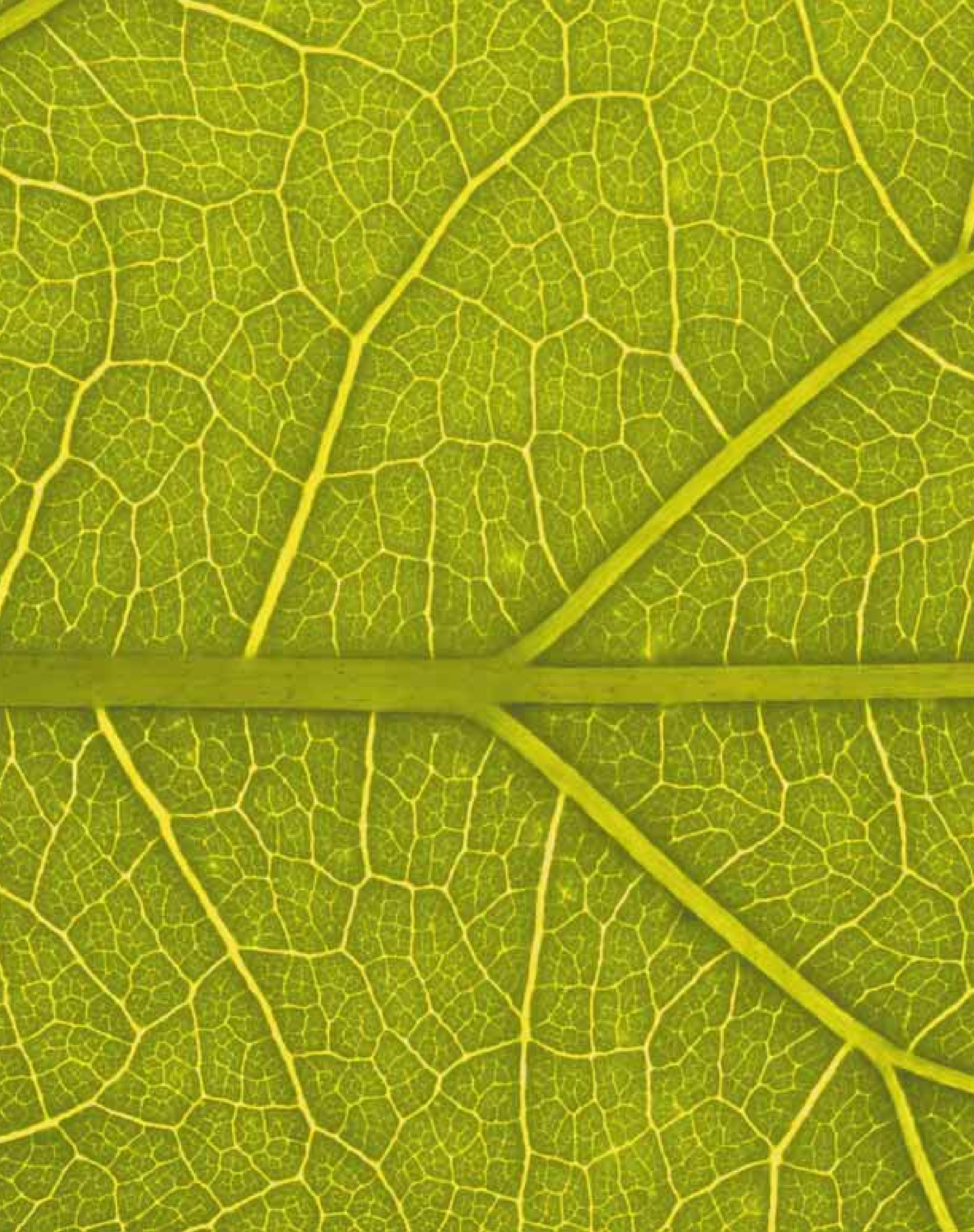
