumber, Belize's leaders have developed a system in which the country uses its forests as an ecotourism destination. Belize also provides a rare example of sustainable ecotourism in which local residents act as guides and teach tourists about local history, their culture, and the region's environment.

Belize houses hundreds of species of mammals, birds, reptiles, and amphibians, but its plant diversity may be most astounding: More than 3,000 species of higher plants live there. For almost 20 years the government has supported eco-business grants, which are funds that help small businesses establish themselves as green businesses, or businesses that emphasize sustainable activities. Meanwhile, local communities form custodial groups that watch for forest fires, illegal harvesting of trees and plants, wildlife poaching, and invasive species.

Traditional tourism can take a toll on land and coasts, and for decades Belize suffered from this type of unrestrained tourism. Habitat began to disappear, residents and animals were displaced, and waste accumulated. Ecotourism, by contrast, focuses on travelers who wish to see plants or animals in their native habitats. In Belize, sustainable ecotourism helps protect the forest habitat while it benefits residents by protecting forest-oriented lifestyles of the native people. Local interests that benefit from today's sustainable ecotourism include arts, crafts, foods, language, and traditional healing methods.

In 1993 a group of business leaders formed the Belize Ecotourism Association to address ongoing issues on conservation and tourism. Some of the current issues covered by this associa-

CHALLENGES IN RESTORATION

Destruction of tropical forests has been going on for generations, but restoration technology represents a new promise. Restoration planners have a daunting task in changing the way communities, businesses, and governments think about their forests. This change in thinking begins with educating communities, as Chico Mendes did in Brazil, to the harm subsistence farmers potentially do to forest resources and their health when they cut down trees. The idea of restoration must be presented to those at higher levels also, such as local leaders, national government agencies, and international organizations. International pressure on

tion are the following: adopt-a-roadway programs; cruise ship traffic; national park management; and studies of proposed dams and other public projects. Through this organization the people of Belize control their destiny without outside influences.

Deforestation remains a serious threat in Belize because of the country's other industries, which include: marine products, citrus, cane sugar, bananas, and garments. Belizean jungles also contain oil reserves, so the country confronts ongoing problems of encroachment and development. Despite the success the country has had in protecting its forests for ecotourism, Belize has arrived at a decision point in which it will either continue along the sustainable ecotourism path or move toward mass tourism and become a resort destination.

To build a promising future in conservation, Belize must fill the gaps in its education system by expanding programs that teach residents how to care for and protect their forests. The Belizean ecologist Colin Young was interviewed in 2007 by the environmental resource site Mongabay.com. Young explained, "Having strong, creative teacher education programs in the sciences for primary- and secondary-level teachers is a necessary first step to excite students in pursuing careers as scientists. Once the number of scientists increases, younger generations will have role models they can emulate." Young added, "What is apparent is that forest resources in Belize need to be managed in a more holistic and transparent manner. . . . Empowering local communities and local people, where appropriate, to become stewards and co-managers of forest resources is also paramount." Belize's forest conservation will depend on dedication from all facets of its society in order to continue its success.

illegal logging and clear-cutting gives restoration projects more time to achieve success.

The process of restoration itself presents several challenges to workers on a restoration project. First, seed dispersal is difficult work in hot, humid tropics. Second, not all seeds grow, and animals also eat about 65 percent of the seeds workers scatter or the seedlings they plant. Third, each section of forest has slightly different environmental conditions that make them unique, so one plan does not always work in all areas. Fourth, logging methods that remove all the native trees from an area also remove their seeds, which would be the best choice for restoring a native forest. Ecologists must therefore raise new seedlings in a nursery.

The erosion of Rio Itambi in Ecuador. Erosion is a natural process in which rocks and dirt wash away in heavy rains but become replenished by new plant growth and the natural uplifting of the Earth's sediments. Deforestation speeds up this process so that rich topsoil erodes, nutrients disappear, and the remaining plants and trees die. By this process erosion leads to desertification. *(Dr. Günter Gunkel)*

Fifth, clear-cut logging removes birds as well as trees, and many birds disperse seeds better than volunteers can. Finally, restoration includes extra work such as the planting of shrubs that protect seedlings and provide shade cover.

Tropical forest preservation and restoration therefore may be one of the most complex jobs in environmental science. Tropical forests require this help more than any other forest type, and the preservation must go into action quickly to head off a pending disaster in biodiversity.

CONCLUSION

Tropical forests inhabit warm, humid regions of the globe, and so they occur at or near the equator. Tropical growth covers about 6 percent of the world's land area but contains at least two-thirds of all plant and animal species. Conservation of these forests affects biodiversity perhaps more than any other forest type, but several threats from human activi-

ties have made tropical forests very vulnerable to destruction. Primary threats represent the underlying factors that threaten almost all the world's forests today. Poverty, population growth, climate change, and government policies are primary threats that contribute to the deforestation of tropical areas. Secondary threats, by contrast, exert immediate damage on tropical forests: logging, ranching, crops, and roads, for example.

Tropical forests have been particularly affected by poverty in developing countries for two reasons. First, governments may encourage deforestation in order to export products, and second, subsistence farming in impoverished areas decreases the forest little by little over time. The status of tropical forest loss due to these factors has not yet been determined in full because scientists have a difficult time monitoring forests, especially dense remote tropical forests. Illegal logging and mining, small-scale subsistence farming, and cultivation in remote places can go on for years before they are discovered and stopped.

Tropical forest restoration begins with the planting of native seedlings in degraded areas. Tropical forest soils normally lack sufficient nutrients, and intense cultivation and grazing depletes those few nutrients. For that reason soil rehabilitation accompanies tropical forest restoration. Sustainable harvesting methods can then be used in restored forests or original forests if timber harvesting remains necessary. Restoration remains a challenge because tropical forests are complex and largely unknown ecosystems located in regions where slash-and-burn logging and ranching have been the norm for a long time. These forests will likely never receive full protection without strong government support.

Sustainable harvesting makes use of reduced impact logging techniques to harvest trees at a rate no greater than the rate of tree replenishment. This objective has become very difficult to achieve as population increases and consumerism grows. Many of the resources that come out of tropical forests go to developed countries rather than the local economy. Ecotourism has proved to be another lucrative source of income that preserves these resources.

The fate of tropical forests rests on a combination of actions that originate at the local level and go to international programs. Any or all of these methods should be investigated further to save tropical forests from further destruction: sustainable forestry; new methods in logging

and mining; alleviation of poverty to aid subsistence farming; ecotourism as an income source instead of lumber exports; and new methods of forest restoration. Most important, industries and governments must commit themselves to conservation plans. Without government help, tropical forests will likely continue to shrink in size until they become an endangered ecosystem.

Temperate and Boreal Forest Preservation

Temperate and boreal forests differ from tropical forests in that they grow at latitudes of cool to cold winters and live in places that receive seasonal variation. Like tropical forests, temperate and boreal forests have been greatly reduced from their original area on Earth. While tropical forests have lost an estimated 50 percent of their area, a very small percentage of temperate forests and boreal forests remain from their original population.

The temperate forests that remain in eastern North America, northeastern Asia, and Europe share the following characteristics: varied temperature from below zero to 85°F (30°C); even precipitation throughout the year; moderately dense canopy with partial light penetration; fertile soil; and seven to 10 tree species per square mile (three to four species per km^2).

Temperate forests contain plant, tree, and animal diversity, and they occupy moderate climates with a long growing season. These factors have made temperate forests attractive to generations of people for timber and hunting. Due to their location in temperate climates, cities and towns have grown up near temperate forests, so the trees have been accessible for logging. As towns expanded, the forests became fragmented, which worsened the conditions for the forest ecosystem.

Boreal forests, also called taiga, occupy the largest biome on the Earth's land surface and grow in the northern parts of North America, Europe, and Asia. These forests contain the following characteristics: cold climates with precipitation mainly as snow; sparse canopy that permits moderate

light penetration; nutrient-poor soil; trees that are mainly cold-tolerant evergreen conifers; and animal diversity that may be greater than plant diversity. Though boreal forests occupy places remote from many urban centers, they have been severely reduced by centuries of logging and are in jeopardy of disappearing within a few generations.

Globalization of economic markets combined with population growth has put pressure on all the world's forests, but these things occur unevenly across the face of the globe. Because temperate forests occur near population centers, throughout history they have been cut down at a faster rate than the remote boreal forests. Regardless of how these forests have been accessed and harvested, temperate and boreal forests require the same dedicated protection as forests in the Tropics. Though local efforts can protect some tropical forests, temperate and boreal forests will likely need the oversight of governments and international organizations. These forests lie in industrialized countries where big businesses and government have often worked in close association. The international Food and Agriculture Organization of the United Nations (FAO) stated in its recent report *State of the World's Forests 2007,* "'What happens to forests' will be largely determined by 'what happens outside forests'." In other words, small local communities may no longer have the power to protect the remaining forests and the success or failure of conservation will rest with strong leadership.

Timber serves the world's peoples as building material, for furniture, in boatbuilding, and for heating fuel, as it has since early civilization. *(Claude Barutel)*

This chapter covers the characteristics that make temperate and boreal forests desirable to people and therefore threatened by extinction. It reviews aspects of the timber industry and forestry methods and delves into the innovations that these areas employ to conserve forests. A section examines the unique threats inside boreal forests. Lastly, this chapter investigates new ideas in ecological foresting methods and the emerging science of forest biotechnology.

TEMPERATE AND BOREAL FOREST LOSS

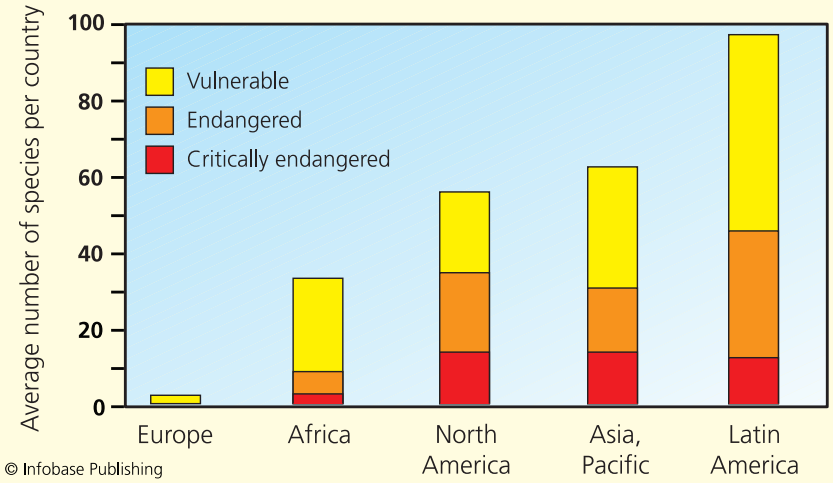
Forest evaluation takes place by two main methods: (1) aerial surveys and satellite imagery and (2) on-the-ground field studies. Aerial surveys gather information on forested regions such as the Blue Ridge Mountains. Satellite images help scientists view much larger expanses such as the total area forests occupy on a continent. Scientists who conduct field surveys gather detailed information by observing forest ecosystems up close. Field surveys typically collect data on the following topics in assessing forest health:

- grass and wildflower ground cover
- wildlife diversity
- densities of small, stunted trees
- numbers of large, old-growth trees
- increased old-growth mortality rates due to thickets of small trees
- large-scale insect or other parasite infestation
- pathogens in rain runoff
- shift from low-intensity ground/grass fires to fast and large canopy fires, called *crown fires*

The FAO report states that the net rate of global forest destruction has slowed in some places, which is an encouraging sign, but overall the world continues to lose forests. For instance, aerial and satellite studies have revealed that forest area has increased a small amount (less than 0.1 percent) in Europe and parts of Asia in the past 15 to 20 years. During the same period, the total area of North American forests did not increase, but their destruction was greatly diminished. Both of these trends suggest that Europe and most of North America have put significant effort into forest conservation. Only Mexico, which loses about 0.5 percent of its trees annually, and select parts of Asia have continued losing temperate forests with no sign of slowing.

The United States destroyed most of its old-growth forests by 1920, especially in the East and Midwest, where secondary forests have now replaced them. Sections of the West and Alaska still experience large losses, however, to the point where plant and animal diversity now differs

The World's Vulnerable Trees



Except for most European forests, forests in every part of the world are threatened with destruction. Latin America, composed of Central and South America, is under the greatest threat of losing forests. Trees in Asia (the eastern Middle East to China) and the Pacific nations such as the Philippines, Korea, Japan, Australia, and New Zealand are also vulnerable to deforestation. North America contains the highest proportion of critically endangered forestland.

from the diversity that sustained Native Americans before European settlers arrived. Between 1600 and 1800, eastern settlements began removing trees for lumber, and the need for wood grew as the settlements became cities. When settlers migrated west, more trees came down for building houses, barns, and fencing. In the 1800s railroads crisscrossed the continent, and the new tracks demanded a constant supply of wood for railroad ties. Today lumber and paper make up the main uses of the country's timber harvest, but trees supply other nonwood products, as shown in the table on the next page.

How has Europe managed to increase the amount of its forested land, especially in one of the most densely populated parts of the world? European countries have taken the lead in exploring sustainable methods in forest management. For example, in Europe tree plantations that restore destroyed forests tend to contain plantings of native trees interspersed with monoculture. This mixture of natural and artificial conditions allows a secondary forest to grow quickly, yet it retains some

Temperate and Boreal Forest Resources

Type of Forest	Main Characteristic	Main Trees with Commercial Value	Nonwood Resources
temperate deciduous	average temperature, 50°F (10°C); average rainfall, 30–60 in. (76–152 cm); four distinct seasons	maple, oak, chestnut, beech, elm, hickory, ash, aspen, birch, walnut, cherry, poplar, alder, apple, pear	sap, nuts, fruits, fiber
temperate evergreen	rainfall mainly in cool winters; predominated by conifers	pine, fir, cedar, mahogany, redwood	oil, fiber
temperate rain forest	coastal with high rainfall; more than 70 in. (182 cm); mixed species	olive, holly, tea, eucalyptus	oil, olives, leaves, berries
evergreen coniferous (cone-bearing) boreal	subarctic climate, minus 50–70°F (minus 10– 21°C); precipitation mainly as snow; 15–40 in. (40–100 cm)	spruce, pine, fir	oil, fiber

of the biodiversity of the original forest. Primary forest makes up only 4 percent of Europe's forest area, so these secondary forests represent the continent's best hope of reversing decades of deforestation. In North America primary forests account for almost 45 percent of total forests, mostly in Canada, and 12 percent of those primary forests have now been entered into conservation programs. The goal is to emulate Europe and begin rebuilding forested area.

Alaska has presented the American public with a unique situation regarding deforestation. Alaska's large expanses of forest have been tempting the timber industry for many years, and the state now supports an active logging industry; about 5 percent of Alaskans are employed by the timber industry. But increased logging and further destruction of forest tracts due to new oil exploration have drawn increasingly heated debate. Laurie Cooper of the Alaska Wilderness League told the *Los Angeles Times* in 2008, "We're at a crucial time right now to make sure we're looking at a future that retains some of this landscape and some of this way of life for future generations."

Alaska contains two principal types of forests: coastal rain forest and interior boreal forest. Most of the timber activity takes place in the coastal regions, and of the total forests available for logging, the federal government owns 51 percent, the state and local governments own 25 percent, and private owners hold about 24 percent. Alaska Native corporations make up 99 percent of all private forest landowners. Alaska also contains the nation's largest and second-largest national forests: the Tongass National Forest, containing 16.8 million acres (68,000 km^2), and the Chugach National Forest, with 5.9 million acres (24,000 km^2). Logging presently occurs in a small portion of each of these forests, but Tongass has of late become a focal point in a debate on the possible expansion of Alaska's logging.

In January 2008, President George W. Bush approved a plan to open an additional 3 million acres (12,140 km^2) of Tongass National Forest to the timber industry. Though the decision sought to relieve financial stress in Alaska's economy, environmentalists pointed out that logging may not help the economy much. Tom Waldo, attorney for the environmental group Earthjustice, warned in a *New York Times* article that logging may harm Alaska more than help it: "It leaves 2.4 million acres [9,712 km^2] of wild, roadless backcountry areas open to clear-cutting and new logging

roads." Meanwhile, the logging industry contributes only about 1 percent of Alaska's economy.

The Pacific Northwest has had similar questions on the extent with which logging should take place, especially when local mill towns depend on timber for their income. One question that turned into a serious argument between the timber industry and environmentalists came in 1986, when the northern spotted owl was placed on the endangered species list. Spotted owls prefer habitat of old-growth forests like the kind that stretch from northern California to Canada. Listing the owl as threatened pitted conservationists against people whose livelihoods depended on logging. Many of these forests now receive federal protection as habitat for the owl, and the mill towns have slowly found income in nonforest pursuits, including tourism.

Temperate forests have not had the controversies that characterize the forests in Alaska or the Pacific Northwest, so the public has perhaps overlooked the dire condition of these forests. Part of this complacency comes from the fact that forests are a renewable resource: The trees grow back after they have been cut. But the time required to replace a forest is hundreds of years, depending on the type of trees growing there. Julia Bonds of the Coal River Mountain Watch in Appalachia said in a 2003 interview on mining and logging in the area of West Virginia where she grew up, "It's [mountaintop mining] not only turning the mountaintops into wastelands, but the valleys as well. The wonderful and valuable hardwood forests are being destroyed, and they will not return for over 600 years, if ever. Our beautiful mountain streams have been devastated." The temperate forested land in the United States has now stabilized, but that may be little comfort to people who remember when these forests stretched for hundreds of miles. The worth of forests is explored further in the sidebar "Old-Growth Forest Ecosystems."

The United States has been able to stabilize its forested land area by reversing its commerce in wood products. The United States exported lumber for decades until the start of the 1990s, when imports began to outweigh exports. Today the value of U.S. wood product imports is double the value of its exports. In other words, the United States spares its forests by relying on wood products from other countries. In addition to primary wood products (raw lumber), the United States imports a large quantity of its secondary wood products, such as furniture.

Old-Growth Forest Ecosystems

Old-growth forests consist of trees that have never been cut so have never been forced to regrow. These primary forests contain the original growth of a tree population and therefore they contain the oldest and most mature trees found in the forest biome. Old-growth trees arise at the latest stage of *forest ecological succession*, and because of this they contain a mixture of species and a variety of sizes. They also contain dead trees that have fallen and begun to decay, broken branches, snags, and several canopy layers. All of these things create specialized habitats for a variety of animal life, plants, and fungi. Old-growth forests contain very complex ecosystems with many interrelationships between species, and of course, this enhances biodiversity.

The unique characteristics of old-growth forests sometimes provide habitat for species that cannot live anywhere else. Some of these specialized habitats include hollowed trees, tree cavities, decaying logs, the canopy, the understory, moist soil, and bark. In dense old-growth forests, the top of the canopy receives direct sunlight for the life in that habitat, while creatures near the forest floor live in dark, shaded surroundings. Animal diversity in old-growth forests includes moose, bear, weasel, lynx, fox, wolf, deer, bobcat, mountain lion, chipmunks, squirrels, shrews, bats, woodpeckers, owls, and hawks. This represents only a partial list and does not account for the microbes, insects, invertebrates, amphibians, reptiles, songbirds, and aquatic species that also

TIMBER HARVESTING

Tree harvesting in the past meant the removal of all trees of any size and regardless of value. Logging companies clear-cut the landscape, which not only destroys the forest but also eliminates ecosystems. Even animals inhabiting the uncut adjacent forest must contend with the increased activity and noise coming from the clear-cutting zone. Clear-cutting also makes the harvested land vulnerable to soil erosion, floods streams, increases silt levels in streams that harm aquatic life, and makes landslides more likely.

During 2007 in Oregon, storms caused landslides in two clear-cut areas and torrents of mud and debris overwhelmed homes and vehicles and covered a state highway. While no humans were killed, several received injuries, and the damage to wildlife has not been fully resolved. Stephen Hobbs of the Oregon Board of Forestry described the event as a rare quirk of nature. He told the *Oregonian*, "Mother Nature threw a

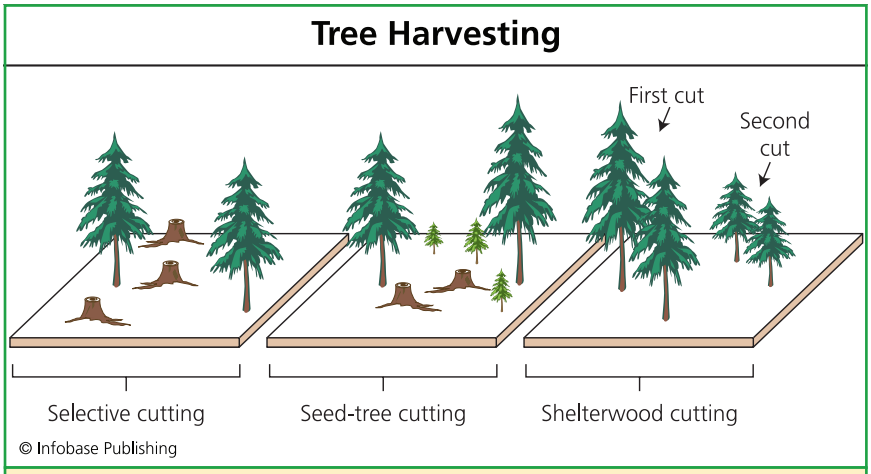
live in old-growth forests. Vines, ferns, shrubs, mosses, lichens, and some grasses dominate the plant diversity. A typical old-growth forest in the Pacific Northwest contains giant redwoods, Douglas fir, spruce, and possibly hemlock and cedar. Each 2.5 acres (0.01 km^2) contain about 20 large trees at least 300 years old, many measuring over three feet (1 m) in diameter.

The health of an old-growth forest depends on fires caused by natural circumstances, such as lightning strikes. Frequent, short-lived ground fires reduce competing vegetation and degrade dead wood, which hastens the return of nutrients to the soil. Fires also thin out the densest growth and open more space for sunlight to reach places that had been cut off from light. Though fires may temporarily destroy some wildlife habitat, fires also create new habitat. For instance, some small mammals may prefer the plants and grasses that first break through the earth after a fire, and only ground fires afford this opportunity.

Old-growth forests and their ecosystems have remained largely a mystery despite the studies that have been conducted in them. They have outlived generations of humans, and they surely contain undiscovered species as well as ecosystems that have not been fully identified. These forests survived from a time when humans did not affect seemingly every corner of the Earth. For that reason alone, they deserve respect within the world of living things.

curveball at us. It was a pretty intense storm event, so you're going to have unexpected things happen." Despite these assurances, other people suspect that clear-cutting creates a danger to human and animal life. The University of Washington professor David Montgomery told the *Olympian* in 2008, "As a geologist, I see no surprises here. When you clear-cut potentially unstable slopes, you increase the risk of landslides up to tenfold." These differences of opinion on the harm of clear-cutting and other tree harvesting methods continue.