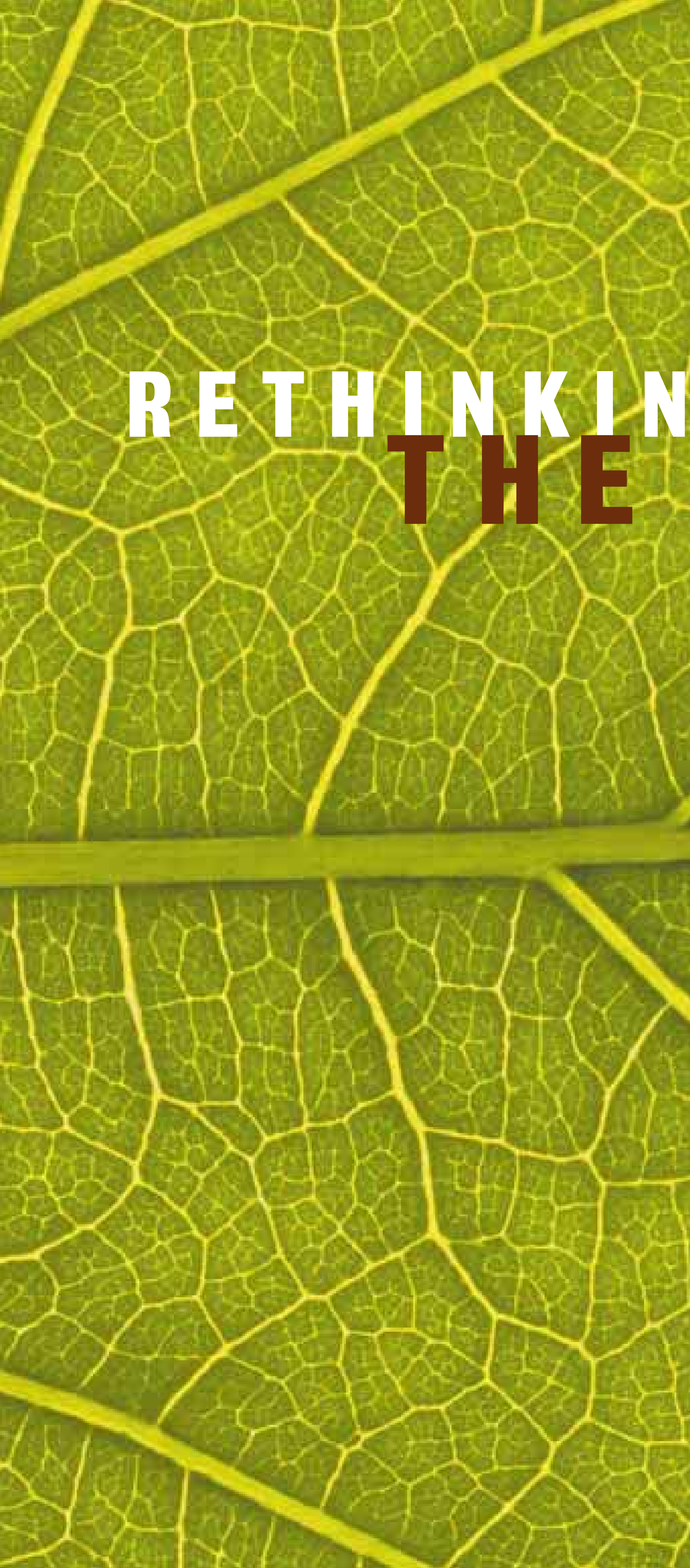