In addition to the harvesting method loggers choose, all harvesting sites require roads built into the forest to give equipment access and allow logging trucks to transport the logs out of the forest. Roads help the overall efficiency of logging, and timber companies cannot do their job without them, but forest roads also harm ecosystems by fragmenting habitat, driving out animal species, and giving access to invasive species. The section beginning on page 82 discusses the issues surrounding logging roads in today's forests.



Three tree-harvesting methods conserve forest and avoid clear-cutting, but selective cutting often leads to clear-cutting within a year.

Once loggers reach the logging site, they can use any of a variety of harvesting methods, described in the table on the next page. Over the long term it is in the best interests of loggers to choose a method that sustains their industry but also conserves forests for future generations.

Logging comprises any of the harvesting methods described in the table below, plus the methods used for felling the trees and the yarding methods for taking the logs out of the forest. Tree cutting can be done in two ways: conventional sawing or mechanical logging. Sawing cuts the full length of trees to the stump close to the ground, while mechanical cutting removes trees using a piece of equipment called a feller (or faller). An operator drives a feller up to the tree to be removed and a blade or saw at the end of the feller's arm cuts the tree, usually leaving a taller stump than the sawing method.

For centuries, horse-drawn wagons hauled logs out of the forest. This required little road-building and made little noise. In the 1800s horse or oxen teams dragged logs to specialized narrow logging railroads or, in areas where railroads could not reach, to mountain streams where workers transferred the logs to another conveyance, a process called off-loading. Gravity simply carried the harvest downstream to a collection point at the bottom of the mountain. Dragging logs downhill to a train or stream soon proved to be inefficient because every forest snag or stump

Timber-Harvesting Methods

Method	Brief Description	Advantages	Disadvantages
clear-cutting	cutting all trees in an area	speed, efficiency	destroys ecosystems and soil
strip cutting	clear-cutting narrow strips or rows	leaves forest for wildlife use and tree regeneration	destroys large swaths of habitat
selective cutting	only mature or intermediate-age trees are marked and cut	minimum disruption to habitat; removes diseased trees; encourages growth of young trees	requires mapping and extra planning; slower harvesting rates than clear-cutting
shelterwood cutting	tall canopy trees cut first	targets mature, marketable trees; allows regeneration of smaller understory trees	requires two or three additional cuts over a decade
seed-tree cutting	cutting all trees except a few dispersed seed-producing trees	seedlings of native trees regenerate the forest	removes almost all the trees, similar to clear-cutting

acted as a fishhook and grabbed at each log on the journey. Loggers soon learned that dragging logs uphill by cable to a mountaintop railroad track was the best approach. This so-called *uphill logging* or skyline logging evolved into the helicopter logging used by many timber operations today in difficult-to-reach terrain. Though horses still haul timber in parts of the world, today most operations use trucks, cables, and helicopters.

Timber harvests consist of whole logs, called *roundwood,* which means logs denuded of branches and bark. These harvests are of three main types: (1) hardwoods from broadleaf, deciduous trees; (2) *softwoods*

from *gymnosperm* trees, including pine, spruce, fir, and juniper; or (3) *pulpwood,* which is any wood harvested for papermaking.

FOREST ROADS

Timber companies must have roads that lead to harvesting sites to allow heavy equipment and emergency vehicles into and out of the forest. The companies usually build these logging roads themselves to meet these needs. But the road-building and the completed roads create a major disruption to forest ecosystems. In addition to the noise and dirt created during road-building, smooth-surface or packed gravel roads make forests vulnerable to the following occurrences:

- increased erosion and sediment runoff
- habitat fragmentation
- biodiversity loss
- enhanced exposure to invasive species, pests, and diseases
- disrupted migration routes by wildlife, reptiles, and amphibians
- wildlife mortalities on roads
- opening of once-inaccessible forests to hunters, off-road vehicles, and illegal farming or logging
- opening of territory to mining and farming

At present, logging roads and helicopter landing areas built on public lands cause those lands to lose federal protection as wilderness areas. In 1997 President Bill Clinton tried to reverse this policy by passing what came to be known as the "Roadless Rule," which authorized the U.S. Forest Service to obliterate hundreds of miles of abandoned logging roads and halt construction on others. At the time, Forest Service officer Bob McDowell in Lake Tahoe, California, told the *Tahoe Daily Tribune,* "The kinds of roads that we will obliterate are the roads that don't go anywhere—old logging roads and landing areas. The ultimate goal is to re-contour some roads, to make the road bed disappear." The recovery of the land under the Roadless Rule has progressed very slowly, and thousands of miles of abandoned logging roads remain in North American forests. Some states, such as Idaho and Alaska, have challenged the Roadless Rule for putting

too severe a restriction on their forest management. For example, at the close of 2003, Alaska had successfully won the right from the USDA and the Department of Justice to exclude the Tongass National Forest from the Roadless Rule.

The effect of abandoned and overgrown roads has not been determined. Scientist Eric Sanderson of the Wildlife Conservation Society said in 2005, "Roads are terrific at providing human access to areas, but unfortunately they bring with that access a host of ecological problems." The timber industry countered that forest roads were

This logging road that served California's timber industry in 1955 demonstrates the damage that these roads do to forest ecosystems. In addition to causing massive erosion, roads remove habitat and disrupt the normal behavior of wildlife. *(California Department of Fish and Game)*

necessary to serve local communities in times of wildfire, meaning an out-of-control fire. In 2005 President George W. Bush did away with the Roadless Rule to allow greater access for mining and logging in the nation's forests. Chris West spoke for the American Forest Resource Council in support of the White House's decision and to

CASE STUDY: BOREAL—EARTH'S NORTHERN WOODS

Forests that cover the northern regions of Canada, Russia, China, Scandinavia, and southern Alaska make up the boreal forests, or taiga. (Smaller areas of Japan, Korea, and Mongolia also contain boreal forest.) They include a band of growth between 45° and 57° north latitudes and form an almost continuous ring at the top of the globe. Boreal forests hold little tree diversity compared with tropical rain forests: They contain only a limited variety of coniferous trees that retain needles year-round and have a short growing season of about 130 days. Boreal forests nevertheless support extensive food webs of plants, mammals, birds, insects, and fish. They also act as a northern watershed by containing numerous lakes, rivers, wetlands, bogs, and marshes.

The boreal forests serve the Earth in the following additional ways: (1) as a carbon reservoir for storing carbon not released into the atmosphere; (2) in filtering millions of gallons of water each day; and (3) by providing resources for resident people that use the forest for hunting, trapping, and fishing. The boreal forests also contain vast potential commercial potential because of their timber, oil, gas, minerals, and hydroelectric power resources, so they have become a central point of interest of both industry and environmentalists.

Large oil and natural gas reserves under the forests of Alaska, Canada, and Russia represent the number-one threat to the future of boreal forests. Fossil fuel reserves in other parts of the world will someday run dry, and countries such as the United States desire a reliable supply of domestic fuel, which the boreal region holds. In addition to the United States, Canada, China, Russia, and Norway have all eyed their own boreal forests for oil exploration.

Global warming also threatens boreal forests because as temperatures rise the health of the cold-tolerant trees may decline, and disease and parasites gain opportunity to infect them. At the same time, warmer temperatures have already made temperate deciduous forests to the south drift north toward the boreal habitat. The warmer temperatures therefore threaten boreal growth from the south, and melting glaciers and polar ice may cause flooding from the north.

Environmental organizations have tried to protect boreal forests from the destruction that has occurred in poorly managed tropical forests. In the United States and Canada, the following organizations act as watchdogs over boreal forests by monitoring the mining, oil drilling, and log-

calm the public's fears over road expansion: "Despite the environmental rhetoric, chain saws, bulldozers and drilling rigs are not gassing up to enter roadless areas." The case study "Boreal—Earth's Northern Woods" discusses how roads and other human activities in the forest have kept this debate alive.

Boreal forests provide habitat for wildlife such as grizzly bears, wolves, moose, wolverines, and the secretive lynx, shown here. *(Erwin and Peggy Bauer, courtesy of U.S. Fish and Wildlife Service)*

ging industries and by participating in global warming talks: the Northern Alaska Environmental Center; the Sierra Club; the Nature Conservancy; the Alaska Department of Fish and Game; and the Natural Resources Defense Council; and Nature Canada.

Forests in Siberia and eastern Russia suffer added threats because of the way they have been managed, and have endured several consecutive seasons marked by wildfires, insect outbreaks, and overgrowth that keeps seedlings from maturing. Enterprises that once operated farms under socialism now own much of Russia's forestland. These owners may view forests as a community resource to be depleted for building personal wealth without much regard for sustainable methods. For example, the Federal Forest Service of Russia for many years controlled more than 90 percent of Russia's forests and has shown interest in conservation, but this agency also ran about 20 percent of the country's logging. The agency furthermore has released no information on forest area land or logging activities, so environmentalist groups such as Greenpeace Russia and the Taiga Rescue Network found it difficult to design conservation action plans.

Environmentalists suspect that forest management in Russia has not been optimal. Fedor Pecar, chief of the Irkutsk airbase in Russia told Greenpeace in 2007, "This year there are more of them [fires] than in all of the previous years. One may think that now everything is being burnt off: fields and old straw. Almost half of the fires were caused by this. The villagers burn off private meadows

(continues)

(continued)

and they are doing it recklessly and carelessly. Thus not only forest, but also buildings and houses catch fire. . . ." In 2000 Russian President Vladimir Putin signed a decree abolishing the Federal Forest Service, the only federal agency with interests in protecting the boreal forests. Fortunately, Russia's boreal forests are very remote, and logging them would be an expense that for the present has kept them safe from large-scale destruction.

The world's boreal forests will not be safe forever if the timber and fossil fuel industries need new places to explore. Boreal forests the world over will require careful monitoring and strong legal protections for their survival.

FIRE MANAGEMENT

Forest fires are caused by natural actions such as lightning strikes, or may result from human activities. In either case, good fire management and periodic natural forest fires help restore the vitality of forest ecosystems.

Three types of fires occur in forests: (1) surface fires that burn leaves, dense vegetation, and small immature trees; (2) ground fires fed by peat and decayed matter that spread to underground fuels; and (3) crown fires that burn up from the ground's surface and travel across the treetops. Surface fires help ecosystems by clearing out constrictive dense shrubbery and leaf litter. Though these fires harm some immature trees, surface fires do not cause significant damage to mature trees, and they travel at a speed that allows wildlife to escape. Ground fires and crown fires present bigger problems. Ground fires smolder for weeks undetected and can suddenly flare into a potentially hazardous situation. Crown fires burn hot, fast, and uncontrolled, and in doing so they destroy trees, surface vegetation, habitat, and wildlife that do not escape. Crown fires have also caused the loss of homes and human lives in forested areas.

Fire management refers to the control of unexpected or planned fires for the purpose of improving the forest. By periodically burning dense growth, managed fires prevent the explosion of dangerous crown fires. Forest officials have two options on how best to manage fire. The first method involves what are called *prescribed burns,* in which ecologists set

small, contained surface fires to thin out dense growth and so reduce the chances of crown fires. Fire crews surround the burn area to assure the flames do not escape and go from a controlled to an uncontrolled situation. The second strategy involves letting natural fires burn uncontrolled as they have for hundreds of years. These uncontrolled fires can seem cataclysmic in news reports, leading to disagreement on whether these fires are better or worse than prescribed fires. The New Mexico ecologist Craig Allen explained to *Audubon* magazine in 2001, "It's not that Smokey was all wrong, but he sure as heck wasn't all right either. Fire's effects are variable, just as landscapes are variable." Allen's comment correctly points out that even the best fire management cannot predict how fires will behave with 100 percent accuracy.

Because prescribed fires and natural uncontrolled fires can behave in unexpected ways, good fire management also includes safety measures for houses and other buildings in the forest. Homeowners or work crews should clear all vegetation from a zone of about 200 feet (46 m) from the building. This helps prevent flames from approaching the structure. Safety zones in combination with firefighting have saved many buildings that were almost completely surrounded by fire.

Forest fire suppression that took place for decades in the United States—encouraged by the Smokey Bear campaign—may have hurt forest ecosystems. A community of organisms depends on fire to reestablish their populations. Though wildfires have been difficult to study, scientists have gathered the following facts on the effect of fire activity on forest biota:

- Some species appear only in postburn habitat.
- Certain conifers require intense heat to open cones and release seeds, a process called *serotiny.*
- Fire clears the ground for new seed germination.
- Some insects seek burned areas, gathering for mating and enhancing genetic diversity.
- Insect species use burned bark as nesting sites.
- Reptiles and amphibians escape fire by hiding in subsurface soils.
- Bats that roost in trees seem unaffected by the fire, and sometimes populations increase due to higher insect numbers.

- Elk, deer, and sheep numbers may decrease slightly; mountain lions and wolves generally escape fire.

The study of fire entails fire science, which covers topics such as how fires burn and travel through different types of trees (tropical versus deciduous, for example), the best use of fire retardants, and postfire rehabilitation techniques. Fire management also contains the following specialties: fire crew safety and clothing; firefighting techniques; fire road planning; aircraft firefighting; and development of new fire suppression chemicals.

In 2003 Congress passed the Healthy Forests Restoration Act, which allows timber companies to burn dense overgrowth in return for taking commercially valuable trees from forests. The companies need not open their plans for environmental review or public comment, which has raised the ire of environmental organizations. The Wilderness Society has stated that the act "poses a major threat to environmental protection and public involvement in federal land management. Furthermore, the bill does virtually nothing to protect homes and communities from wildfire." On the contrary, President George W. Bush felt the bill represented "good, common-sense environmental policy. During seasonal droughts, these small

Forest Fire

Naturally caused fires remove forest litter and so speed up the return of nutrients to soil, and they remove branches and vines to allow ground vegetation to get sunlight. Crown fires are dangerous, fast-moving, and confined to the canopy where winds feed them. Ground fires are also dangerous because they can smolder underground for weeks.

trees act as ladders for fires to reach to the top of our oldest and tallest trees." Much of the disagreement arises from the many unknowns regarding forest fires. Ecologist Allen put it simply, "This is a story we don't know the answer to yet." Like many aspects of natural resource management, fire management involves differing viewpoints and many questions for the future.

LEGAL PROTECTIONS FOR FORESTS

Forests and grasslands in the United States, Puerto Rico, and the U.S. Virgin Islands receive legal protections from the federal government so that their land area will not be destroyed for industry or urban development. (Six states do not currently have a national forest or grassland: Connecticut, Delaware, Hawaii, Massachusetts, New Jersey, and Rhode Island.) These protections ensure that plant and animal life in these ecosystems survive for generations, but also ensure that people can visit and enjoy these environments. The Forest Service of the U.S. Department of Agriculture (USDA) has the legal authority to manage the nation's forests and grasslands. Currently the U.S. Forest Service's authority covers 44 states plus Puerto Rico and the Virgin Islands, 155 national forests and 20 national grasslands, including 193 million acres (777,000 km^2) and the following management categories:

- minerals, mining, rangeland, timber, wilderness, wildlife, and recreation management
- cultural resources
- water resources
- trails
- wild and scenic rivers
- fire service roads
- international forestry
- business administration

U.S. forests receive protections from the six federal laws summarized in the table on the next page.

Laws alone cannot protect forests if government leaders or industries try to revise them in order to aid free commerce. For example, in

U.S. Forest Protection Laws		
Law	**Date Enacted**	**Intent**
Weeks Law	1911	authorizes federal government to purchase land for protecting the natural flow of streams and for establishing national forests
Multiple-Use Sustained-Yield Act	1960	established guidelines in forest use for recreation, timber, rangeland, fish and wildlife, and as watersheds
National Environmental Policy Act (NEPA)	1969	requires Forest Service to allow public review and comment before beginning any change in forest management
National Forest Management Act	1976	established a national policy for human use and also environmental protection for forests
Roadless Area Conservation Rule (the Roadless Rule)	1997	governed the management of roads through forests and wilderness areas
Tribal Forest Protection Act	2004	established federal protections for Native American forestland

2006 the White House removed forest management from the NEPA so that forest officials would no longer be required to prepare environmental impact reports before changing forest management plans. As a consequence, management plans do not receive scientific review or public comment. A few years earlier, the federal government exempted the Tongass National Forest from the Roadless Rule. Both of these changes presumably give oil exploration, logging, and other industries easier access to forests.

Presidential adviser Karl Rove summarized the intent of weakening forest protections to *National Review* in 2007: "On energy, the environment, and climate change, he [President George W. Bush] is developing a new paradigm. Emphasizing technology, increased energy-efficiency partnerships, and resource diversification, his policies are improving energy security and slowing the growth of greenhouse gases without economy-breaking mandates and regulation." Shortly before the changes to the NEPA went into effect, the Wilderness Society president Bill Meadows remarked, "It is a shame that this administration refuses to recognize that public participation in major decisions about projects like timber sales should not be feared and fought, but should be a welcome and helpful part of making informed and thorough decisions." Almost every person holds a different vision of what should be done to protect the nation's forests and also ensure the nation's economic well-being.

One of this country's first conservationists, John Muir, described the difficulty of finding common ground in managing forests: "God has cared for these trees, saved them from drought, disease, avalanches, and a thousand tempests and floods. But he cannot save them from fools." The sidebar "John Muir" provides more insight on this environmentalist.

ECOFORESTRY

Ecological forestry, or ecoforestry, refers to sustainable practices that conserve forests even as humans receive value from them. Ecoforestry can be thought of as equivalent to sustainable forestry.

For centuries people measured the value of forests in terms of the natural resources they provided: wood, paper, maple syrup, fruit, etc. Forests will undoubtedly continue to provide these things, but in order to assure a future for forests ecoforestry offers ways in which people can help forest ecology even while forests provide products. In order to sustain a forest so it can provide monetary (also called *instrumental* benefits) and aesthetic (or intrinsic) benefits, people must follow many of the sustainable techniques discussed in this chapter. For instance, sound fire management, selective tree harvesting, and protecting forests from encroachment play roles in ecoforestry. The following list summarizes the main aspects of ecoforestry:

- manage forests to conserve biodiversity, soil, and water
- consider nonwood products to replace wood products

- choose selective cutting over *strip cutting* and strip cutting over clear-cutting
- limit logging and road-building that fragments uncut forests

JOHN MUIR

John Muir was born on April 21, 1838, in Dunbar, Scotland, the son of a farmer who moved his family to Wisconsin in 1849. Muir dabbled throughout his youth in interests beyond farming as inventor, clockmaker, and writer. He also followed his inclination to wander the United States and soon became an astute naturalist and conservationist. John Muir's description of nature, "Everything is hitched to everything else," remains the most succinct definition of ecology.

In 1868 John Muir traveled to California, where he explored the San Joaquin Valley, the Sierra Nevada, and Yosemite, earning his way by herding sheep through much of the wilderness. Yosemite's geography and waterways in particular fed his fascination, and Muir theorized that they had been carved by glaciers during the Ice Age 1 million years ago. His idea was ahead of its time; scientists eventually developed theories that explained how glaciers formed Yosemite's landscape.

John Muir (1838–1914) was a Scottish-born naturalist with an intense interest in wildlife, plant life, waterways, and rock formations. Muir visited several wilderness areas in the United States, but he is best remembered for his love of the nature and spectacular vistas in California's Yosemite Valley. *(Library of Congress Prints and Photographs Division)*

Muir traveled to Alaska, Europe, Africa, and the Pacific, but he always returned to the Yosemite Valley. Through his own experience, Muir wrote about the damage that sheep-herding caused on mountain terrain and the damage grazing caused on the valley floor. "Incredible numbers of sheep are driven [in Yosemite] to the mountain pastures every summer, and in order to make easy paths and to improve the pastures, running fires are set everywhere. . . . Campers of all kinds permit fires to run, so also do mill-men, but the fires of 'sheep-men' probably form more than ninety percent of all destructive fires that

- avoid clear-cutting, *seed-tree harvesting*, and *shelterwood harvesting* on steeply sloped hillsides
- leave fallen and dead trees to provide habitat and to recycle nutrients

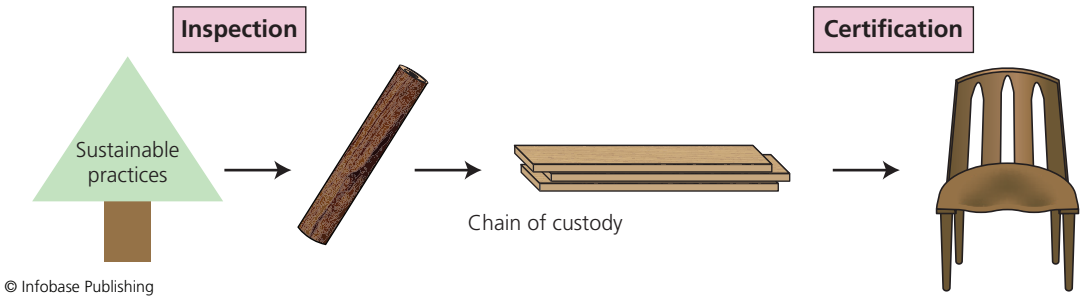
sweep the woods." Due to Muir's persistence, Congress established two new national parks at Yosemite and Sequoia. In 1892 Muir founded the Sierra Club with the goal of promoting further wilderness conservation.

In 1903 President Theodore Roosevelt visited Muir at Yosemite, and the two men discussed the future of the country's wilderness. In his autobiography (1913), Roosevelt would write, "John Muir met me with a couple of packers and two mules to carry our tent, bedding, and food for a three days' trip. The first night was clear, and we lay down in the darkening aisles of the great Sequoia grove. The majestic trunks, beautiful in color and in symmetry, rose round us like pillars of a mightier cathedral than ever was conceived even by the fervor of the Middle Ages. Hermit thrushes sang beautifully in the evening, and again, with a burst of wonderful music, at dawn." Upon returning to Washington, D.C., Roosevelt added millions of acres to the existing federally protected forests.

John Muir became one of history's most recognized conservationists because of three talents: (1) He described the nature in beautiful prose; (2) he gained the attention of like-minded government leaders; and (3) he had an ability to observe nature as it is and not for what it might offer to humans. In a 1877 letter to his friend Jeanne (Mrs. Ezra) Carr, Muir described a recent hike to the Tuolumne River: "Dear Mrs. Carr, I made only a short dash into the dear old Highlands above Yosemite, but all was so full of everything I love, every day seemed a measureless period. I never enjoyed the Tuolumne cataracts so much; coming out of the sun lands, the gray salt deserts of Utah, these wild ice waters sang themselves into my soul more enthusiastically than ever, and the forests' breath was sweeter, and Cassiope fairer than in all of my first fresh contacts." Muir's love of nature has been his legacy to generations of visitors to Yosemite.

In 1913 the city of San Francisco commissioned the damming of the Hetch Hetchy Valley in Yosemite National Park to make a reservoir for supplying water to the city 200 miles (322 km) away. Muir died a year after the decision to flood parts of Yosemite was made. Muir may well have been dispirited by the change that the reservoir would cause the environment, but he could also be proud of the conservation ethic he started throughout the West.

Forest Product Certification



Certified sustainable wood and wood products come from sustainable forestry in which new seedlings and tree plantings replace the harvested trees. The timber chain of custody from lumber to final wood products also uses methods that reduce fuel and energy consumption.

- buy only woods certified as grown in a sustainable manner
- choose natural regeneration over monoculture methods
- use low-impact cutting, harvesting, and yarding methods

The Forest Stewardship Council (FSC) administers a certification program that assures the public that wood or paper products have been produced by sustainable methods. Timber companies can apply for this certification by fulfilling the council's requirements. During the certification process, council representatives inspect the path of a wood-derived product from the forest all the way to the final product, whether it is a sheet of paper, a cardboard box, or a plank of lumber. FSC-certified products bear a logo that informs the public whether a wood product comes from sustainable harvesting and manufacturing methods.

Ecoforestry also promotes new technologies in alternate wood products and new sciences for maintaining forest health. Forest biotechnology provides an example of a fast-growing specialty within ecoforestry.

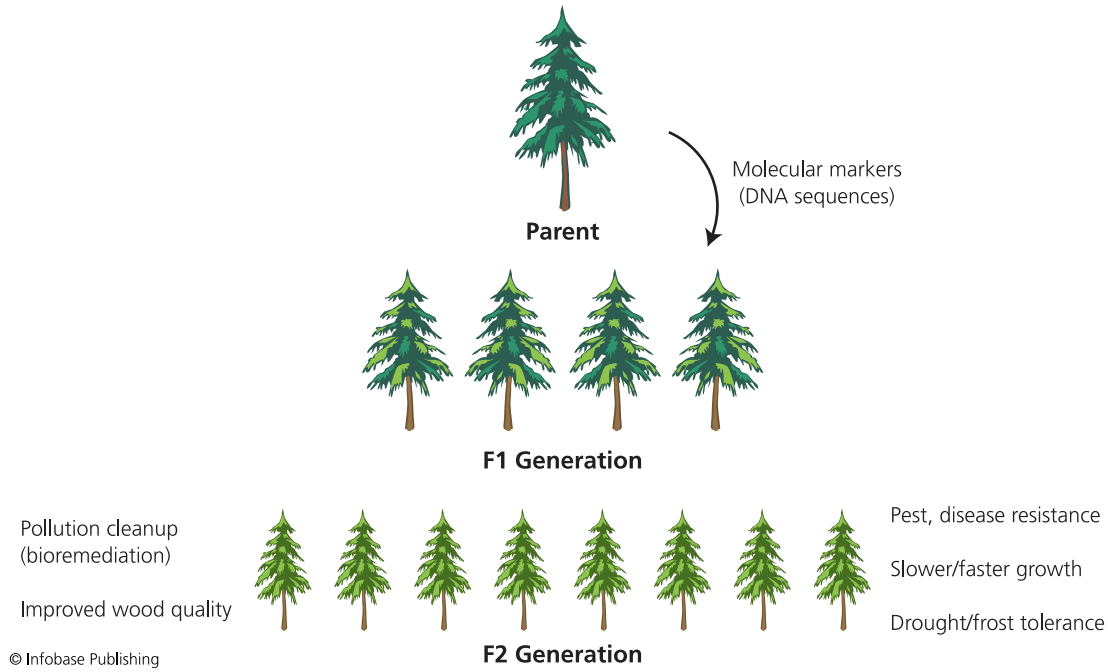
FOREST BIOTECHNOLOGY

Forest biotechnology is a 50-year-old science that uses molecular biology to improve aspects of tree metabolism and wood and fiber production. Molecular biology is the science of isolating and studying genes that carry specific traits in living things. It often includes *recombinant engi-*

neering in which a scientist transfers one or more desirable genes into a different tree species. Forest biotechnology therefore uses recombinant techniques for the purpose of bringing favorable attributes into a population of native trees.

In forest biotechnology, scientists can improve natural, native trees by following a series of steps that begin by selecting a tree with superior qualities. Examples of desirable qualities are disease resistance, drought tolerance, or resistance to climate change. A biologist isolates the desired genes from the superior tree's deoxyribonucleic acid (DNA) and puts them into normal tree DNA. This gene transfer can take place either by crossbreeding the two types of trees or by putting the new genes into regular seeds by recombinant techniques. (Crossbreeding is the process of breeding two different types of individuals so the offspring contain traits from

Forest Biotechnology



In forest biotechnology, scientists find trees with desirable traits that help them survive better than other trees. The scientists put these genes into seeds, which give rise to successive generations that incorporate the desirable genes into their population.

both parents.) After the first generation grows, the biologists again cross-breed the new type progeny with other superior progeny to produce a new generation of improved trees.

Forest biotechnology currently works in the following major areas: molecular details of wood formation; synthesis process of the fibers lignin, cellulose, and *hemicellulose;* pathology and disease resistance; plant hormones; and *in vitro* growth of tree tissue. Forest biotechnology has also turned to finding ways of affecting climate change. Future biotechnology projects may develop the following innovations: improved *biofuels* from cellulose-derived *ethanol;* trees that capture and store more carbon; trees that withstand wider temperature ranges; forests that produce more wood in smaller areas; trees that resist invasive plants and pests; and trees that remove contaminants from the soil.

All of the focus areas in forest biotechnology aim to achieve one or more of three main objectives:

1. studying and improving tree genomes
2. creation of new biofuels
3. preservation of *heritage trees*

Heritage trees are trees of particular importance to a community because of their age, size, location, history, or ecological significance. Many U.S. cities identify anywhere from a few to hundreds of heritage trees that would be considered a terrible loss if they were cut down or killed by disease.

CONCLUSION

Temperate and boreal forests make up the part of Earth's forest biome that lives in climates that range from four distinct seasons to predominantly cold-temperature climates. Today's temperate forests have largely been removed for population growth and commercial use, but boreal forests remain mostly intact even though they are also under significant threat from people and from the environment.

Many U.S. timber companies have moved away from the most destructive methods of tree harvesting and have adopted more and more sustainable practices. Though this trend is encouraging, temperate and boreal forests remain threatened because they occupy real estate that people find

valuable for other reasons, such as construction, roads, and exploration for fossil fuels. Sustainable practices and better methods in forest management may allow people to conserve forests while at the same time derive products from the forest. This requires a delicate balance in emphasis, however, that must be helped by government and industry.

Today's forest management has options that are useful for conserving temperate and boreal forests. New low-impact timber-harvesting methods help spare the forestland, as does good planning of forest roads and a dedication to abiding by the legal protections on forests. Fire management represents a major aspect of forest management that has been hindered by disagreements over the best methods for managing fires. Though forest experts acknowledge that fire is a necessary event that helps forest health, the threat of loss of property or human life due to fire may continue to complicate fire management in the future.

The best hope for a healthy future in the forest resides in ecoforestry and perhaps forest biotechnology. Both of these disciplines have emerged only within the past several years, so their full benefits may not yet be known. Ecoforestry and biotechnology should receive attention, however, because no one knows if forest health will suddenly decline due to climate change, pollution, or other human-caused factors.

One of the thorniest issues in forest management arises from the different views on how forests should serve people. Temperate forests have been lost to urban expansion mainly because they were in the way of new construction and also supplied the wood for that construction. Boreal forests have been spared this fate up to this point, but their disappearance may also accelerate if these forests are opened up to large-scale drilling, mining, or logging. No one knows how these issues will resolve. Most likely, forest protections will continue to be influenced by political interests and industry demands. Forest conservationists will therefore need to keep communications open with both of these groups so that someone can speak for the forest ecosystems.

Like tropical forest conservation, temperate and boreal conservation requires a blend of ecology, economics, and science. It demands a favorable relationship among government, industry, and environmental groups. Finally, temperate and boreal forest health depends on the extent to which people can slow global warming. These are all difficult goals that affect all ecosystems and are not reserved solely for protecting forests.

Desertification

When forests have been destroyed, poorly managed, or harmed by climate change, areas of land once covered with lush greenery can turn into barren land within a decade. Land that has been degraded by intense agriculture practices, overharvesting, or urban development may reach a stage in which the environment no longer replenishes itself. All of Earth's terrestrial plant life emerges from soil, yet nutrient-depleted soil or eroded topsoil cannot provide enough sustenance for healthy growth. The world's people truly depend on the quality of topsoil to produce enough food to keep them alive. When the land turns from a productive place to one that can sustain very little vegetation useful for humans or wildlife, the outcome is called desertification.

Soil develops over a long period of time by the *sediment cycle,* also called the rock cycle. In the sediment cycle, rock formations deep in the Earth's crust gradually migrate upward by either melting and turning into hot magma or by moving toward the surface as it weathers. These deep rock formations are called *metamorphic rock*—created by heat and intense pressure—and migrate upward over hundreds or thousands of years as the surface degrades and erodes. Magma moves quicker toward the surface, forced upward by volcanic action. Rocks, soils, sediments, and mud at the Earth's surface continue degrading by wind, rain, the Sun's heat, and freezing. The rocks, pebbles, and dirt slowly migrate toward bodies of water where they form dense, packed sediments that very slowly become pressed into new metamorphic rock. The portion of the sediment cycle most vital to plant life lies in the topsoil, which is the nutrient-containing earth no more than a foot deep (0.3 m) that supports plant and seedling root systems.

Rich topsoil contains high levels of minerals and organic matter formed by microbial actions on decomposed plant and animal matter. The topsoil and deeper soils that provide nutrients to deep root systems can be drained of nutrients over time by repeated crop cultivation, especially when the same crops grow season after season. Soil erosion additionally washes away large amounts of topsoil and so takes away nutrients. Desertification entails the degradation of the land due to natural climate change, prolonged drought, and human activities such as agriculture. The desertification process involves a unique characteristic: It is caused by erosion, and it also causes increased erosion. In either case, topsoil degradation represents a hallmark of desertification.

The UN General Assembly cited 2006 as the International Year of Deserts and Desertification, highlighting the fact that this phenomenon had grown to global proportions. The UN Food and Agriculture Organization (FAO) summarized the problem in 2007: "Desertification constitutes one of the world's most alarming processes of environmental degradation. It affects about two-thirds of the countries of the world, more than one-third of the Earth's surface (more than 4 billion hectares) [9.9 billion acres; 40 million km^2], and more than one billion people, with potentially devastating consequences on livelihoods and food security." The progression of desertification over the Earth has been difficult to measure. The World Bank and other international institutions measure its impact in terms of the economic losses caused by the loss of cultivatable land to nonproductive desert. The FAO reported, for instance, that sub-Saharan Africa loses 1 percent of productive cropland annually to desertification; in the last 40 years this region that already suffers mass starvation has lost 20 percent of its crop-growing capacity. Other spots where desertification has emerged are the Caribbean, parts of Latin America, China, and Spain. Up to 70 percent of land once used in crop agriculture may have already been lost to desertification.

This chapter explores the process that takes place when vibrant cropland turns into barren land. It also covers the threats desertification cause to sensitive ecosystems such as grasslands, methods for halting the desertification process, and actions being taken in areas already lost to the desert. The chapter covers the special connection between drought, desertification, and global warming with a troubling example in Africa. Finally, this chapter explores the difficult challenge of raising livestock in a sustainable manner that avoids dangerous depletion of ranchland.

This abandoned ship in the former Aral Sea, near Aral, Kazakhstan, gives dramatic testimony to the effects of desertification. *(Staecker)*

BARREN LAND

Desertification occurs when the productive potential of land falls by 10 percent or more. When this happens, nondesert areas become more like deserts, a biome in which water is not readily available to the biota and where evaporation rates exceed the precipitation rates. (Desertification does not cause true deserts, which are natural biomes.) Desertification ranges from moderate (10–20 percent drop in productivity) to extreme in which the land supports less than 50 percent of its former productivity and topsoil has been replaced largely by sandy soil.

Desertification caused by the drying conditions associated with climate change usually begins at the edge of land that is already fairly dry.

Therefore, desertification expands into existing deserts and the outskirts of grasslands. Desertification caused by human activities occurs at a vulnerable spot and then creeps outward if the climate remains dry. For example, overgrazed ranchland can turn too dry to support grazing and the dry, barren land can spread into adjacent areas.

Forests do not turn into desert spontaneously, but climate change has contributed to a progression of some forest areas into dry barren land. Higher temperatures in the mountains and smaller snowpack melts have contributed to drought, drying of the land, and then severe wildfires. These fires are becoming more frequent as well as hotter and more dangerous as climate continues to change. Furthermore, some places in the United States have suppressed fires to protect homes built in the woods, but this only creates more burnable fuel should a fire strike. Fire, drought, or disease infestation—all events that increase with global warming—kill living things faster than they regrow. Craig Allen, a landscape ecologist in New Mexico, explained the matter for *National Geographic* in 2008: "This is a dilemma for the Park Service. The projections are that Joshua trees may not survive in Joshua Tree National Park. Sequoias may not survive in Sequoia National Park. What do you do? Do you irrigate these things? Or do you let a 2,000-year-old tree die?" Fire management decisions therefore have an impact on the rate of desertification in some places.

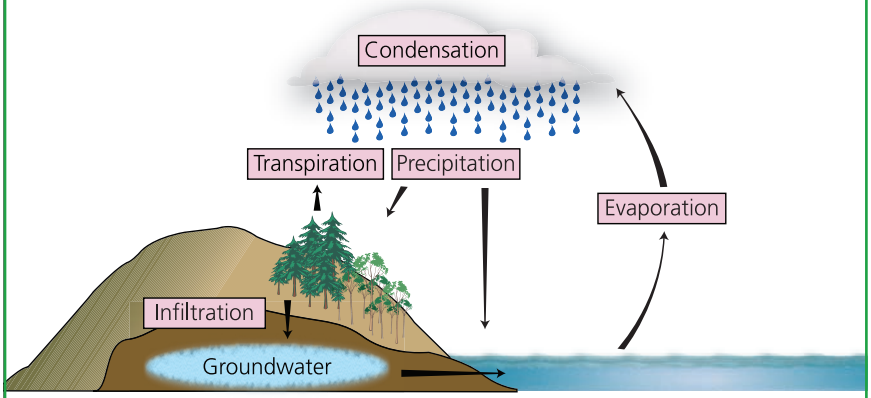
Desertification leads first to soil erosion, which then leads to poor crop production for food for animals and people. Poor crop cover causes more soil erosion, leading to a downward spiral of the land's quality. In countries suffering severe water stress, the process leads to famine, economic losses, and poorer living conditions. The past few decades have seen a new type of nomad walk the Earth: environmental refugees. Environmental refugees are people forced to migrate from their homelands to find food and water in other places. At the same time, people living in drought may add to the dry conditions by drawing water from sources far away to irrigate the few crops they have left. Bodies of water eventually run dry and the drought worsens.

At its worst, desertification results in parched land with poor drainage that cannot retain moisture, so its water evaporates faster. The high evaporation rate leaves behind dried minerals. *Salinization* refers to the increased salt levels in evaporated soil; these salts are sometimes called *white alkaline salts* when they contain arsenic or zinc. Some dry lands in the western United States contain elevated levels of selenium, an element

- condensation—conversion of water vapor into droplets of liquid water
- precipitation—water that falls from the atmosphere to land or to surface waters as rain, snow, sleet, or hail
- infiltration—downward movement of liquid water through soil
- evaporation—conversion of liquid water into gas, or water vapor
- transpiration—movement of liquid water from plant roots, upward in vessels, and into the atmosphere from the leaves as water vapor

Forests serve in the water cycle in two critical ways: transpiration and water storage. Both animals and plants transpire water vapor into the air, but animals transpire as part of aerobic respiration when they exhale moisture from their lungs. Plants and trees possess special cells on the underside of their leaves, called guard cells, that release water vapor from the plant into the atmosphere. The transpiration process begins when

The Water Cycle



The Sun's energy powers the water cycle, which is critical for conserving Earth's water. Within this cycle, oceans account for more than 80 percent of evaporation, and more than 80 percent of rainfall lands in the oceans.

warming problem seen today, but it is important to note that natural climate cycles also contribute to drying the land. Specific human influences, other than global warming, that contribute to desertification are the following:

- overgrazing and poor grazing management
- cultivation of sensitive dry lands already at risk of desertification
- deforestation
- intentional or accidental burning of vegetation from arid and semiarid areas
- incorrect irrigation leading to erosion, soil compaction, and salinization

Arid lands are true deserts where little precipitation ever occurs; semiarid lands are dry lands that receive small amounts of precipitation, approximately 10–20 inches (25–50 cm) per year.

Overgrazing has been a major cause of the increased rate of desertification in the past 40 years. For centuries semiarid rangelands supported cattle because herders moved their animals over large ranges to allow the grazed land and its grasses to recover. Early civilizations simply copied the natural grazing-migration behavior practiced by animal herds in North America, Africa, or Asia to this day. These animals followed the seasonal grasses and the pans that filled with water after a rainy season. (A pan is a shallow pool filled in the rainy season and dry in the dry season that supplies water to migrating wildlife.)

Modern grazing includes fencing animals into large but confined ranges. Windmills and irrigation systems supply water to rangelands so that herds do not need to migrate in search of water. Poorly planned wells and irrigation have added to the overall desertification process by pulling the last remaining amounts of water out of the ground. All of these activities have put regions of the world into water-stressed conditions.

Population density and poverty also force people to overwork their land. As mentioned, this process leads to poor crop cover, patchy dry areas, soil erosion, and then further drying. As an example, the Department of Conservation Biology at South Africa's University of the Western Cape has reported that South Africa loses 330–440 tons (300–400 metric tons) of

topsoil each year due to overgrazing and overcultivation. In 2007 a spokesperson for South Africa's Department of Environmental Affairs explained to a United Nations conference on desertification, "Most of African communities live on agriculture-based economies, and survive by subsistence farming or productivity of marginal lands." This spokesperson added that the entire problem cannot be placed at the feet of impoverished communities. "However, activities that take place in the developed economies can indirectly contribute to the livelihood of these distant communities due to the global impacts of climate change and desertification." In short, poverty contributes to environment decay.

THREATS TO GRASSLANDS

The grassland biome consists of land dominated by grasses instead of shrubs and trees. Grasslands go by various names in different parts of the world: In North America, grasslands are called prairies; in South Africa, they are velds; in Asia, they are called steppes; in Australia, rangeland; and in South America, the pampa. Two types of grasslands occur on Earth: temperate and tropical (also called the *savanna*). Temperate grasslands are found north of the tropic of Cancer and south of the tropic of Capricorn, while tropical grasslands occur near the equator.

Grasslands receive varied precipitation from season to season, ranging from deluges of rainfall to prolonged dry periods. The dry periods can be made worse for the ecosystem by overgrazing, the overuse of pesticides, invasive species, and the depletion of groundwater sources. The savanna's shallow soil bakes in the hot dry seasons, and its porous consistency allows water to drain quickly, so even though savannas experience distinct dry and wet seasons, heavy downpours in a few concentrated regions must serve widespread ecosystems. Grazing, cutting, fires, and the trampling of the land by animals represent the greatest threats to grasslands, all of which lead to desertification. For example, elephants have been blamed for trampling large areas of African savanna that have turned into desert. Temperate grasslands have a wider temperature range than the savanna, but they receive slightly less rain. Savannas average 20–50 inches (51–127 cm) of rainfall per year; temperate grasslands receive 20–35 inches (51–89 cm).

China's grasslands provide examples of the varied forces that conspire to bring a sensitive ecosystem to disaster. From the 1950s to the early

1980s, Chinese leaders encouraged the development of self-sufficiency within the population along with food security. Farmers and ranchers migrated to the steppes to cultivate the land and release cattle to graze. Without adequate knowledge of grassland conservation, the steppes became overgrazed and turned into barren land. Droughts and soil erosion had been increasing in the vast China plateau at the same time. Until 1998 China had no national plan for recovering the steppes or preventing further desertification, and even since then only two national laws focus on land loss from desertification. Currently, global warming has accelerated glacier melt on China's Qinghai-Tibet plateau. The melting causes large amounts of runoff to erode the plateau's soil, to be followed by desertification.

Black-footed ferrets are one of many species, plants as well as animals, that have become vulnerable because their grassland habitat is disappearing. *(U.S. Fish and Wildlife Service)*

By the late 1990s, massive sandstorms swirled across China's plateau, burying barns, vehicles, and sometimes animals. *China Daily* reported that between April 14 and 18, 2006, 330,000 tons (299,375 metric tons) of sand landed on the city of Beijing after the wind swept it across thousands of miles of steppes. Efforts have begun to recover the land from the desert by replanting it, but progress has been slow and frustrating. Farmer Zhang Minqing, a resident of Sichuan Province, was quoted in the *New York Times* as saying, "Last year [2003] our first crop failed because we didn't know what we were doing. We didn't provide enough water and they all died." Still, once farming rebounds in China, the land will stabilize and offer more hope for improved conditions.

Each year in March through May, the sandstorms in China roll east. Yang Weixi, the chief engineer at the Desertification Control Center, lamented in 2006, "Given the millions of square kilometers of desert in China, they will continue to be a source of sandstorms in the future, and we cannot cherish unrealistic expectations this problem will vanish overnight." Once desertification has taken hold, it is very difficult to reverse.

IRRIGATION

Irrigation is the process of supplying water to crops by artificial means. Each farming region's terrain, precipitation, soil drainage, and type of crops determine the amount of water a farming operation needs. Irrigation worldwide has increased as the population has grown and as desertification has taken over previously healthy cropland. The FAO has stated that from 1950 to today, a period in which the world population went from 2.5 billion to 6.5 billion people, irrigated area doubled and water withdrawals tripled. Though irrigation helps agriculture meet the increasing demand for food, it also contributes to desertification if not done the correct way.

Farmers in arid and semiarid regions obtain irrigation water from surfaces waters, such as lakes, rivers, and ponds. This water must usu-

DROUGHT

Drought is a period of dry weather with insufficient rainfall. Droughts are natural occurrences in climate cycles, and most plants and animals have mechanisms for getting through these periods unharmed. Prolonged droughts can, however, affect people and ecosystems. Severe water shortages cause lakes, ponds, and streams to dry up and may lower the water table as people draw water out of underground sources.

Droughts have an immediate effect on plant growth. This in turn harms food chains; predators have a harder time finding prey animals and fresh water sources. People, too, suffer in drought conditions, especially those living by subsistence farming. In addition to crop losses, soil conditions decline, and winds blow away precious topsoil. Droughts often occur in marginal areas that have already been subjected to desertification. Crop failures in areas burdened with poverty can lead to famine, which may force people to migrate and encroach on wildlife habitat. At the same time, drought degrades habitat conditions by reducing vegetation and altering entire food webs.

Certain technologies lessen the effects of drought, such as the development of drought-resistant plants, drought-resistant soil blends, *ground cover* plants to reduce evaporation, and rain-fed irrigation and other water conservation techniques. In impoverished areas, however, even these actions have been difficult to establish. In China, for example, the Gobi Desert expanded 20,240 square miles (52,400 km^2) during a five-year period in the 1990s; today it has crept to within 100 miles (161 km) of the Beijing metropolis. Japan and Korea now suffer springtime dust storms that originate in China's desert, a distance of about 2,000 miles (3,200 km).

ally be carried long distances from its source to the fields. Underground water supplements surface waters, and in some instances it serves as the sole water supply. If irrigation draws water out of the ground quicker than nature replaces it, an *overdraft* occurs. In an overdraft the land above the aquifer may sink. In Europe water officials have used this process to their advantage. Workers drill deep wells alongside rivers, and the wells draw water from saturated soils close to the riverbank. Soil and gravel partially clean the water as it filters through on the way from the river to the well. Only very severe droughts interfere with this method of water purification. More about this topic is found in the "Drought" sidebar.

Irrigation of severely dry land must include precautions so that water does not simply rush over the ground's surface and take soil but never reach the crops' roots. Irrigation water may be supplied by the following

Pat Mulroy, head of the Southern Nevada Water Authority, spoke to the *New York Times* in 2007 about water conditions in Las Vegas: "This country is going to have 100 million additional people in it in the next twenty-five to thirty years," she said. "Tell me where they're supposed to go. . . . Every community says, 'Not here,' 'No growth here,' 'There's too many people already.' We have an exploding human population, and we have a shrinking clean-water supply. Those are on colliding paths. This is not just a Las Vegas issue. This is a microcosm of a much larger issue." As Mulroy suggests, this condition could describe almost any other place in the world today.

In the United States, the National Oceanic and Atmospheric Administration (NOAA) uses a calculation called the *Palmer Index* to put a value on the severity of droughts. A zero value indicates normal conditions; negative numbers indicate drought, and positive numbers indicate ample rainfall. The Palmer Index relates to the local climate so that it can be as useful in the Mojave Desert as it is in Maine. The *crop moisture index* provides similar information but calculates conditions during short-term periods—weekly, for instance, rather than seasonally as in the Palmer Index. Farmers use the crop moisture index to assess the best times for planting and harvesting crops.

Resource wars is a new term for the possibility of increased warfare throughout the world over natural resources that are necessary for civilization. Resource wars have taken place in human history over gold, salt, diamonds, and oil. Today society confronts increasing conflicts over food and water, and drought will intensify the problem. Increased irrigation works well during short-term

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The Palmer Drought Index

	Soil moisture value
Extreme drought	-4.0 or less
Severe drought	-3.0 to -3.9
Moderate drought	-2.0 to -2.9
Mid-range	-1.9 to +1.9
Moderately moist	+2.0 to +2.9
Very moist	+3.0 to +3.9
Extremely moist	+4.0 and above

Serious drought has more than doubled from the 1970s to the 2000s as a result of global warming and deforestation. An area's dryness can be calculated by using a formula that accounts for temperature and rainfall. The results make up the Palmer Index, which gives an indication of the severity of a specific drought.

dry periods, but a constant reliance on water reserves threatens groundwater storage and leads to salinization. Climatologist Roger Pulwarty of the NOAA told the *New York Times* in 2007, "You don't need to know all the numbers of the future exactly. You just need to know that we're drying. And so the argument over whether it's 15 percent drier or 20 percent drier? It's irrelevant. Because in the long run, that decrease, accumulated over time, is going to dry out the system." Resource wars over water may dominate the future the way conflicts over oil have affected the present.

systems: sprinkler systems; field-flooding; filling furrows between crop rows with water; subirrigation (in which water from ditches or porous vessels percolates into the soil); or drip irrigation. Drip irrigation offers the most efficient water delivery approach, especially in water-precious dry parts of the world. Drip irrigation periodically delivers small amounts of water to the soil above root systems through small tubes. Drip irrigation

provides the three following advantages: (1) reduced total water requirements; (2) slow release that prevents large losses by evaporation; and (3) adaptation to hilly or flat terrain.

Improper irrigation causes unneeded damage to lands already threatened by desertification. First, repeated irrigation that does not allow the soil to absorb the water can cause salinization as salts slowly accumulate in the soil. Salinization, as mentioned earlier, further reduces the soil's quality and leads to more desertification. Farmers who try to remove salinization with water may create a second problem from irrigation—waterlogged soil. Waterlogged soil eventually raises the water table and kills plant roots. At the same time, soil microbes cannot carry out their normal metabolism so they do not degrade organic matter. Both salinization and waterlogging have become serious problems in parts of the world suffering desertification.

SOIL CONSERVATION

Soil conservation involves techniques for reducing soil erosion and retaining the nutrient value of topsoil—especially important when facing drought or expanding desertification. Soil conservation helps make floodplains suitable for growing crops and also helps certain crops that have strict requirements for soil nutrients.

Soil conservation includes eight main methods used by farmers to reduce soil loss to wind and water. These methods are described in the table on the next page. The land's terrain, weather, climate, and the type of crops being grown contribute to one or more methods that a farmer might choose to help retain healthy topsoil.

The Web site of the Monsanto Company—a chemical company that serves the agriculture industry—contains interviews with farmers from around the world, discussing their preferred methods for conserving soil. Almir Rebelo, president of a growers' organization in Brazil, explained his approach to tilling and conservation: "Our problem with erosion was very serious and it was very damaging to the environment to the extent that, in these crops, to produce one ton of grain in Brazil, we lost ten tons of soil per hectare [2.5 acres; 0.01 km^2] per year." Farmers like Rebelo have adopted conservation farming, which combines efficient tilling methods with water conservation and alternate choices in fertilization. The case study "Lake Chad Is Shrinking" describes conditions when water loss and soil damage reaches critical levels.

SOIL CONSERVATION METHODS

METHOD	DESCRIPTION	EXAMPLE CROPS
no-till farming	seeds, fertilizers, and herbicides mechanically injected into unplowed soil	grains, corn, grasses, vegetables
minimum-till farming	soil left undisturbed over winter; before planting, tillers loosen soil but do not turn over topsoil	grains, cotton, corn
contour farming	plowing and planting in rows across slopes so each row slows rain runoff	vegetables, fruits, vineyards
terracing	broad, level rows on steep slopes conserve water and reduce runoff erosion	potatoes, vineyards, rice
strip cropping	alternating rows of crops with ground cover such as grass, which reduces evaporation and holds soil	corn, cotton
alley cropping	one or more crops planted in rows between rows of shade trees or shrubs, which reduce evaporation	fruit trees
cover crops	leave crop residues on ground after harvesting to protect and hold the soil	corn
shelterbelts (windbreaks)	rows of trees next to cropland to reduce wind erosion	vegetables, fruits

CONSERVATION FARMING

Conservation agriculture, or conservation farming, resembles sustainable agriculture because it follows principles that conserve natural resources and minimizes the *ecological footprint* of raising crops or food animals.

An ecological footprint is the amount of land and water needed to provide a population with resources to sustain life and dispose of wastes.

Conservation farming today includes four main aspects that work together to reduce ecological footprint: water conservation, soil conservation, efficient tilling methods, and low environmental-impact fertilization methods. Sustainable agriculture may be considered to be stricter than conservation farming with respect to ecological footprint because, unlike sustainable methods, conservation farming accepts the following:

- meat production
- some water-inefficient crops
- monoculture
- seasonal crops
- use of prime cropland
- some use of pesticides and herbicides

Conservation farming aims to convert traditional inefficient food production methods into methods that are both sustainable and efficient. For instance, traditional farming of 20 to 50 years ago often included the following characteristics: several passes over the fields with tilling equipment before sowing seeds; preemptory weed control with heavy doses of herbicide; fertilizer use at inefficient levels; and acceptance of any crop yields. Today conservation farming uses more efficient tillage and soil conservation methods. In the 1970s farmers cultivated their soils at least four times and often as 10 times before planting. Conservation farmers have found this overcultivation to be unnecessary, not to mention a waste of manpower, fuel, equipment, and soil. In weed control, conservation farming borrows from sustainable methods by using ground cover plants and natural methods (birds, small mammals) to combat weed growth.

Conservation farming uses both organic and inorganic fertilizers to return nutrients to the soil between each growing season. Organic fertilizers come from plant or animal materials such as manure. Green manure consists of cut crops that are plowed back into the soil to replenish some nutrients for the next crop. Green manure also includes compost, which is decomposed plant material that has been broken down by microbes on a site away from the fields, and may then be applied to fields like any other fertilizer. Brown manure consists of solid wastes from cattle, horses, sheep,

Case Study: Lake Chad Is Shrinking

Lake Chad lies next to the Sahara in western Africa. This shallow lake (16–26 feet; 5–8 m) has been shown in air surveys and satellite imagery to expand and shrink with intermittent droughts that occur in the region. Since 1960, however, Lake Chad has not followed this pattern; rather the lake has shrunk to one-tenth of its normal size.

Villagers from countries bordering Lake Chad—Nigeria, Chad, Cameroon, and Niger—have relied on the lake's fish for generations, but the steady downward trend spells disaster for an area of the world already burdened by hunger and water stress. One resident told the BBC in 2006, "Survival becomes a real problem here because we have no means of other livelihood. We solely depend on the water, and when there's not enough we have a serious problem." Bata Ndahi, director of Nigeria's Lake Chad Research Institute, added, "The water is moving farther and farther away. We believe desertification has contributed most to the demise of Lake Chad." The villagers who once depended on fish cannot reach the water, so they have turned the exposed land over to planting crops that do not supply enough protein for the human diet.

The Lake Chad Basin Commission (LCBC) now includes representatives from the four bordering countries plus the Central African Republic to devise ways to save Lake Chad. The ambitious program intends to return the 373,360-square-mile (967,000-km^2) area to near its former size by starting new types of water management, shoreline care, water efficiency in the surrounding cities, and by studying an aquifer that has potential to supply water during drought. The LCBC realizes that desertification has made Lake Chad's future questionable, but years of water inefficiencies and damming rather than drought may have caused the worst abuse to the lake. LCBC director Wakil Bakar told the BBC, "It's going to be a massive project, but the end result is what

or poultry, and even urine, which contains nitrogen in the form of urea. Inorganic fertilizers produced by chemical companies provide a set amount of nitrogen, phosphorus, and potassium to the soil with each application. Conservation farming makes use of both types of fertilizer; organic fertilizer provides a slow-release spectrum of plant nutrients, and inorganic fertilizer provides a fast-release influx of nutrients most likely to be depleted from soil each season.

Crop rotation conserves fertilizer by planting different types of crops on the same land every other year. Crops such as corn or cotton deplete nitrogen from the soil, so rotation with legumes the next year helps return

we're after. This lake has to be saved. We know the benefit. We know how people have suffered. All the countries—Chad, Niger, Cameroon, Nigeria—we know what we have lost. It's going to be a huge benefit to all of us." The Lake Chad restoration project therefore faces dual challenges: restoring a severely damaged ecosystem and returning a healthy water system to an area decimated by desertification.

The LCBC's plans have not yet saved Lake Chad. Little progress has been made in stopping the lake from disappearing, and the region struggles with poverty, food, and water conflicts, and wars in neighboring countries. In 2008 Nigerian President Umaru Yar'Adua expressed his concern to the Voice of America: "Over the next four decades, it is projected that the present population of 30 million will increase by almost 100 percent, resulting in 30 to 50 percent more water drawn. . . . Already the region is water-stressed. Unless urgent action is taken, the situation could escalate to crisis proportions, further diminishing Lake Chad's capacity to be of value to those whose livelihood depends on it." Unless the LCBC project succeeds, Lake Chad may become one of history's worst victims of drought and desertification.

Lake Chad has not yet disappeared forever, and the LCBC's plan still has a chance to work. The plan contains the following main directives: (1) establish coordination among national agencies that work on the project; (2) strengthen regional policies on water use; (3) recruit local communities by providing incentives and education; (4) develop water conservation methods; and (5) solicit funds from donors. These objectives are general and contain no specific details on how water conservation will be implemented in the area or how a water system infrastructure will be built. Without these details and quick action, Lake Chad's future remains very much in doubt.

nitrogen to the soil. Legume plants contain bacteria-filled nodules on their roots that draw in nitrogen from the atmosphere and convert it to a usable form for plants, a process called nitrogen fixation. In addition to recycling nitrogen, crop rotation reduces erosion by keeping a crop on each field rather than letting the field lie fallow (unplanted) for a season.

Drought and desertification put pressures on conservation farming, often in the issue of water conservation. Different irrigation systems offer more or less efficiency to watering fields, as already discussed. But what happens if there is no water at all? The "Desalination of Water" sidebar discusses one option in world water conservation.

SUSTAINABLE LIVESTOCK PRODUCTION

Livestock serves as an excellent protein and mineral source for humans, but those nutrients come with a price paid in water. One pound (0.45 kg) of meat protein requires 8,124 gallons (30,744 l) of water to produce. By comparison, the same amount plant protein of equivalent quality requires 3.1 gallons (11.6 l) to produce. Put in another perspective, a pound of sugarcane needs 21 gallons (80 l) of water, but a pound of leather requires 2,000 gallons (7,571 l) of water to produce.

Of all livestock industries, beef production requires the most water and the most rangeland. Feedlots account for almost half of all beef and pork production and three-quarters of poultry production. In terms of efficiency, feedlots that concentrate all animals in pens provide an advantage over free-range production, wherein animals roam outside cages to graze on the land. The United States depends to a large extent on feedlots, using energy-

DESALINATION OF WATER

Desalination (also desalinization) converts salt-containing waters such as seawater into freshwater. Desalination has the potential to be particularly valuable in places suffering drought, countries in severe water stress, or in areas of expanding desertification.

Two common methods for removing salts from water are *distillation* and *reverse osmosis*. Distillation is an inexpensive process in which freshwater evaporates out of heated salt water. Reverse osmosis (RO) requires more expensive filtration equipment than distillation. In RO pressure forces seawater through a filter, called a *membrane*, containing very small diameter pores. The pores let water pass through but remove about half of the dissolved salts. The concentrated salt water can be returned to the ocean and the freshwater used for irrigation. More advanced RO systems contain membrane pores in the range of 1 micrometer (μm) that make the treated water safe to drink. Microfiltration uses smaller pores of 0.05 to 0.5 μm diameter, and ultrafiltration uses pores of 0.001 to 0.01 μm diameter. Both of these filtration techniques ensure that water is safe to drink because they remove even very tiny contaminants such as viruses. RO plants usually employ a pre-RO filtration step called coarse screening that catches large insoluble materials on a screen to make the membrane filtration more efficient.

At least 7,500 desalination plants operate worldwide with about 60 percent of them in the Middle East. Saudi Arabia, Kuwait, and Israel depend on desalination for a major portion of their clean freshwater. Saudi Arabia owns the world's largest plant, which produces 130 million gallons

dense grains to feed the animals rather than natural grasses, but many people object to this style of factory farming on ethical grounds. The Humane Society of the United States has explained, "The vast majority of our meat, dairy and eggs comes not from animals on small farms but from factory farms—massive operations that treat animals like profit-making machines, routinely subjecting them to terrible abuses. . . ." Feedlots furthermore produce large amounts of manure, which has the potential to pollute waterways, yet these operations do not spoil the land as grazing often does.

Whether free-range or feedlot-raised, meat production is an inefficient way to produce energy. Meat-producing animals convert grain to animal body weight on a pound-to-pound (kg-to-kg) basis as follows: fish, 2.0; chicken, 2.2; pigs, 4.0, and beef, 7.0. Cattle and sheep present another problem in the environment because they belch large amounts of gas that forms in their normal digestion of fibrous plants. This gas contains about 60 percent methane and 40 percent carbon dioxide, both greenhouse gases. The agriculture and

(492 million l) of freshwater daily. North Africa, the Caribbean, and countries in the Mediterranean region have also explored desalination; Mexico and the United States use it on a small scale.

Though desalination technology can supply water to thirsty areas of the world, it currently produces less than 1 percent of the world's water needs. Three disadvantages contribute to desalination's slow acceptance. First, the treatment plants, especially RO, are expensive to build. RO requires costly equipment, and both distillation and RO consume large amounts of energy, so desalination's costs create too great a burden for drought-stricken developing countries. Even in developed nations, desalination costs more than other water treatment methods. Second, the desalination process creates a large quantity of salt, which must be cleaned from equipment on a regular maintenance schedule. Third, the excess salt and high-salt wastewater must be returned to the environment. Dumping the high-salt wastes into the ocean harms aquatic ecosystems in the area; dumping it on land has the potential to contaminate surface waters and groundwaters.

In order for desalination to lessen world water shortages, technology will need to design more efficient, inexpensive filters. The Canadian author and water treatment expert Maude Barlow said in 2008, "Even with current plans to triple global production, including nuclear-powered desalination plants, this technology cannot meet the demand for freshwater in the world." Desalination adds to the world's water supply, but it does not appear that it will be part of sustainable water use in the near future.

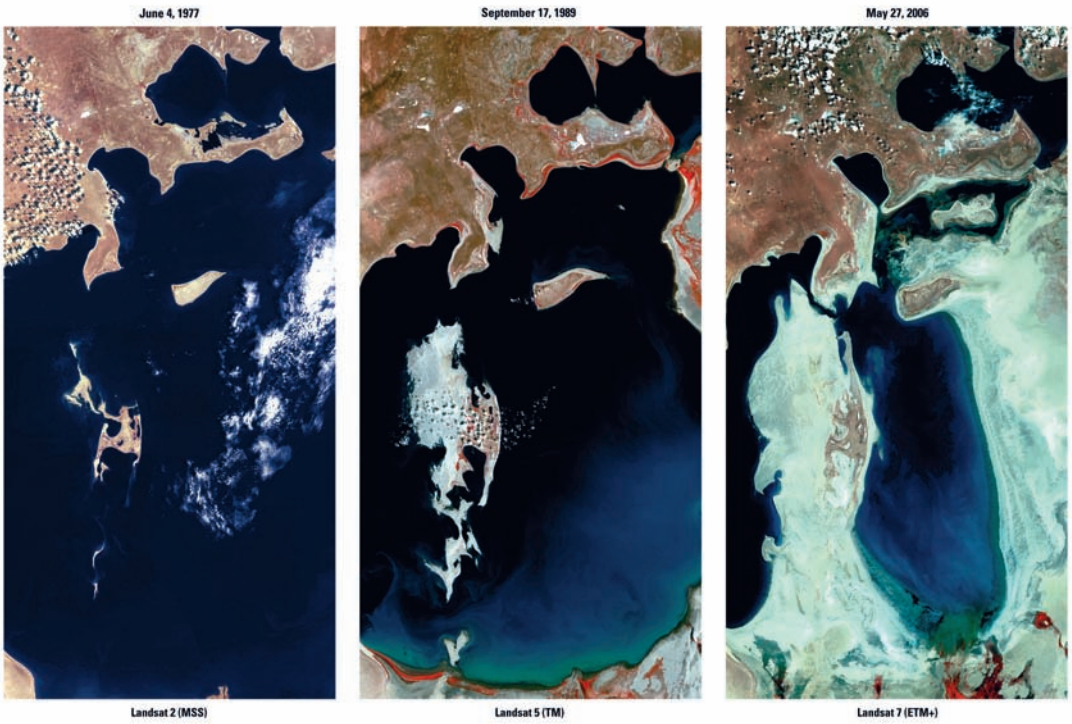
energy industries have studied ways to capture ruminant gasses as an energy source and also so they do not add to global warming. The dairy farmer Richard Huelskamp described the plan clearly in a 2006 interview with the University of Minnesota's *Minnesota Daily*: "I believe that agriculture has got to be supplying 25 to 50 percent of our domestic energy. We need to maintain sustainability." Can meat production be transformed from one of the most inefficient types of production to a sustainable activity?

Dairyman Huelskamp developed a sustainable use for the so-called *biomethane* his cows produce. A month's worth of manure from Huelskamp's farm travels on conveyers into digester tanks where the solids partially decompose and the gases form. The farm recovers the majority of the gas by funneling it to a generator to produce energy. Part of the decomposed manure serves as fertilizer to reduce the farm's total waste output.

Sustainable meat production incorporates other devices to reduce its ecological footprint. People can contribute by changing their diet to more seafood and poultry and less beef and pork. In the meantime, livestock operations can adopt as many water and soil conservation techniques as possible. Cattle and sheep, though inefficient, offer the following advantages: Free-range animals eat grasses that humans cannot eat; rangeland that supports grazing is usually poor in supporting crops, so does not cause a conflict with plant agriculture; and many of the world's poorest regions have access only to cattle as a reliable protein source.

Meat is an important source of protein, but its production requires large amounts of land, can lead to deforestation, consumes large amounts of water, and produces tons of waste. *(Clemson University Edisto Research and Education Center)*

The Worldwatch Institute predicts meat consumption will increase 2 percent per year until at least the year 2015. For this reason, sustainable livestock farming seems a necessity. The future of sustainable livestock raising will likely consist of the following methods: raising livestock with free-range methods rather than with feedlots to decrease waste loads; incorporating goats with cattle to more efficiently use all rangeland for meat production; raising grains on the farm using water and soil conservation and to



This series of satellite images of the Aral Sea shows the progress of desertification. In less than 30 years the Aral Sea has shrunk by more than half. *(USGS)*

reduce fuel use; selling only to local meat producers to reduce transport fuel consumption and emissions; and designing operations to produce less beef and pork and substitute with other products to maintain the farm's income.

CONCLUSION

Desertification is an environmental crisis that comes from poor land management and poor or insufficient water conservation. Desertification is therefore a wide-ranging problem, but the good news is that many opportunities exist to correct this problem. The main and biggest issue leading to desertification is global warming, which changes air patterns in the atmosphere and accelerates the drying of arid regions. Global warming is a worldwide problem that has drawn attention from the international

scientific community and governments. Desertification may also be influenced by activities that local communities may feel they can control better than climate change. These things include forestry methods, grassland conservation, dependence on ranching, agricultural practices for growing crops, and water use and conservation methods.

Several methods in land use have developed for the purpose of conserving natural resources, and in the process they also help resist desertification. Proper irrigation techniques and soil conservation keep the land nourished without depleting either soil or water. Conservation farming and sustainable livestock production represent a small portion of agriculture in the world, but they may prove to be answers in producing food and avoiding desertification.

Overall, desertification causes critical stresses to regions that already confront poverty, hunger, and a limited supply of clean water. The only defenses against desertification may be a dramatic reversal in global warming and an immediate adoption of sustainable food production. These are not simple adjustments, but rather they represent the key issues in almost every other aspect of care for the environment. Desertification does not happen by itself; it is part of the interrelationships between the living and nonliving components of the Earth.

Saving Riparian Habitats

Riparian habitat comprises the trees, shrubs, plants, and physical features found on the banks of rivers, streams, and nonbeach borders of lakes. Riparian areas occupy a small portion of the Earth's total land area, but they serve two major purposes in the environment: (1) they contribute to watersheds and (2) they hold a large amount of plant and animal biodiversity. Riparian areas serve watersheds by the following means: lessening damage caused by floods; improving the supply to groundwater sources; removing chemicals from runoff by filtering water through their wetlands; and reducing wind erosion on nearby land. Also important, riparian areas serve as wildlife corridors and as a transition zone where aquatic and terrestrial habitats meet.

Much of the human-caused damage to riparian habitat comes from upstream chemical pollution, and a portion of that starts with intentional misuse of rivers and streams. People use rivers and streams for dumping waste, ranging from household garbage to used appliances. Riparian areas that run through private property often receive landscaping that changes the normal habitat. Lawns additionally put runoff, animal wastes, and chemical fertilizers into the water. In forests, off-road vehicles and trucks cause damage when they drive across streams and stir up sediments that cloud the water downstream. The small sediment particles harm aquatic invertebrates, block sunlight from plant life, and change the water's temperature. Perhaps one of the most frustrating occurrences has been intentional restructuring of stream sides and riverbanks with concrete walls or slopes. Many of these structures prevent flooding, but they also create a place where biodiversity of any kind cannot exist. Only 5 percent of the original riparian habitats in the United States are thought to remain in

their original condition. For this reason, riparian ecology focuses on restoration more than conservation.

This chapter describes the role riparian habitats play in ecology. It explores the main threats to riparian biota, how riparian ecosystems work, and different methods of riparian restoration. It also takes a detailed look at one species of fish that has been threatened by the disappearance of clean, cool rivers and streams.

WATERSHEDS AND ECOLOGY

A watershed is an area of land surrounding a riparian habitat that supplies all of the habitat's water. Environmental damage to a watershed in

Clean water, lush vegetation, shade, and biodiversity characterize healthy riparian habitats. *(Natural Resources Conservation Service)*

the form of pollution or erosion directly affects its riparian waters. Conversely, a healthy environment and watershed give rise to healthy riparian habitat. For instance, undisturbed watersheds containing trees and plant life have riparian areas with clean, clear water. Vegetation, ground cover, and extensive root systems in these places prevent sediments and runoff. In heavy rainstorms, water rushes into streams and dirties the water with soil. A slow leaching of soils and vegetation, by contrast, adds nutrients to the riparian system rather than polluting it.

Clean inflow from healthy watersheds replenishes riparian habitat for a diverse collection of microbial, plant, and animal life. The banks and sediments of streams contain bacteria and fungi that decompose organic matter in the water and soil. Life on the water's bottom, on rocks and pebbles, is usually composed of microbial communities called *biofilms,* made up of bacteria and algae, and small plant life called *phytoplankton.* Invertebrates and dissolved minerals in riparian water feed insect larvae and small fish, and many riparian habitats contain freshwater fish upon which large and small mammals prey. Riparian sites also provide shelter for animals, migration routes, and a shady resting place in hot climates.

Riparian vegetation prefers moist, shady conditions; some species contain root systems that have adapted to a shallow water table and tolerate seasonal flooding. The deep roots of riparian trees prevent erosion and the undercutting of banks in which flowing water wears the bank away from the bottom up. Native plants along waterways provide shelter for insects, amphibians, reptiles, mammals, and birds. Vegetation that overhangs flowing waters also helps keep the waters cool for fish such as trout and salmon, which are discussed in the sidebar "Salmon."

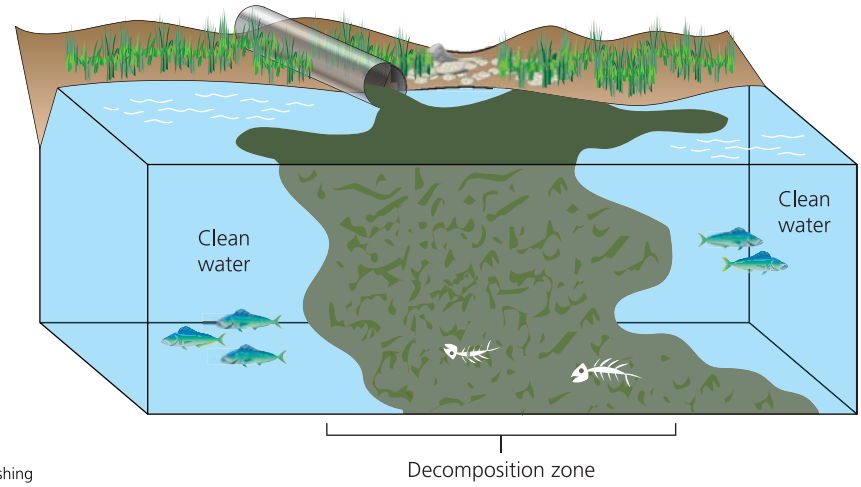
THREATS TO WATERWAYS

Waterway pollution threatens the health of the biota that depend on aquatic habitat and the people that depend on the waterway as a drinking water source. In developing regions, chemical pollution and sewage have created a serious threat to both habitat and people. More than half of the rivers in India, Africa, and Latin America contain heavy pollution, but the greatest problem may be in China, where most of the coasts, rivers, canals, and lakes contain industrial pollutants. Hundreds of thousands of people in China turn to bottled water because no other safe

water source exists, but the wildlife living in these areas have no choice but to ingest contaminated water. China's Ministry of Environmental Protection has waged a war on the pollution problem and has managed to control some of the pollution, but waterway pollution remains a problem that industries have not yet addressed. The Beijing environmentalist Ma Jun told the *New York Times* in 2008, "We need to have an understanding that this is just the turning point in pollution discharges; this isn't the turning point in the environment." Waterway pollution control remains an enormous obstacle to a healthier environment in China and other nations.

The main sources of river pollution worldwide are sewage, effluent from livestock farms, manufacturing and industrial discharges, mining wastes, materials from housing and road construction, and the myriad wastes carried in rain runoff, including gasoline and oil. Urbanization adds its own mixture of eroded soil, solid wastes, rubbish, and organic matter. The relative amounts of these pollutants differ between developed and developing countries, but each of these pollutants represents worldwide problems in riparian health.

Waterway Pollution



Waterway pollution creates zones where aquatic life differs depending on the constituents in the water. The only life that exists in the polluted decomposition zone comprise species that can ignore the contamination or use some of the pollutants as a nutrient source.

Four factors cause riparian destruction in addition to pollution: physical alterations; destruction of *catchment* areas; mismanagement of fish resources; and invasive species. Physical alterations include structures built into or near waterways for the purpose of flood control, landscaping, or power generation. Some urban centers alter waterways simply because the city wants the water to pass through it in a more convenient way. Altering riparian areas is not confined to large cities, as a Glenwood Springs, Colorado, resident pointed out in a 2008 letter to the *Glenwood Springs Post Independent*: "There are large subdivisions all over the [Roaring Fork] Valley where the prime riparian has been ripped up entirely to support exclusive subdivisions, malls and golf courses. . . . I don't find golf courses, shopping centers and parking lots a positive addition to the environment. All that manicured green grass, asphalt and chemical warfare has replaced the oak brush, sagebrush and the natural habitat. The irony is the new pavement is named Heron Circle, Eagle Court, Hawk Lane, yet we've destroyed the birds' actual habitat." Construction that was once well-meaning has turned into a hazard for habitat and biodiversity.

Some of the major restructuring projects that have been completed on rivers and streams that cause major impact on riparian environments are the following:

- dams for flood control, drinking water reservoirs, or power generation
- clearing of riparian vegetation for landscaping
- constructed channelization through urban areas
- river diversion in urban areas
- deepening, straightening, or widening rivers for ship use
- docks and boardwalks for recreation

Physical alterations change waterways' normal routes, sediment settling, water temperature, and water chemistry. All these factors affect biota from microbes to old-growth trees that live in the catchment area. Catchments consist of mountain lakes, ponds, and streams as well as the moisture stored in trees and soil. New developments on mountaintops that cut down trees and landscape the area for roads and views change the catchment's capacity to store water for later use downstream. Clear-cutting, mining, and agriculture impose similar effects on catchments.

Salmon

The general names *salmon* and *trout* represent a number of different fish species that are born in freshwater, migrate to the ocean to mature, and then migrate back to inland freshwaters to reproduce. This migration is called a salmon run. Reproduction consists of a female laying eggs in a streambed's gravel, the male fertilizing the eggs, and then the development of young fish; the entire process is called spawning.

Salmon populations exist in the Atlantic Ocean, the Pacific Ocean, and some large lakes, but all salmon populations have undergone declines over the past century, possibly due to altered habitat and overfishing. (When fewer salmon migrate in freshwater rivers and streams, bears, river otters, mink, and eagles are threatened because salmon make up a large portion of their diet and protein needs.) Most salmon species are fall spawners, meaning they travel hundreds of miles upstream from the ocean in time to spawn in the fall. The young stay at the spawning site for up to two years before heading to the ocean in the spring. Because each generation of salmon depends on safe, clean, flowing rivers and streams, riparian destruction has been endangering salmon for several years. Salmon runs in the Pacific Northwest have declined to 1–3 percent of the levels they attained when Lewis and Clark visited in the early 1800s.

Ideal riparian habitat for salmon consists of the following factors: year-round flow of cool (below 68°F, 20°C), clear water; streams with pools and *riffles*; clean and exposed spawning gravel; stable stream banks; dense shade canopy from trees; a supply of small branches fallen from trees;

Mismanagement of fish resources in natural rivers and streams also damages riparian habitat. Illegal fishing, overharvesting, or fishing without regard for the environment affects these habitats as does the use of poisons, nets, and even explosives. Other ills brought by irresponsible fishing are the waste pollution and overuse of the same riparian location. Overuse causes three main damages to the riparian habitat: destroyed terrain; trampled vegetation on the banks; and alteration of wildlife's normal patterns.

Riparian habitats also receive damage from invasive vines or bushes that people plant along waterways. These plants have the potential to displace native vegetation that serves as food, shelter, and nesting sites for wildlife. Invasive fish species also alter the natural ecosystem in ways that may affect biota far downstream, particularly by interfering with normal food chains.

adequate supply of insects to eat; and an abundance of hiding places. Hiding places include shade-covered pools, rocky nooks, overhanging vegetation, and stationary tree branches, leaves, or other plant debris. Riparian destruction affects many of these vital factors. Even riparian habitats that people think are well maintained may be the biggest threat to salmon. Cutting down trees and clearing out overhanging vegetation allows more sunlight to warm the waters where salmon migrate. These warmer waters interfere with the normal physiology of adults and the survival of the young.

Scientists have begun to track Pacific salmon populations to assess the threats to the fish's survival. To do this they catch salmon with nets at the river's mouth and gently push a transmitter that holds an antenna into the fish's stomach. This method has been used in the Oregon Rogue River Spring Chinook Conservation Plan. Since the Rogue River was dammed in the 1970s, yearly runs of chinook salmon fell from 28,000 on average to 9,000 in 1990 and fewer than 3,000 today. The scientist Tom Satterthwaite explained in 2008, "Results from this year will tell us how best to capture and tag fish, and most importantly, the minimum number of fish that need to be tagged to get statistically reliable results. We need to know this number because successful upstream migration of tagged chinook in other rivers varies from 30 percent to 90 percent, and in the Rogue, these fish face added stress from high summer water temperatures." These studies may help explain the reasons behind salmon losses in the past several decades.

DAMS

One of the most dramatic physical alterations of waterways arises from the building of dams. Large dam projects began in the United States in the 1930s with good intentions, but ecologists now realize that dams affect ecosystems, natural water flows, and water conservation in both good and bad ways.

Dams provide benefits in water management in the following ways: (1) They conserve water by storing it in reservoirs; (2) they supply irrigation water; and (3) they reduce flooding downstream. In addition, many dams have been built for the main purpose of producing electricity. All of these factors have helped preserve people's property, and the waterpower from dams serves as a sustainable energy source.

Dams conserve water in two ways: Reservoir water behind dams serves as low-cost storage for a community's drinking supply, and the

downstream flow provides a constant source of irrigation water. Both situations conserve groundwater. Lakes behind dams provide outdoor recreation areas and places for fishing, perhaps sparing wilderness areas from excess human activities. For each of these positives, however, there is also a disadvantage, summarized in the table below.

When dams interfere with natural water flows, they affect aquatic ecosystems that live in riparian habitats. Dams do this by changing the normal flow of sediments that carry nutrients to microbes and invertebrates, taking away long stretches of running water that some migrating fish need, and slowing water flow enough to allow salt water from estuaries to move upstream. Salt water contamination kills the diverse microbes, invertebrates, amphibians, fish, and plants that need freshwater.

Two opposing schools of thought have grown regarding the role of dams in the environment today, and not surprisingly, the arguments become contentious. Butch Hopkins of California's Reclamation Board explained the major issue swirling around the American River's Auburn Dam to the *Sacramento Bee* in 2006: "The dam is incredibly controversial because it runs flat into the fundamental beliefs of fiscal conservatives and environmentalists." Those words describe almost all large dam projects in place today.

Dams allow communities to take advantage of a renewable energy source while they also practice water conservation. But environmen-

ADVANTAGES AND DISADVANTAGES OF DAMS

ADVANTAGES	DISADVANTAGES
aids water conservation	floods upstream habitat
protects against downstream flooding	less efficient water storage than covered tanks due to evaporation
provides recreational area	interferes with natural flow of nutrients for downstream aquatic habitats
acts as water storage for drinking and irrigation	changes the natural volume and flow rate of waterways
serves as power source for producing electricity	

talists have called for the removal of large and small dams, and in the past few decades many dams have in fact come down, either because they had become dangerously degraded or because they were part of a riparian restoration. Three environmental groups—Friends of the Earth, Trout Unlimited, and American Rivers—published a report together in 1999 that detailed case studies of dam removal projects. *Dam Removal Success Stories* summarized the rationale behind dam removal: "Even for some functioning dams, removal may be a sound solution when a dam's benefits are outweighed by the significant environmental damage it causes. . . . Clearly dam removal is not appropriate for all—or even most—of the nation's 75,000 large dams. Many dams continue to serve public or private functions such as flood control, irrigation, and hydropower generation." But for dams that have a clear and devastating effect on the environment, their removal helps restore riparian habitat. The report said of dam removal: "Dams all across the country have been or are in the process of being removed for three primary reasons: environmental, safety, and economic. Most removal decisions involve a combination of all three of these reasons." Thousands of small dams remain in the United States in areas that at one time supported farming or logging.

Proponents and opponents have come to an uneasy truce regarding hydroelectric dams, meaning dams that produce electricity. Hydroelectric power replaces the need for coal-burning power plants, so these dams receive support from many people in the public and in government. John Doolittle, who served in the California House of Representatives during the time a dam was planned for the town of Auburn, stated in 2006, "Any dam will eventually pay for itself. If you build a multipurpose dam, it's a moneymaking machine because it generates the sale of electricity and of water." At present, people continue to weigh the advantages of dams against the disadvantages. The sidebar "Three Gorges Dam" explores one of the world's most famous and controversial dam projects.

RIPARIAN ECOSYSTEMS

A typical riparian ecosystem consists of life that has evolved in flowing freshwater rather than in static waters. Any ecosystem that has adapted to living in running water is called a lotic ecosystem. Part of the riparian

ecosystem also consists of animals that use areas as migration corridors and feed on riparian plants and animals. Riparian ecosystems represent edges, a place where two different habitats meet. Lush and shady conditions next to a stream, for example, differ from the sunny dry

THREE GORGES DAM

China's massive project to construct the Three Gorges Dam across the flood-prone Yangtze River brings together almost all of environmentalists' fears. The Three Gorges Dam controls a drainage area of 386,300 square miles (1 million km^2) and when complete it will be the world's largest water conservation structure. The project's leaders have assured their country and the world that the Three Gorges Dam will be a masterpiece of flood control and energy generation. Critics have cited other factors associated with the dam that will have worse effects on the environment.

Criticism of the dam centers on three health threats: (1) increased disease due to larger mosquito and other pest breeding grounds; (2) downstream droughts when flow is diverted for energy production; and (3) increased incidence of earthquakes due to the size of the structure in the Earth's crust. George Davis, a specialist in tropical medicine at George Washington University in Washington, D.C., cautioned in 2008, "When it comes to environmental change, the implementation of the Three Gorges dam and reservoir is the great granddaddy of all changes. Once you dramatically change the climate and change water patterns, as is now seen in the Three Gorges region, you change a lot of environmental variables. Almost all infectious diseases are up for grabs." Davis argues that the standing waters behind the dam create perfect conditions for swimmers to catch infections from polluted water, be invaded by parasites, and attacked by mosquitoes.

Since the Three Gorges building project began at the close of 1994, ecologists have wondered about all the environmental changes about to begin. Warnings came early in the construction, but the Chinese government found no reason to question the dam's value. By 2007, however, leaders in China admitted that the environmentalists' cautions about the Three Gorges project might have been right. The *Xinhua* news agency published the following statement released by the Chinese ruling party: "There exist many ecological and environmental problems concerning the Three Gorges Dam. If no preventive measures are taken, the project could lead to catastrophe." All of the ecosystem damages, upstream and downstream, have begun to emerge in the Three Gorges project. The difference between this and other dams is the magnitude of the potential problems.

meadow a short distance from the stream. Some predators seek edges because they contain a greater number and variety of prey animals, and when predators hunt in riparian habitats, they also become part of the ecosystem.

Sediments accumulating in the water behind the dam have prompted environmental engineers to worry about structural failure. Also, flooding of the lake behind the dam would cause lake waters to spread to sewer systems and landfills, and thus pollute the water when the lake recedes. These problems could occur in addition to the normal disadvantages to the environment that dams are known to cause.

Dams have been built for thousands of years for the purpose of flood control, water reservoirs, and fishing. Present-day dams, like China's massive Three Gorges Dam shown here, are often built mainly for energy production. Although Three Gorges and other large dams cause negative impacts on the environment, they produce electricity in an efficient and clean manner. *(Brian Sealy)*

Navigation has returned to normal on China's important Yangtze River—a lock system raises or lowers oceangoing vessels—and some of the dam's 26 generators have begun to produce energy. The dam uses two power plants on either side of the structure to produce 84 billion kilowatt-hours, or almost 1.5 times the energy produced by the world's second-largest dam, which is shared by Brazil and Paraguay. The project's leaders stress that this amount of energy will replace 40–50 million tons (36–45 million metric tons) of coal each year. Three Gorges Dam provides an example of the environmental questions, both troubling and hopeful, raised by massive dams.

Rivers and streams are general terms for bodies of flowing water: rivers are larger and usually empty into an ocean, bay, or large lake; streams are smaller and empty into larger streams, rivers, and seashores. The following four types of rivers or streams make up riparian habitat:

- perennial (or permanent) rivers/streams—flow year-round
- intermittent rivers/streams—flow only in certain seasons, after storms, or when snow melts
- ephemeral rivers/streams—flow for short periods of time in rainy seasons, but hold shape year-round
- interrupted rivers/streams—flow aboveground in some places and belowground in others

Riparian habitat contains only a one-way flow of freshwater—downhill—and with the capacity to transport sediment and reshape the land. Therefore, ecosystems at the low-volume head of a river—even the Mississippi River starts as a stream—differ greatly from the ecosystems in a large tributary a few miles from the sea.

The ecosystems in large slow-moving rivers resemble lake ecosystems. Phytoplankton, tiny invertebrate plant life, dominates the open waters and captures the Sun's energy by photosynthesis. River food chains build upon the single-celled phytoplankton, with larger invertebrates, fish, and predator fish toward the top of the food chain. As water flows faster, phytoplankton density falls, and the water becomes clearer. Phytoplankton may build up, however, in swirling pools carved from the riverbank by fast-flowing rivers or produced by rocks. These areas of choppy water called riffles provide young fish with a safe place to hide from predators and to eat. When the fish grow large enough, they leave the riffles and spend the rest of their time in the main body of water.

Some large rivers contain extensive wetlands that provide safety for fish spawning and for waterfowl to hatch eggs and raise their young. These areas, called backwaters, also provide the normal benefits of wetlands: cleaning water of pollution; removing silt; providing specialized habitat; and controlling floodwaters.

Streambeds contain a mixture of organic (phytoplankton, *zooplankton,* insects, worms) and inorganic (sediment, rocks, insoluble minerals) nutrients. Faster-flowing streambeds contain less of these nutrients than

slow-flowing streambeds, but because streams are shallow, terrestrial creatures make use of them as well as aquatic life. Rocks in streams also contain slippery sheets of biofilm that hold a mixture of organic and inorganic matter captured from the flowing water.

Streams also house an assortment of insects, insect larvae, and nymph forms, and invertebrates that transfer energy from plant life to a form usable by predators. Leeches, worms, mollusks, and crustaceans make up the next level in the riparian food chain. These lower levels of the food chain nourish fish, large insects, reptiles, amphibians, and birds. Waterfowl, rabbits, and rodents eat aquatic grasses and plants along the stream's banks. The riparian ecosystem contains the varied components that characterize healthy ecosystems, while it harbors changing conditions affected by heavy rainfalls, flooding, and droughts.

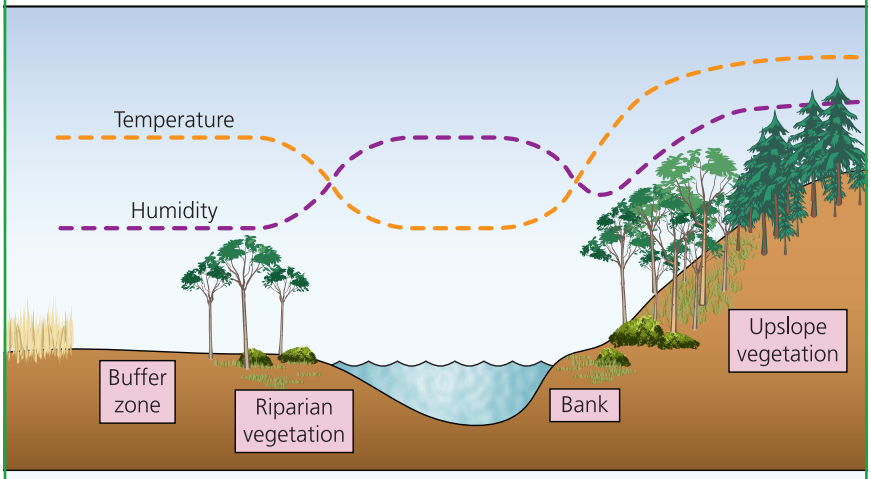
VALUE OF RIPARIAN ECOSYSTEMS

Riparian areas hold rich biodiversity and their food webs can become quite complex. In addition to providing habitat, shelter, food, and water for the animals of riparian ecosystems, these systems also provide general benefits to the environment.

Riparian areas possess moist soil rich in organic matter replenished by periodic flooding. Unique physical features provide habitat for some biota that live nowhere else but along streams and rivers, some for their entire lives. Other species use riparian areas only at certain times of the day, in particular seasons, or in specific stages of their life cycle. Songbirds, for example, come and go, but they depend on riparian areas, perhaps because songbirds do not possess exceptional hunting skills and the density of plant and insect life along streams suits them. Many owls also station themselves in riparian areas for hunting nocturnal animals seeking water. Any predator gains an advantage by hunting in a locale where food comes to them rather than expending energy to find and stalk prey.

Riparian ecosystems also affect the neighboring land, especially in flat open countryside where vegetation next to the water offers an oasis from heat and a refuge from winter winds. The unique physical features of riparian areas create a microenvironment, a defined place that has its own climate. Riparian areas occur in low-lying places so they hold moisture and humidity longer than open spaces. The high moisture and

Riparian Habitat



Riparian habitats create unique microclimates, meaning they have temperature, humidity, and other weather characteristics distinct from the larger surroundings. Riparian habitats aid the environment by modulating local weather and creating a unique habitat for species. Many plant and animal species live almost exclusively in riparian habitats.

shady conditions help these areas reduce extremes in temperature and humidity, partially explaining why many species use riparian habitat to raise offspring. The moisture and shade also moderates air temperature in the riparian area. Taken together, riparian areas offer stability in climate, temperature, plant life, and animal life. It is no wonder that animals living in sparse, arid conditions—on the plains or on the savanna, for instance—probably view riparian habitat as an important means of sustenance.

Humans have encroached to the very edge of many urban rivers and streams so that these ecosystems have been severely altered. Even regions with fewer people put pressure on the species that live only in riparian habitat. Livestock ranchers value riparian areas for watering their herds, which ruins the bank. From the 1700s through the 1800s, timber companies used fast-flowing streams to carry logs down mountains to sawmills, and farmers have used them as an easy source of irrigation water and good soil for crops.

Even wild animals in arid regions can in time damage stream sides and riverbanks. Riparian habitats in Africa, for example, serve as places where elephants, rhinoceroses, and herds of hoofed animals come in to drink. These large animals need water, but as they visit the same sites by day or by night they do significant damage to the habitat.

PASSIVE RESTORATION OF RIPARIAN HABITAT

Restoration ecology is the process of assisting the recovery of a damaged or destroyed ecosystem. In the best circumstances, restoration teams try to make as few changes to the area as possible and allow nature to slowly regain its former vitality. This hands-off approach is called *passive restoration,* which is the elimination or reduction of anything that degrades an ecosystem and then giving the ecosystem time to recover on its own.

Passive restoration of riparian areas returns water flow to its natural path; the more a stream meanders, the more diverse its habitats. Restoration teams allow time for native vegetation to establish and grow, and then they watch and wait for animal life to reestablish complex food webs. Natural processes can restore even badly damaged riparian areas, but scientists must make a choice of how much or how little help to give the natural unfolding of an ecosystem. For instance, passive restoration may involve removing invasive plants, or it may require the removal of a predator until prey populations rebound. Some passive restorations include the reintroduction of a native species to help other parts of the ecosystem to arise naturally.

Severely damaged riparian habitat that has retained a small amount of soil and vegetation may require extra actions: planting native seedlings; enriching depleted soil with nutrients; and removing solid wastes such as garbage, camping and fishing wastes, and any dumped materials. Some passive restorations require nothing more than returning a manicured lawn to a more natural state (See the sidebar "Lawns, Turfgrass, and Erosion"). Workers try to avoid removing native plants, but may need to fertilize or mulch to aid in their revival. In any restoration project, therefore, planning the activities that suit the site always gives the best results. After natural restoration has taken hold, biologists monitor the site to assure the damage does not return.

Both passive and active restoration benefits from buffer zones between the riparian habitat and the adjacent land that may contain livestock, crops, or houses. Buffer zones protect riparian habitats by reducing the chances of pollutant-carrying runoff reaching the water. They also prevent the habitat from acting as floodplain and catching erosion, and reduce human disturbances to wildlife.

Lawns, Turfgrass, and Erosion

Most grasses used for decades in residential lawns were nonnative species selected for the level of care they required and their growing season. The 48 contiguous United States contains three general grass season zones: the warm-season zone from southern Arizona to Florida, extending north into North Carolina; the transition zone from southern California to Virginia, offering climates that shift from predominantly warm to cool temperatures; and the cool-season zone from the Pacific Northwest to New England. These zones contain more specific regions inside each of them. Lawn care specialists mix seeds from a variety of grasses to achieve the healthiest-looking and greenest lawn possible for these growing season zones.

A lawn is any land planted with grass and used mainly for recreation and appearance. The grasses used for durable lawns consist of turfgrasses, which are grass varieties that grow dense leaf blades, strong roots, and stand up well to regular mowing. In the United States, several turfgrasses predominate in the three season zones, as follows:

- **warm-season zone:** bluegrass, Bahia grass, carpet grass, centipede grass, hybrid Bermuda grass, Kikuyu grass, Saint Augustine grass
- **transitional zone:** annual ryegrass, Bermuda grass, fine fescue, rough bluegrass, seashore paspalum, tall fescue
- **cool-season zone:** buffalo grass, Kentucky bluegrass, orchard grass, perennial ryegrass, zoysia grass

(Colonial bent grass, creeping bent grass, quack grass make up the remainder of the turfgrass species, but these do not usually work well in lawns.)

Conventional lawns enhance the appearance of homes and office buildings, but they cause the following concerns: (1) They are not part of the natural vegetation so they alter the natural populations of insects, birds, and mammals; (2) they require mowing, which uses fuel and emits air pollutants; (3) they produce large amounts of yard waste; (4) lawns use large amounts of water;

ACTIVE RESTORATION OF RIPARIAN HABITAT

Riparian habitat that has been completely denuded of vegetation requires a restoration approach called *active restoration*. Active restoration has been chosen in two particular situations: (1) for habitats that have received

and (5) chemical fertilizers and pesticides often are applied to lawns, which pollute runoff. Lawns also exert two opposite effects on erosion. Established lawns with good root systems hold soil in place, but newly seeded lawns erode easily. Gardeners often cover newly seeded lawns with netting to reduce wind erosion, but rain runoff can still carry away topsoil.

Sustainable gardening involves the use of natural vegetation instead of manicured lawns. Natural lawns and natural meadows consist of plants native to the local area that provide the same ground cover as turfgrass. Natural lawns and meadows tolerate periodic dry periods because they are native to the climate. They also require less watering, benefit from natural pest control, do not need mowing, and contribute to natural ecosystems. Natural lawns and meadows also produce flowers and shade and can act as windbreaks.

In addition to planting native species as lawn cover, the following activities are part of sustainable lawn management:

- early-morning watering to reduce evaporation loss
- watering less frequently than conventional lawns
- leaving clippings on the ground as mulch
- no more than twice-a-year fertilization with slow-release organic fertilizer
- substituting corn gluten for chemical herbicides to kill weeds
- adding fallen leaves to a compost pile rather than raking and adding to trash
- learning from weeds: dandelion growth indicates alkaline soils that need sulfur fertilization; clover indicates soils that need nitrogen fertilization

In lawn management, perhaps the hardest challenge comes from convincing homeowners that a uniform green lawn does not look appealing in nature's eyes. High-maintenance grass lawns represent unhealthy ecosystems, possible chemical pollution, water waste, and often damage to riparian systems.

Healthy lawns prevent soil erosion into nearby riparian areas, but lawns that receive large amounts of chemical pesticides and fertilizers can potentially pollute riparian habitats. Environmentally responsible lawn care should therefore stress nonchemical means of pest control and fertilization. *(LawnOrder)*

channelization (rivers that have been straightened, deepened, had natural rock formations removed, or had banks paved with concrete), or (2) habitats that must be restored faster than passive methods allow.

Active restoration begins with the removal of manmade structures such as paved banks, boat launches, piers, boardwalks, and docks. In a few instances boardwalks that have been built off the ground can remain in the area to be restored and may serve as part of a nature trail. The next step involves planting vegetation native to the riparian area with the primary purpose of attracting native wildlife. If possible, a stream should be returned to its original shape, a step usually based on old photographs of the site. Returning stream shape, depth, and flow helps riparian com-

munities reestablish themselves, and creates pools and riffles needed by aquatic species.

Some stream restorations have been aided by reintroducing beavers, which restructure streams according to nature. Beaver dams regulate flow speed, control erosion, and release sediment in a way that restores the streambed and replenishes soils along the banks. The combination of beaver reintroduction and restriction of livestock from rural riparian areas allows riparian willows and other native vegetation to return to natural conditions in about three years.

Extensive restorations of badly damaged ecosystems need more work than simply reintroducing plants and animals. Florida's Kissimmee River restoration provides one such example. *Kissimmee* is a Calusa Indian word for "long water," aptly named since the original river flowed more than 100 miles (161 km) from Lake Kissimmee near Orlando, through thousands of acres of wetlands, and into Lake Okeechobee in southern Florida. In the 1800s farmers began drying out the wetlands for agriculture, and the river endured years of dredging for boat access and irrigation water. Then between 1961 and 1971, engineers turned the stretch between the two lakes from a 103-mile (166 km) river to a 56-mile (90 km), 30-foot (9 m) deep straight channel in order to prevent flooding. The restructuring drained two-thirds of the Kissimmee's floodplain—it successfully stopped flooding—and caused a dramatic decrease in the waterfowl and wading birds that used the area for wintering. Almost before the project had been completed, plans began for bringing the river back to its original condition. The restoration that began in the 1990s consisted of the following five steps:

1. survey the river's original course
2. backfill 7.5 miles (12 km) of the flood-control canal with sediments from adjacent lands, which were once part of the riparian area
3. force water flow through the remaining waterways about 15 miles (24 km), that had not flowed for more than 30 years
4. remove two dams and one lock
5. monitor water quality and natural return of native vegetation and wildlife

Severely damaged areas like the Kissimmee will likely never return to their original state, but they can reach a condition that supports almost the entire original ecosystem. Dennis Duke of the U.S. Army Corps of Engineers' Jacksonville, Florida, district said in 2007, "The effects of the backfilling have been incredible, with the return of wildlife species. This restoration will reduce peak flows and allow vegetation to soak up nutrients, yielding cleaner water in Lake Okeechobee." This Florida project shows that even very large instances of riparian destruction can be improved upon with aggressive active restoration. "In terms of sheer geographic size and the number of species that this project benefits," Duke said, "Kissimmee River restoration is among the largest ecosystem restoration projects in the world." As environmental scientists tackle more restoration projects, they will learn additional techniques for inviting nature back to riparian habitats.

WETLANDS RESTORATION

Until the 1970s most people in the United States did not have a clear understanding of wetland ecosystems and the benefit wetlands give to the environment. Wetlands were thought of as swamps, places containing dangerous animals, poisonous plants, and the source of disease. Of the 215 million acres (870,000 km^2) of wetlands present when European settlers first arrived, less than 50 percent remain. They have been dredged for use as marinas and ports, altered with dikes to control flooding, or filled in to create land for development. In 1992 scientists at the National Research Council developed a restoration plan for the nation's wetlands with the idea of restoring 100,000 acres (405 km^2) of wetlands a year for the next 10 years. Much progress has occurred, but in the United States as in other parts of the world, wetlands have become one of the most threatened habitats on Earth.

Wetlands vary in location and the type of habitat they provide, described briefly in the table on the next page. Each classification of wetlands receives a different restoration plan.

Wetland restoration takes four forms: creation, restoration, enhancement, or mitigation. Creation activities convert a non-wetland area into a wetland that never before existed there. People usually create such wetlands to carry out a specific objective. For example, sustainable houses that treat their own liquid wastes use created wetlands, also called *constructed wet-*

lands, to serve as a partial wastewater purification system. Restoration means returning a degraded wetland to as close to its original condition as possible. Restoration includes many of the same activities as the riparian restoration of

Types of Wetlands

Classified by Plant Type	Plants
freshwater marsh	grasses, sedge, herbs
tidal salt and brackish marsh	salt-tolerant grasses and rushes
prairie potholes	grasses, sedge, herbs
fens	sedges, grasses, shrubs
bogs	moss, shrubs, trees
swamp bottomland	cypress, gum, red maple
mangrove forest	black, red, and white mangroves
Classified by Environment	**Environment**
marine	open ocean on continental shelf; intertidal areas, reefs, rocky shores
estuarine	deep tidal areas enclosed by some land; subtidal and intertidal wetlands, forested wetlands, rocky bottom
riverine	rivers and streams
lacustrine	deepwater habitat in land depression or behind dam; lakes with permanent vegetation and at least an area of 20 acres (0.08 km^2)
palustrine	nontidal areas dominated by trees, shrubs, and permanent vegetation; ponds, bogs, prairie potholes

CASE STUDY: THE WORLD'S BARRIER ISLANDS

Barrier islands consist of low, sandy and narrow islands situated several hundred yards to a few miles off ocean coastlines, and influenced by waves, currents, and tides. Barrier islands, also called barrier reefs, serve two important functions in ecology: (1) They protect the mainland from storm damage, and (2) they develop unique habitats for plant and animal life. These islands have been difficult to develop because they shift position and shape with each violent storm, yet people have found ways to build hotels and houses on the widest and most stable barrier islands even though these are very fragile places.

The barrier islands off the U.S. East Coast may have developed about 18,000 years ago with the decline of the last ice age. As glaciers melted during this period, sea levels rose and flooded low-lying areas behind the natural ridges that wave activity built. Waves washed into the areas behind these ridges, and eventually the bay or the sound behind the island acquired tides. Each tide moved sediments and brought in nutrients for the development of hundreds of ecosystems. In a period from about the late 1800s to today, people built seasonal fishing villages, then vacation bungalows, and then permanent homes on the barrier islands. As a consequence, long strips of the islands lost the capacity to perform their functions as mainland protectors and as independent ecosystems. Not only were barrier island ecosystems in peril, but altered islands affected how tides reached wetlands and estuaries on the mainland.

Barrier islands have been prime areas for development, as shown in this photo of North Carolina's Wrightsville Beach to the north of protected Carolina Beach. Undeveloped barrier islands serve the environment by absorbing strong tides in storms, protecting sensitive wetland ecosystems, and providing dune and marsh habitats. *(Shore birdworld.org)*

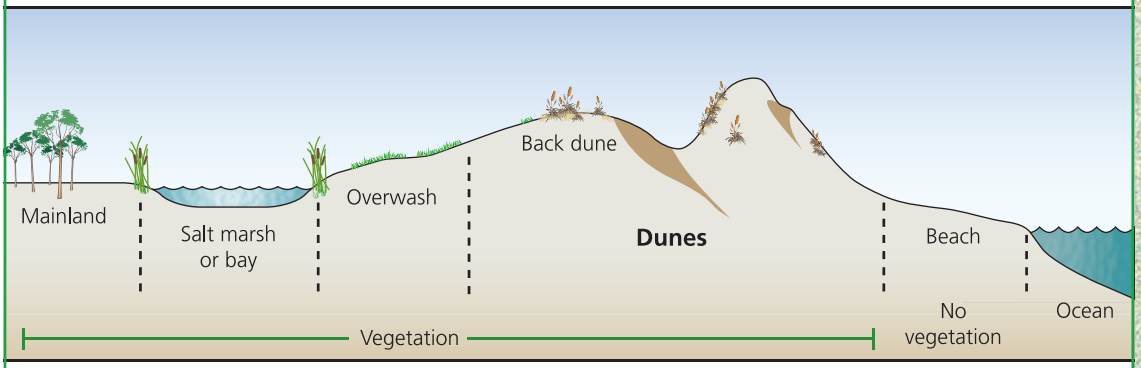
The complexity of barrier island ecosystems is not yet completely understood in marine biology. Most islands contain a basic structure beginning at the ocean's beach, across multiple rows

of dunes, and to a salt marsh, a type of wetland fed by seawater. Each of these sections contains its own unique habitat. The beach habitat contains plants and animals that live in freshwater-parched conditions but receive regular dousing by salt water. Very few plants live in the beach habitat; animals that live there permanently usually consist of insects, worms, invertebrates, crustaceans, and mollusks. But even the beach habitat can be divided into smaller habitats: rocks, cliffs, the tidal zone, and the intertidal zone. The dune habitat contains subcategories depending on the amount of wind it receives off the ocean. Dunes collect some rainwater to provide a small freshwater supply, but in general the dunes are a salty, sandy place. Area behind dunes range from open marshes to forests called *maritime forests*. All of these places represent microhabitats.

Development upsets the normal behavior of barrier islands in four main ways. First, buildings anchor sand and soil that would naturally move in response to wind, rain, and storms. The natural turning over and renewal of the islands therefore never takes place once development has stabilized them. Second, tall oceanfront hotels create shade over the beach, dunes, and marsh, affecting the natural rhythms of plant and animal life. Third, oceanfront development often includes jetties, which jut out into the ocean several hundred feet to make beaches gentler and to protect inlets from sediments. Over time, however, ocean sand builds up on the incoming side of the jetty and erodes from the reverse side of the jetty. The erosion undercuts the land so that the ocean creeps closer to the buildings each year. Fourth, islands not allowed to shift with the storms begin to take the brunt of each storm; ocean water flows completely over sections of barrier islands almost every year, an event called *overwash* (also washover). Barrier islands hampered by development are more vulnerable to destruction than undeveloped islands.

The best conservation method for barrier islands would be the removal of all manmade structures. Geologist Laura Moore of Oberlin College in Ohio explained to Reuters news agency in 2006, "If we prevent barrier islands from migrating, we will then prevent them from moving to higher elevations and they will eventually perhaps be more prone to catastrophic failure. If the sea level rises too fast there may be little we can do in the very long term to prevent failure from occurring." It is unrealistic to expect the buildings to disappear, but barrier islands would be helped by halting all further construction on them. These islands can then nourish their ecosystems if allowed to shift with the tides and winds as they have for thousands of years.

Barrier Islands



Barrier islands appear to be mostly barren strips of sand with little life other than gulls and crabs. On the contrary, barrier island ecosystems abound with life from tiny invertebrates that act as the foundation of food chains to predator and scavenger birds and mammals at the top of food chains. The barrier islands have become some of the most threatened of all ecosystems.

rivers and streams, but in this case, restoration requires flooding an area that will hold the water or will permit water to flow very slowly. Enhancement involves adding to the natural functions of a wetland. Flooding a wetland, for instance, may help reestablish endangered fish species. Lastly, mitigation resembles passive restoration used on riparian habitats. Mitigation sets up a program that reduces things known to harm a wetland. A fence built around a wetland acts as a type of mitigation by keeping people and dogs out while allowing time for mammals, birds, reptiles, or amphibians to recover.

Like riparian habitat, some wetlands are irreversibly damaged as a direct or indirect consequence of human activity. Wetlands near coasts, for example, disappear due to rising sea levels, which is an effect of global warming. Global warming contributes to a faster-than-normal cycle of glacier and snowpack melt; the continued melting is causing sea levels to rise. (See the case study "The World's Barrier Islands" on page 140 for more about threats of rising sea levels.) Marine biologist Mark Schexnayder of Louisiana State University described the situation in his state, where about 1.5 acres (0.006 km^2) of wetland disappear every 35 minutes: "Down here when we speak of wetlands loss, it's actual, physical loss. You can't stand on [the land] anymore. It's gone." Only active restoration has any chance of saving these wetlands and in many cases it is already too late.

CONCLUSION

Riparian habitats are those located in the immediate region of rivers and streams or lakes. The habitat consists of plants, animals, and microbes that live at the interface of dry land (a riverbank, for example) and flowing water. Riparian habitats across the world have been badly damaged by people in various ways: pollution, construction or channelization, draining, or damming. All of these activities upset natural riparian ecosystems, but they also affect the life upstream and downstream. Wetlands and barrier islands have received similar damage from human activities. Each of these environments requires a different level of restoration to return it to its original form and to once again support natural ecosystems.

Though riparian habitats make important contributions to the environment, many of them have degraded to a point in which they will never be restored to their original form, especially in cities. Two approaches to restoration can be used on other riparian habitats that can and should be restored. Passive restoration consists of minimal activities that allow a riparian area to reestablish on its own. Active restoration consists of activities that rebuild the riparian area. These activities may involve dam removal, concrete barrier and wall removal, native seedlings replanting, and reintroduction of native species.

The reality of riparian habitats, wetlands, and barrier islands is that these places will never be allowed to return to completely natural condition. Riparian habitat around which cities have grown have already been lost, as have wetlands that were filled in years ago for new housing developments. The protection and the restoration of places where water meets land can be difficult because these are also places where people like to congregate. Large rivers serve the world over as major routes for shipping. Human populations along waterways will not disappear; they will likely grow larger. Some riparian habitats away from population centers can be restored to almost their original condition, and this work has already begun. Other riverside or coastal areas can be protected only by stopping all new construction on them. Although this may be an ecologist's wish, most people will probably be unwilling to give up places that have long been available to them for recreation and other uses. The future of these habitats may be bleak unless governments and the public make a dedicated effort to save the remaining waterside habitats.

Reducing Wood Waste

Strong wood has carried people since the earliest human ancestors. Ancient huts and canoes made use of wood's strength, durability, and ability to repel water. Only in the 1950s and 1960s did metal and plastics become more popular than wood for common household items. Today wood remains the favorite building material for house frames, wooden decking, stairs, and furniture. All of these items put a strain on the world's timber supplies.

Timber cut from forests come from various tree species. Some of these trees are abundant, but others are vulnerable to extinction, endangered, or critically endangered. Each of these classifications describes the likelihood of the species going extinct because of reduced habitat or few numbers of individuals. The environmental group Friends of the Earth monitors the status of the major timber types in use today and publishes updates on endangered species.

Wood products come through a multistep process from forest to retail store. After cutting timber in the forest, workers load the logs onto trucks that transport them to a mill. The mill debarks the logs and cuts them into set lengths in a step called bucking. A sawyer then uses a large *headrig* saw to cut the wood into a variety of thicknesses and widths to make the most efficient use of the entire log. Small diameter logs produce about 13 pieces of lumber; larger diameter logs produce up to 45 pieces of lumber. Some lumber types require a heating step called seasoning in which the wood bakes at 110–180°F (44–82°C) to drive out moisture. Other woods need only air-drying to do the same thing. The pieces of lumber then enter a machine called a planer that cuts the lumber to its final dimensions and smoothes the edges. A quality inspector places a

grade on each batch of lumber based on the number of defects in the wood. The mill bundles the lumber and then trucks take the bundles to lumberyards for sale.

Despite efforts to reduce wood waste, the timber industry produces waste from every tree it cuts down. Prime timber comes from old trees, but old-growth forests have dwindled as the world's population has grown, so most timber companies now cut second- or third-generation trees at a younger age. The wood from these trees offers less durability than prime timber. The timber industry has solved this problem by taking different trees apart and combining the wood types into one piece of lumber to improve the characteristics of the wood. (Plywood is an example of composite wood in which workers glue planks of wood together.)

The U.S. timber industry rises and falls with the economy. Strong economies encourage construction and furniture purchases, both of which demand lumber; weak economies slow construction and purchasing. International timber markets also affect timber supply and demand. Forests in Borneo, shown here, have been dramatically threatened by legal and illegal logging to provide inexpensive raw materials for furniture and other wood products sold in Asia, the United Kingdom, and the United States. *(Real Adventures)*

These composite woods have helped the timber industry conserve forests. Though wood is a renewable natural resource, many trees require 100 to 300 years to reach maturity. This long time frame makes timber seem as if it is a nonrenewable resource, and in fact, sustainable wood production views timber as a nonrenewable natural resource.

This chapter examines technologies for conserving natural wood or replacing wood altogether. The chapter opens with a review of today's timber industry and explores the options available for this industry's future. The main topics stressed in this chapter are sustainable wood production and use, wood alternatives, and renewable wood resources.

THE TIMBER INDUSTRY

The global timber industry has been affected by factors that have changed the way it does business and also how other industries do business: globalization, poverty, and climate change. Almost every strategic plan in industry must take these three factors into account. In the 1980s, prior to large-scale globalization, timber served a national market; only specialty woods and rare woods were imported into the United States. Today wood products trade on international markets like many other commodities. Poverty has also affected the timber industry because subsistence farming encroaches into the forest, especially in tropical forests. Trees in these areas are usually used for heating and cooking or are cut to clear land for cultivation. Climate change also relates to the world's timber supply. Forests help reduce global carbon dioxide levels, but fewer trees mean less carbon dioxide can be captured from the atmosphere, which accelerates global warming. In addition, slash-and-burn harvesting methods put more carbon dioxide into the air as the wood burns, also adding to the atmosphere's greenhouse gases.

The United Nations Food and Agriculture Organization (FAO) in 2007 listed the current trends in the global forestry industry and its projections for the future:

- Deforestation will continue in developing regions for the near future.
- In tropical countries, subsistence farming and commercial agriculture might increase.

- Deforestation has slowed, and forests might expand in North America, Europe, and industrialized parts of Asia and the Pacific.
- Climate change will increase the incidence and severity of forest fires, and pest and disease infestation.
- Increased interest in biofuel may cause expansion of some forests and faster degradation of others.
- Biotechnology and materials technology in wood science will play a larger role in conservation.
- In many developing countries, wood will remain the primary source of energy.

In the future the timber industry will likely become tied to trends in fossil fuels. A shift away from fossil fuels and toward biofuels may put forests in jeopardy because farmers will want increased cropland to grow biofuel crops. Fortunately, many people now understand the value of forests and have supported the protection of forests. The sidebar "Theodore Roosevelt" discusses how the forest conservation movement grew in the United States to where it is today.

PAPER

About half of the wood harvested globally goes to industrial products and the other half is used for heating and fuel. The majority of timber harvested for industry becomes primary wood products (such as lumber), secondary wood products (furniture), primary paper products (sheet paper), and secondary paper products (books). Primary paper products account for 34 percent of the value of wood products sold today; primary wood products account for 21 percent, and the rest consists of secondary products. The paper products industry therefore dominates the final destination of timber harvested for nonfuel, nonheating purposes each year.

Wood pulp, or simply *pulp,* is the fibrous raw material removed from wood for use in papermaking. Harvested pulpwood usually consists of softwoods such as spruce, pine, and fir. Pulp contains strong fibers called lignin wrapped through more flexible fibers called cellulose. Pulp mills mechanically or chemically degrade much of the lignin to release the cellulose needed for papermaking. The pulp and papermaking process results

Theodore Roosevelt

Theodore Roosevelt, the 26th president of the United States, was one of the country's earliest influential conservationists. During Roosevelt's two terms in office (1901–09), he made conservation of natural resources a national goal and created the first programs in which government would take charge of conservation. Before Roosevelt, private landowners made their own decisions on how best to use or to conserve the natural resources on their property.

Roosevelt ushered in a new approach to running the country he called the Square Deal. Conservation made up one of four initiatives that Roosevelt planned on stressing during his administration. In addition to conservation of natural resources, the Square Deal called for national emphasis on national social problems, the need for regulating big business, and greater control over railroads.

A milestone in conservation policy highlights each of Roosevelt's terms in office. In his first term he acted under the Forest Reserve Act of 1891 to put 125 million acres (0.5 km^2) of western timberland and 85 million acres (0.3 km^2) of Alaskan forest under federal protection as national forests. In Roosevelt's second term he gathered scientists, university presidents, business leaders, and elected officials to develop policies for long-term protection of natural resources. This gathering gave birth to the National Conservation Commission, which prepared the nation's first inventory of natural resources in four categories: water, land, forests, and minerals. Roosevelt eventually created six study commissions for the purpose of designing conservation plans for rangeland, rivers, rural communities, state conservation efforts, federal land management, and land reclamation. Roosevelt made the astute decision to fill these posts only with volunteers who had little connection to big industries that coveted natural resources.

in thin, high-cellulose sheets of paper used for writing and printing. *Paperboard*—commonly known as cardboard—represents the industry's third major product. Paperboard is a thick (0.01 inch; 0.025 cm), strong material used in making boxes and packaging. The term for the layered construction of cardboard boxes is *corrugated fiberboard*.

The advent of computers had been expected to transform the world into a "paperless society," but even though computer use has grown since the 1980s, the World Rainforest Movement has estimated that paper use has continued to rise ever since the 1960s. Today advertising (catalogs, junk mail, newspaper inserts) and product packaging account for two-

Under Theodore Roosevelt's guidance, new National Park, National Forest, preserves, or federal reservations totaled an astounding 230 million acres (931,000 km^2), or 84,000 acres (340 km^2) for each day he served in office. Theodore Roosevelt told the 1909 North American Conservation Conference, "It is evident that natural resources are not limited by the boundary lines which separate nations, and that the need for conserving them upon this continent is as wide as the area upon which they exist." Environmentalists and a portion of the general public now view wilderness as Roosevelt viewed it: Each large expanse of undisturbed land is considered first for protection before measuring its commercial value. U.S. citizens can then communicate their hopes for a new protected status to their representatives, who carry the message to leaders in the nation's capital. These actions were all made possible by Roosevelt's vision for wilderness protections.

John Muir and President Theodore Roosevelt shared an understanding of the value of forests as a tangible home for wildlife and habitat for various plant life. They also appreciated the intangible benefits of forests: beauty, nature, solitude, and a sense of humanity's place in the universe. *(Library of Congress Prints and Photographs Division)*

thirds of paper consumption; writing and printing account for only one-third. In industrialized countries, average paper use has dropped since 2000 from 531 to about 500 pounds (241–228 kg) per person per year, but the United States continues to consume as much as 655 pounds (297 kg) per year, and Finland uses an extraordinary 714 pounds (324 kg) per year. Worldwide, each person uses about 120 pounds (54 kg) of paper per year. People certainly do not live in a paperless society.

Though total paper consumption is declining, industrialized countries consume above-average amounts of paper and waste quite a bit of it. Technology may be partly to blame for this waste. The convenience offered by

companies in providing free use of copiers, scanners, and printers encourages people to print long reports and e-mails that do not require archiving because they are already stored in electronic form. Paper now composes 35 percent of municipal solid waste and barely half of used paper gets recycled. The paper industry therefore has two responsibilities to promote sustainable paper use: (1) more paper recycling and (2) paper made from nontree sources.

Wood did not come into prominence as a paper source until the 1850s, when Friedrich Keller invented a grinding method that liberated fibers from wet wood. Before then, linen, straw, and hemp supplied paper production. The idea of tree-free papermaking is therefore not new, and now seems a good time to reinvestigate this technology.

Tree-free fibers for papermaking come from two sources: agricultural residues and paper crops. Agricultural residues (also called *bagasse*) comprise the husks and stalks left over after crops such as barley, oat, wheat, rye, rice, and sugar have been harvested. Paper crops comprise fast-growing plants that produce fairly strong fibers such as hemp plants, flax, and kenaf. The U.S. Department of Agriculture (USDA) first studied kenaf as an alternative paper source during World War II in the 1940s when natural resources were at a premium. Kenaf is a plant in the Malvaceae family, as are cotton and okra, and which offers the following advantages in paper production:

- rapid growth: kenaf reaches 12–18 feet (3.6–5.5 m) in 150 days compared with the common pulpwood southern pine, which takes 14–17 years
- high yield: kenaf produces 5–10 tons (4.5–9.0 metric tons) of fiber per acre (0.004 km^2); three to five times more than southern pine
- easy paper production: kenaf contains less lignin than pine, 9 percent vs. 29 percent, respectively

Kenaf costs more than tree-produced paper, but the costs of any item tend to decrease quickly when the item is produced in large quantities, a phenomenon called *economies of scale.*

Tom Rymsza, director of the American Kenaf Society, told the Conservatree organization, based in San Francisco, California, "Buying kenaf paper is not about saving a buck; it's about saving a planet. Trees don't grow

fast enough." Additional types of tree-free paper might also soon come from wild grasses, bamboo, and waste from cotton textile production.

SUSTAINABLE WOOD PRODUCTION

The world's forests supply an insatiable desire for wood that can be alleviated somewhat by sustainable forest management. In the mid-2000s total world paper and pulp consumption approached 388,000 tons (352,000 metric tons), roundwood harvests totaled 1,815,000 tons (1,647,000 metric tons), and fuel wood totaled 1,838,000 tons (1,767,000 metric tons). Sustainable forestry and wood production can slow this consumption.

Sustainable wood production involves three main focus areas: (1) harvesting trees no faster than they can replenish; (2) protecting old growth; and (3) reducing forest vulnerability by finding wood alternatives. The Scientific Certification Systems run by the Forest Stewardship Council (FSC) has since 1993 graded wood producers on their level of meeting sustainable practices to make their product. To certify that a forest product was made in a sustainable manner, FSC inspectors visit the production site and look for the following practices:

Logging is one of the oldest industries in the United States. These loggers worked for the Mendocino Lumber Company in California in the 1870s. *(Mendocino Historical Society)*

- Tree harvesting rates do not exceed the forest's regeneration rate.
- Harvesting maintains the natural forest ecosystems of plants and wildlife.
- Operations protect rare, threatened, and endangered species.
- Tree plantations do not replace natural forests.
- Tree plantations occupy only agricultural or pasturelands.
- Harvesting maintains conservation zones or buffer zones around the forest.
- Chemical use is minimized or eliminated.
- Logging companies protect riparian areas from erosion runoff.
- Workers, communities, and indigenous tribes benefit from the operations.

Additional actions that contribute to sustainable wood production are: growing timber on long rotations to replenish trees; no clear-cutting, protection of seedlings and planting new seedlings, or shelterwood cutting on steep slopes to prevent erosion; use of selective harvesting; no fragmentation of forests to maintain habitats; leaving dead trees and fallen timber for habitat and soil replenishment; reducing road-building into uncut forests to prevent habitat fragmentation; and conserving soil and water. Tree plantations contribute to forest conservation as well, though they require special management to protect ecosystems. These issues are detailed in the "Tree Nurseries" sidebar.

WOOD ALTERNATIVES

Wood alternatives are any nonwood materials that substitute for wood in the making of traditionally wooden products. Materials that serve as wood alternatives come from either biological sources or are synthesized. Most construction materials remain entirely or partially wood-based, but products made of wood alternatives are gaining wider acceptance. Sustainable wood products can also be thought of as a wood alternative because, though they contain wood, their manufacture does not result from the large-scale destruction of forests.

Tree Nurseries

Tree plantations grow the same type of tree, all at the same age, for selling. These plantations or farms contain tree monocultures in which all of the vegetation is of one or two species. Monocultures support very little biodiversity because they lack the complexity needed to build food webs, but tree plantations can support sustainable forestry if properly managed. Today's tree plantations supply the following tree-based products: pulpwood, hardwood, Christmas trees, fruit, nuts, maple syrup, flowers, rubber, firewood, ornamental trees, and shade trees. Most of these products start out in either commercial nurseries or research-based nurseries.

Commercial nurseries produce trees that can earn a profit. Nurseries can be either indoor or outdoor facilities that nurture immature trees from seedlings. Workers monitor the seedlings' growth to assure that the young trees do not become infested with pests or disease and remove any weak or infected trees. Some specialized nurseries raise trees with characteristics desired by farmers and horticulturists. Immature trees grown indoors must be replanted outside to allow them to mature. At harvesting time, workers clear-cut the plantation's stand of trees that have all reached the same maturity and size. They then reseed the nursery to begin a new monoculture.

Setting up tree nurseries and plantations support sustainable forestry, but only if the owners follow strict practices. Otherwise these monocultures waste land, destroy habitat, and foster soil degradation. Sustainable tree nurseries and plantations should strive for the following:

- use only land that is not forested or deforested
- employ soil and water conservation with ground cover plants
- plant native shrubs, flowers, or trees on the perimeter to encourage native wildlife
- use organic fertilizers and chemicals sparingly or not at all
- avoid fencing to allow natural migration corridors
- maintain riparian habitat in its natural condition

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Sustainable practices cannot undo two disadvantages of tree monoculture: (1) Each cutting contributes to the total carbon dioxide in the atmosphere, and (2) most tree nurseries raise nonnative species, which affect local ecosystems. Fast-growing trees furthermore draw large amounts of water and deplete soil more rapidly than a natural forest that replenishes itself. The World Rainforest Movement is an environmental organization that has published on its Web site pointed opinions on the threat posed by tree monoculture: "Trees—any trees—are presented [by tree farmers] as synonymous to forests, and forests are rightly perceived by most people as good and necessary to humanity. The truth is plantations are simply tree crops aimed at ensuring the future supply of the pulp and paper industry once its traditional resource base—native forests—becomes depleted." Sustainable forestry can nonetheless make good use of monoculture by developing research-based nurseries with a goal of replacing natural forests.

Universities use research-based nurseries to develop tree strains with superior traits that help in repopulating damaged forests. These nurseries contain crossbreeding studies as well as forest biotechnology experiments. The improved trees that come from these studies can be used for restoration projects, replanting logging or mining sites, or natural landscaping. In these ways, nurseries can support sustainable practices in forest management. It is important to note also that these research-oriented nurseries use bioengineering as a means of developing stronger, healthier forests. Environmental groups such as the World Rainforest Movement oppose bioengineering even though they also want to restore forests. Scientists in biotechnology must therefore keep lines of communication open so that people will understand the benefits of bioengineering, express their concerns, and yet allow everyone to find an acceptable way to restore forests.

A popular wood alternative, plastic lumber, contains no wood; it is composed of more than 90 percent plastic with the remainder made up of strengthening materials. Common compositions for plastic lumber products are the following: recycled milk jugs, 93 percent, and fiberglass, 7 per-

cent; recycled low-density polyethylene, 50 percent, and wood fibers, 50 percent; glass-reinforced plastic; plastic-rubber combinations; and plastic-peanut shell combinations. Plastic lumber and similar wood alternatives provide the following advantages over wood lumber: They do not rot so they last longer; they use up solid wastes that otherwise would be incinerated or put in a landfill; and they resist termites and other insects. Plastic lumber manufacturers make their products from recycled plastics by applying heat and pressure to mold the new product into desired shapes. Unlike plastics synthesis, this process minimizes the use of hazardous chemicals and high energy–consuming steps. The following table shows the many current uses of plastic lumber.

Common Uses of Plastic Lumber

Industry	Example Uses
construction	decking, railings, outdoor furniture, roof shingles
civil engineering	retaining walls, sound barriers, walkways, railings
manufacturing	flooring, loading docks, pallets
gardening	fences, pots, compost bins, flower bed borders
agriculture	vine stakes, fencing, gates, animal stalls, feed buckets
parks and recreation	benches, picnic tables, playground equipment, kiosks, wetland walkways, footbridges, decking
transportation	noise barriers, signposts, guardrail supports, speed bumps, railroad ties
marine engineering	piers, pilings, seawalls, docks, bulkheads

Other synthesized materials that play small roles in replacing wood are the following: linoleum, tile, plaster, stucco, or sealed concrete for flooring, and steel for support structures. Biologically derived wood alternatives that have developed a small but growing market are hemp fiber, wheat straw, sunflower hull, and sorghum stalk. Innovative sustainable homes have even used quarried limestone for building materials and roof shingles made of recycled tires.

Wood alternative suppliers must increase the visibility of their products so that consumers will have a wide choice in materials that conserve forests. Wood alternative manufacturers must also assure that their products perform as well if not better than wood, and that the manufacturing process minimizes pollution and waste. In 2002 Jesse Taylor, owner of a deck-building business, assured the *New York Times,* "Right now I'd say that 95 percent of the decking and railing materials we're using are [wood] composites or vinyls . . . because dollar for dollar, it's going to pay over time to have a vinyl or composite system." The only job left is to convince his customers.

RECYCLED AND SCRAP WOOD

Recycled wood consists of wood products that have been recovered from furniture or structures and reused to make other wood products. Some recycled wood also comes from trees that have been cut down for landscaping. Scrap wood consists of the chips and waste that accumulate from logging, milling, and construction.

Furniture makers have turned wood recycling into a small but growing industry, and recyclers or salvagers have responded by finding raw materials in unique places. For example, recyclers recover wood from old furniture, old buildings, demolished bridges, fallen trees, driftwood, and bonfires. Designer William Stranger, who makes furniture from recycled wood, explained his job to the *Los Angeles Times* in 2006: "Adapt to the material that's available." A cottage industry has in fact grown in the last decade that targets old homes that face the wrecking ball. Wood salvagers now work closely with demolition companies to find houses and snatch framing, flooring, and paneling before the demolition. These old woods contain scars and a patina that only aging can render, described by California wood salvager Michael Kuhn as "wood that comes with a great story."

Old wood makes it into only 1 to 3 percent of new homes that are built today, mostly because old wood costs two to three times more than

new wood. Yet for those who are willing to install old woods, the benefits become clear. "With manufactured wood you'll see a pattern after a while," said Anita Howard of the National Wood Flooring Association in 2006. "With the old pieces, no two are alike. I saw a floor that was made entirely out of old wine barrels with the label name wood-burned into it. It's really something you can't find anyplace else." Reusing valuable old woods demonstrates that anyone can create a demand and a market for recycled material.

Logging and construction projects create a large volume of wood waste. Some of this waste goes into the making of flooring, pallets, furniture, small wood products (cutting boards, canes, jewelry boxes, knife handles, musical instruments), wood chips, and wood shavings. *(Recycle Construction and Demolition Debris)*

Old-wood dealers often have a special appreciation of the history of different tree types, and they use this information to make furniture that has a unique background. Much of the history of wood has been preserved by programs that save individual specimens of important trees. This specialty is highlighted in the case study "The National Register of Historic Trees."

Scrap wood often comes in sizes and shapes that do not work in furniture making. Yet scrap wood serves to conserve living trees in the following ways: as fuel for wood-burning stoves; crafts material; and use in composites, which are materials that combine scrap wood with a nonwood material such as plastic. Scrap wood in large quantities also works well as mulch, compost, or landfill cover.

RENEWABLE WOOD RESOURCES

Renewable wood refers to materials that replace the normal woods that have been used for years in construction and furniture. Renewable woods

Case Study: The National Register of Historic Trees

The nonprofit conservation group American Forests has since 1917 managed a program named the National Register of Historic Trees. This registry preserves individual trees or tree stands that have special significance in the United States; 2,000 trees have been listed thus far. The organization also keeps a record of the largest individual tree of each of the 826 species in the United States and provides an online "green calculator" for people to determine how many trees are needed to sustain their fuel, energy, and other natural resource use. The registry stores seedlings from each of its historic trees and anyone can purchase a seedling and plant it in his or her locale.

To add a tree to the list of historic trees, a person or community nominates a tree according to the following criteria:

- The tree grows at or near an important site in U.S. history.
- The tree stands at the home of an important government figure, writer, inventor, philanthropist, or other significant person.
- The tree was planted by an individual or group of national or local significance.
- The tree has been depicted in prose, poetry, song, or art related to a historic event.
- The tree is part of legend or lore.

In 1940 forester Joseph Stearns proclaimed, "Let every tree lover, every forester, every lumberman rally . . . to fight for the preservation of our biggest tree specimens." In that year American Forests and volunteers set out to find the largest and strongest tree representing each of the country's species. Their work resulted in the National Register of Big Trees, a listing that has spurred quite a bit of good-natured competition between big-tree owners across the country.

Interest in special trees helps communities see the value of trees in their urban surroundings. For many years urban centers have been losing their tree cover to new construction, highways,

grow fast and economically, so they have fit well into plans for new green building plans. The main renewable woods in use today are the following: bamboo, cork, palm, eucalyptus, invasive cedar, and oriented strand board.

and road widening, but some cities have begun to reverse this trend by making tree planting or conservation part of any new city development plan.

Many U.S. cities now have teams of so-called *urban foresters* that initiate tree-planting programs among adults and students. Replanting urban centers is not an easy task. "The city sidewalk can be one of the most hostile environments for a young tree," the urban forest researcher Gregory McPherson told the *Washington Post* in 2008. "A virtual conflict zone," added another volunteer. Dore Burry, who leads a tree-planting program in Los Angeles, warned about the places most in need of trees, "These are often the harshest environments, communities on the bad side of environmental justice issues—lots of renters, working class, two-job individuals. Sometimes there has been no organic life on the street for twenty years." Another problem occurs in many inner cities: "They don't have water hoses."

The Angel Oak on John's Island, South Carolina, is about 1,500 years old—the oldest living thing east of the Mississippi River. The tree reaches only 65 feet (20 m) in height, but its limbs stretch to 89 feet (27 m) and the trunk's circumference measures 25.5 feet (7.8 m). *(angeloaktree.org)*

The National Register of Historic Trees makes a modest attempt to increase the awareness of trees that have existed before any living person was born. In its way this organization plays a role in forest conservation.

Bamboo has become the primary choice as a substitute for traditional hardwoods such as oak, pine, spruce, and walnut. Bamboo is durable, hard, strong, and grows quickly. "Environmentally, it's hard to argue with a wood substitute that matures in three years, regenerates without need

for replanting and requires minimal fertilization and pesticides," noted Alex Wilson, editor of *Environmental Building News*. "In fact, the larger species of bamboo have been used in construction for thousands of years in Asia." Bamboo flooring and walls also contain grain patterns similar to conventional woods.

Cork goes into less new construction at present than bamboo, but it is as durable as bamboo, is lightweight and low density, it insulates, and it makes a soft and resilient flooring. Cork consists of bark scraped off cork oak trees native to the Mediterranean region. Harvesting the bark does not harm the tree and the tree replaces the cut section in about nine years.

Salt cedar (also called tamarisk) invades riparian areas and makes soil unsuitable for native plants because it accumulates salt then releases it in high concentration into the earth. Another invasive tree, eucalyptus, comprises about 500 species originating in the Australian continent, as well as New Zealand, Tasmania, and other Pacific islands. Once cut, eucalyptus trees take 14 to 16 years to regrow. This is faster than oak, cherry, maple, and pine.

Oriented strand board (OSB) represents a group of alternative woods called *engineered wood*. OSB consists of a mixture of small pieces of fast-growing aspen poplar, southern yellow pine, and mixed hardwoods. Manufacturers arrange the wood fibers, or strands, in cross-directional layers, and then press the layers together while heating them. OSB forms panels rather than planks and provides strength and durability as support in roofs, floors, and walls.

CONCLUSION

Tree conservation depends on wood conservation, and alternative materials play an important role in managing forests in a sustainable manner. The timber industry has become as efficient as it can in using all the wood it harvests with minimal waste, but forests grow slowly and wood waste is a priority for this industry. A large portion of the wood waste also takes the form of paper waste, compounded by a lack of paper recycling. Sustainable wood production and the use of wood alternatives both play a role in reducing the forests that are cut down only to be wasted as scrap wood and waste paper.

Sustainable wood production combines harvesting methods that protect the forest environment, the reuse of wood scrap, the recycling of wood

and paper, and choices for alternative woods that preserve forests. Sustainable methods also require a degree of creativity for finding new uses for reusable materials such as plastic to replace wood.

Sustainable wood and new wood alternatives have led to small specialized businesses that have invented various ways to reduce wood waste. The future of forests will depend on this combination of science, forestry, recycling, and even art to make use of the wood waste. Each new technology that reuses wood and paper waste contributes to forest conservation.

Future Needs

Trees are renewable natural resources because after they have been cut down they can grow back in their original habitat. But this regrowth into mature trees takes a long time, longer than humans live. As more trees become raw material for wood products, paper, and fuel, the world's forests will not be able to keep up with the destruction. A globe without living trees seems impossible to envision, and in reality, that situation would be improbable. But already people have downed enough trees so that the remaining forests can no longer remove the carbon dioxide that builds up in Earth's atmosphere.

Conservation of every living thing must begin with the conservation of plant life because plants represent the foundation of food chains, where the Sun's energy becomes usable energy for humans and wildlife. Conserving forests starts with steps to ensure Earth's water cycle operates as it should. Therefore, water and air pollution, soil erosion, destruction of riparian habitats, and actions that lead to desertification must all be reversed as soon as possible. These tasks can be accomplished only with the cooperation of the public, industry, environmental scientists, and international governments.

Many of these sectors of society have taken the lead in conservation. Forests have received legal protections from governments that have helped preserve the remaining undisturbed forestland in their countries. Environmental groups have used a combination of teaming with government and more aggressive action plans to save forests. Even industries that have been blamed for destroying forests have made attempts at new restoration methods. Society may be slowly turning the corner in forest protection: For the first time in 100 years, Europe's tree cover has grown rather

than declined, and tree cover in United States is coming close to doing the same.

The future of forests remains in doubt despite the encouraging signs. Some industries still need to explore forests for the fuel and raw materials that society wants. Forests are simultaneously threatened by the things that threaten all ecosystems today: pollution, poverty, and global warming. These things may prove to be much more difficult to change than are laws to protect forests.

People's perception of plant and tree life may work against any urgency to save them. Thousands of square miles of lush, green forests cover many parts of the world and suggest that the forest biome has unlimited resources. People also know that forests grow back given enough time and space. Biologists who study forests from the air or on the ground realize that the forests are not as vast as they seem. Illegal logging has infiltrated deep parts of the Amazon rain forest, and an unhealthy environment has weakened entire tree populations in temperate and boreal climates. The best approach in forest management may be to view forest as a nonrenewable resource that cannot be replaced in a single human lifetime.

Forest management will continue to seek new methods in fire control, forest health, ecosystem studies, forest regeneration, and the economics and legal aspects of protecting forests. At the same time, scientists and entrepreneurs will devise new materials that take the place of wood in construction, furniture, and other wood products. Finally, communities must be willing to take on restoration projects that return land to forest and riparian habitats, even if this means withdrawing from those areas to let them recover on their own.

Restoration has worked well on riparian habitats along waterways. In populated urban places, riparian habitats have been decimated, but methods exist to remove the damage and begin rebuilding the riparian ecosystem. Depending on the extent of damage, forest and riparian restorations take either a passive approach or an active approach. The bulk of new restorations will undoubtedly fall somewhere in the middle of these two approaches. Restoration has not been a foolproof undertaking, however. Some forest regions have lost their battle with encroaching populations or the needs of impoverished people. Wetlands and specialized habitats such as barrier islands have been changed to the point where restoration does not make any sense. Perhaps part of the future in conservation entails educating people on the finality of lost resources.

It may not be realistic to expect an imminent end to poverty or its opposite: consumerism that demands ever more natural resources. Even if society does solve these problems, by then the plants and trees will have already been reduced to a small collection of survivors. Climate change, pollution, and overpopulation will complete the job. This, of course, is a bleak scenario that responsible people can prevent with good environmental judgment.

Conservation requires a worldwide effort because every place on Earth has some relationship to every other place on Earth. John Muir said it best when he commented that "everything is hitched to everything else." Whether a forest lies at the equator or under the northern lights, environmentalists must continue to keep a steady watch on industry's needs and government policies toward forests. Population growth must at last be addressed and controlled. Finally, society can conserve natural resources through small actions such as saving paper or large programs run by international environmental organizations.

This century may be a landmark in human history in which the world's inhabitants witness Earth's turning point from boundless natural resources to depletion of those resources. Conservation applies not only to forests and wildlife, but also to the air, water, soil, and climate that sustains them, and which sustains humankind. Humans can live without wood, but they cannot live without plant life. They can live without oil, but they cannot live without water. Conservation of the world's grasslands, riparian habitats, and forests, and the ecosystems they contain, rests on the ability of humans to distinguish between things they want and the things they need.

Appendix

Forest Conservation Organizations		
Organization	**Web Site, URL:**	**Main Emphasis**
Main Focus in the United States		
American Conifer Society	www.conifersociety.org	Cone-bearing trees and woody plants
American Forests	www.americanforests.org	Science-based tree conservation
Environmental Defense Fund	www.edf.org	Solving environmental crises with science, economics, and law
Friends of the Earth	www.foe.org	Activism against environmental decay
National Audubon Society	www.audubon.org	Ecosystem conservation, focus on birds
National Forest Foundation	www.natlforests.org	National forests and grasslands
Natural Resources Defense Council	www.nrdc.org	Activism in all environmental issues
Nature Conservancy	www.nature.org	Conservation by protecting land and water

(continues)

FOREST CONSERVATION ORGANIZATIONS *(continued)*

ORGANIZATION	WEB SITE, URL:	MAIN EMPHASIS
Resources for the Future	www.rff.org	Scientific, legal, and economic think tank for environmental policy
Sierra Club	www.sierraclub.org	Community-based conservation initiatives
Society of American Foresters	www.safnet.org	Organization for professionals in forestry
U.S. Fish and Wildlife Service	www.fws.gov	Maintains list of endangered and threatened species under Endangered Species Act
Wilderness Society	www.wilderness.org	Science and advocacy for environmental issues
International Focus		
Conservation International	www.conservation.org	Science- and community-based conservation
Convention on Biological Diversity	www.cbd.int	Global strategic planning on biodiversity
Earthwatch Institute	www.earthwatch.org	Research in sustainable activities to protect environment
International Union for the Conservation of Nature	cms.iucn.org	Maintains Red List of Threatened Species

Organization	Web Site, URL:	Main Emphasis
Rainforest Action Network	ran.org	Activism against corporate destruction of environment; focus on rain forests
United Nations Environment Programme	www.unep.org	Cooperation among nations on environmental issues; child and youth environmental programs
World Conservation Monitoring Center	www.unep-wcmc.org	Resource for scientific and government cooperation on conservation
World Resources Institute	www.wri.org	Think tank for environment and indigenous people
Worldwatch Institute	www.worldwatch.org	Collection and dissemination of data for conservation science
World Wildlife Fund	www.worldwildlife.org	Protection of the world's important natural places

Note: All Web sites were accessed November 7, 2008.

Glossary

ACTIVE RESTORATION method of returning damaged land to its original condition by using human actions rather than waiting for nature to restore the land.

BAGASSE agricultural residues such as husks and stalks left over after crops have been harvested.

BARRIER ISLAND low, narrow, and sandy island near a mainland's coast that protects the coast from heavy storm damage and which shifts in response to tide, wind, and weather.

BIOCULTURAL RESTORATION restoring of a habitat to benefit animals and a local community at the same time.

BIODIVERSITY HOT SPOTS areas of greatest diversity and also greatest potential for habitat loss.

BIOFILM a diverse collection of microbes that attach to surfaces in flowing water and work together as a single community.

BIOFUEL gas or liquid fuel made from biomass, usually plants.

BIOGEOCHEMICAL CYCLE natural recycling of Earth's nutrients in various chemical forms between living and nonliving things.

BIOMASS organic matter from plants, animal wastes, or wastewater treatment that can be used as fuel.

BIOME a terrestrial area defined by the things living there, especially vegetation.

BIOMETHANE methane produced from biological actions such as fiber digestion in cattle.

BIOPROSPECTING searching a forest for the sole purpose of finding and taking useful biological products.

BIOTA living things; plant, animal, or microbial.

BOREAL predominantly conifer forest that grows in northern latitudes.

CANOPY uppermost part of a forest where branches of the tree crowns meet; includes the upper overstory and the next layer toward the forest floor, the understory.

CARRYING CAPACITY maximum population of a species that a habitat can support in a given period of time.

CATCHMENT upland area that receives and stores rainfall.

CLEAR-CUTTING tree harvesting method that cuts all trees in a single cut.

CLIMATE CHANGE long-term change in a region or the world's average weather conditions.

CONSERVATION prudent use of the world's natural resources so that the resources are not used up rapidly or at all.

CONSTRUCTED WETLAND artificial wetland built to either restore damaged wetland habitat or to serve as a waste-purification system that mimics natural wetlands.

CORRUGATED FIBERBOARD material used for making cardboard boxes, usually consisting of two flat layers on each side of an inner layer containing alternating ridges and grooves.

CROP MOISTURE INDEX calculation of drought conditions over short periods, such as weeks, in a specific region.

CROWN the uppermost leafy part of a tree.

CROWN FIRE hot, fast-moving forest fires that spread through the uppermost part of the forest and the dense vegetation nearer to the ground.

DECIDUOUS type of tree that survives cold seasons by shedding its leaves.

DEFORESTATION removal of trees from forested land.

DESALINATION conversion of salt water to freshwater.

DESERTIFICATION any use of land that causes it to lose at least 10 percent of its productivity.

DISTILLATION method of recovering freshwater from salt water by heating.

ECOFORESTRY sustainable methods of harvesting trees and replacing harvested trees to keep from destroying a forest.

ECOLOGICAL ECONOMICS the science of studying the generation and production of natural resources that have no substitute for the purpose of putting a monetary value on those resources.

ECOLOGICAL FOOTPRINT amount of land and water needed provide a population with resources to sustain life and dispose of wastes.

ECOLOGICAL SUCCESSION process in which plant or animal species are replaced by other species over time, usually progressing from simple organisms to complex organisms.

ECONOMIES OF SCALE situations whereby the cost of producing an item decreases when the item is made in large quantities.

ECOSYSTEM community of species interacting with one another and with the nonliving things in a certain area.

ENGINEERED WOOD material made by heating and pressing together a mixture of various wood pieces and fibers.

ENVIRONMENTAL ECONOMICS the science of studying the generation and production of natural resources for the purpose of finding sustainable methods for conserving those resources, especially resources that have no substitute.

EPIPHYTIC type of plant that lives only in the tree canopy and draws water and nutrients directly from the atmosphere.

EROSION process of loosening, rinsing, or blowing soil or sediments from one place and depositing them in another place.

ETHANOL an alcohol containing two carbon molecules with the formula C_2H_5OH.

ETHNOBOTANY science of learning about medicinal plants and harvesting them in a sustainable manner.

EUTROPHICATION physical, chemical, and biological changes that take place when water is polluted with nutrients, usually nitrogen and phosphorus, and leading to oxygen depletion in the water.

FOOD WEB complex network of many interconnected food chains.

FOREST ECOLOGICAL SUCCESSION process in which plants, shrubs, and trees are replaced by other trees over time, usually progressing from simple organisms to complex organisms and from short-lived to long-lived species.

FOREST MANAGEMENT science, economics, and other principles employed to maintain healthy forests.

FORESTRY science of using forest conservation methods and tree harvesting methods in the best manner to supply raw materials to the wood and paper industries.

GLOBAL WARMING the ongoing rise in temperatures at the Earth's surface due to the accumulation of greenhouse gases in the atmosphere.

GROUND COVER low-growing plants, herbs, and shrubs that prevent soil erosion and water evaporation from soil.

GROUNDWATER water that flows into soil and is stored in underground reserves called aquifers.

GYMNOSPERM any type of vascular (containing internal vessels) plant or tree that contains exposed seeds, that is, seeds not enclosed in a fruit.

HABITAT the place where a plant or animal lives.

HADLEY CELL air circulation pattern in which warm, moist air rises from the equator toward the top of the troposphere, and cool air condenses into rain and then spreads toward both poles.

HARDWOOD wood of high density and often from broad-leafed, deciduous trees.

HEADRIG an apparatus used in sawmills to cut debarked logs into various thicknesses and widths.

HEMICELLULOSE any type of carbohydrate molecule found in plants and containing a mixture of five- and six-carbon sugars arranged in a long chainlike structure.

HERITAGE TREE tree of particular importance to a community because of age, size, location, history, or ecological significance.

INSTRUMENTAL value of an organism, species, ecosystem, or biodiversity for the benefits it gives to people.

INTRINSIC value of an organism, species, ecosystem, or biodiversity for itself and not because it may benefit people.

INVASIVE type of species not normally found in a habitat or ecosystem because it was intentionally or accidentally released there.

IN VITRO scientific activities that take place in a laboratory or other artificial environment rather than nature.

LAND ETHIC (or evolutionary ecological land ethic) theory that proposes that humans should be involved in land management but in a way that does not exploit the land or use up its resources.

LOGGING the harvesting and processing of trees as a raw material for products.

MARITIME FOREST forest that grows behind ocean dunes.

MEMBRANE a type of filter containing very small pores, as small as 1 micrometer in diameter, that purifies water by removing tiny particles.

METAMORPHIC ROCK rock produced from existing rock that has been subjected to intense heat and pressure.

MICROBE a microscopic organism such as bacteria, protozoa, or viruses.

MICROHABITAT an area within a larger habitat that has unique characteristics found nowhere else in the environment and that supports the growth of organisms found at no other place on Earth.

MINE TAILINGS excess materials left over from ore or coal mining.

MOUNTAINTOP MINING mining method that removes the topmost portion of a mountain to gain access to coal reserves.

NEOCLASSICAL ECONOMICS the science of studying the generation and production of natural resources that might be depleted in the future with the understanding that future technologies will find substitutes for those resources.

NITROGEN FIXATION the conversion of nitrogen gas (N_2) by plant roots into a form that can be used by the plant.

OVERDRAFT situation in which water is taken out of the ground quicker than nature replaces it.

OVERSTORY part of a forest containing the upper foliage and branches that touch and form a continuous community receiving full sunlight; often used interchangeably with "canopy."

OVERWASH (*also* washover) event whereby ocean washes completely over a low-lying body of land; the area behind dunes on a barrier island where ocean surf sometimes reaches.

PALMER INDEX calculation to put a measurement on the severity of long-term drought.

PAPERBOARD thick, string paper product used for making boxes and packaging.

PASSIVE RESTORATION method of returning damaged land to its original condition by allowing nature to reestablish by itself with minimal help from people.

PATHOGEN any disease-causing microbe or parasite.

PHYTOPLANKTON small, sometimes single-celled, plant life in aquatic ecosystems, which serves as the foundation of food chains.

PRESCRIBED BURNS small, intentional forest or grassland fires to clear out dense growth.

PRESERVATIONIST ETHIC theory in which nature is valued for its intangible qualities.

PRIMARY FOREST an original forest that grew on land that has undergone a natural succession of small plants to small trees to larger trees and which has never been disturbed by human activities.

PULP fibrous material from wood treated by chemical or mechanical means as a first step in making paper.

PULPWOOD wood harvested for the paper products industry.

RECOMBINANT ENGINEERING the biological science and methods involved in removing a gene from one organism and inserting it into the genetic material of another organism.

REDUCED IMPACT LOGGING tree harvesting techniques designed to minimize the disturbance caused to forest ecosystems.

REFORESTATION renewal of trees and other vegetation on land that has been cleared of forest.

RESOURCE CONSERVATION ETHIC theory that proposes that people should view nature as a natural resource for their use.

RESOURCE WARS armed conflicts over a necessary and scarce natural resource, such as water.

RESTORATION process of repairing and reconstructing damaged ecosystems or habitat.

RESTORATION ECOLOGY the science and methods for returning damaged land to its original, or near original, natural condition.

REVERSE OSMOSIS a small-pore filtration method to separate salts and minerals from salt water to make freshwater.

RIFFLES shallow portions of a stream that causes swirling and broken water flow.

RIPARIAN HABITAT trees, shrubs, plants, and physical features found on the banks of rivers, streams, and nonbeach borders of lakes.

ROUNDWOOD harvested trees with branches and bark removed—that is, logs.

SALINIZATION an increase in the salt content of water or soil.

SAVANNA a grassland biome characterized shrubs and isolated trees in a hot, dry climate.

SEDIMENT CYCLE (*also* rock cycle) geologic processes that form and modify rocks in the Earth's crust.

SEED-TREE HARVESTING tree-cutting method in which almost all trees are removed except for a few mature trees to produce seeds and so regenerate the forest.

SELECTIVE CUTTING tree-harvesting method in which specific mature, intermediate-age, or diseased trees are removed and the remainder are left in the forest to grow.

SENESCENCE normal aging process of living things.

SEROTINY behavior of some plants that retain their seeds in a protective structure, such as a pine cone, for long periods of time before being induced to release the seeds when exposed to fire.

SHAFT MINING method of extracting ore from underground by either building a tunnel directly downward or at a gradual angle from the surface to the ore deposit.

SHELTERWOOD HARVESTING tree-cutting method in which large mature trees are removed first, then the next oldest trees are removed in a second cutting, and so on, over the span of a decade.

SHIFTING CULTIVATION clearing forest and planting crops on it for a few years until the soil is depleted, then repeating the process at new sites.

SLASH AND BURN method of clearing forest for cultivation by cutting down all the trees in an area and burning most or all of the fallen timber.

SOFTWOOD low-density wood usually from conifers.

SOIL ZONE an upper layer of the earth beneath the topsoil that contains varying moisture content.

STRIP CUTTING tree-cutting method in which a band of trees are clear-cut along contours of the land, leaving untouched forest on both sides.

STRIP MINING method of extracting ore from underground by removing all the land above the ore deposit for the purpose of exposing the ore.

SUSTAINABLE FORESTRY method of harvesting trees and regenerating the forest based on water and soil conservation, natural pest control, and low-impact logging.

TEMPERATE type of forest that grows between the tropical region and the polar regions, with distinct seasons.

THROWAWAY SOCIETY any community of people that consumes resources at a high rate, wastes resources, and makes little attempt at reducing waste.

TREE PLANTATION (*also* tree farm, forest plantation) an area planted with only one or a few species of trees all of the same age.

UNDERSTORY part of a forest directly underneath the canopy and predominated by the trunks and branches of tall trees and the crowns of shorter trees and receiving filtered sunlight.

UPHILL LOGGING method of harvesting timber by dragging logs upward toward a mountaintop for removal by rail or helicopter.

URBAN FORESTERS persons who participate in organized tree-planting programs in cities.

WATER CYCLE (*also* hydrologic cycle) movement of water through the atmosphere to Earth and then through living things and back to the atmosphere.

WATERSHED total amount of water stored in the ground, surface waters, and trees in a specific region.

WATER STRESS conditions in which a region's water requirements exceed water availability.

WATER TABLE area underground where water has completely filled the spaces between rocks and soil particles.

WETLAND land other than lakes, streams, rivers, and the ocean that is covered all or part of the time with water.

WHITE ALKALINE SALTS inorganic compounds that are water-soluble, white, and have a basic (nonacidic) pH in solution.

YARDING process of hauling cut timber out of the forest to sawmills.

ZONE OF SATURATION underground area that holds water for long periods of time.

ZOOPLANKTON small, sometimes single-celled, animal organisms in aquatic ecosystems

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