PART I

WORLD RESOURCES 2000-2001



RETHINKING THE LINK

Chapter 1

LINKING PEOPLE AND ECOSYSTEMS

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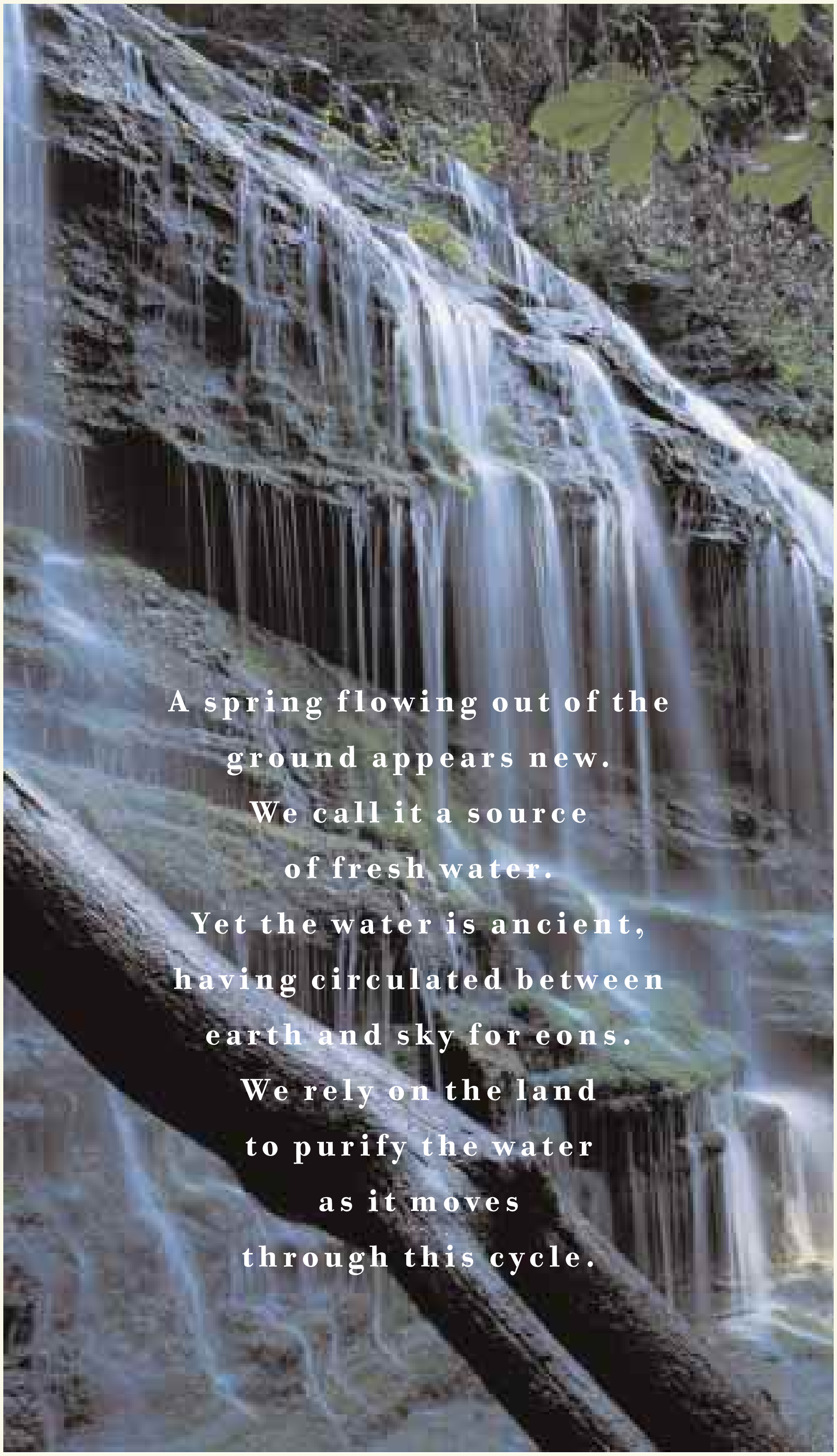
ADOPTING AN ECOSYSTEM APPROACH


A spring flowing out of the
ground appears new.
We call it a source
of fresh water.
Yet the water is ancient,
having circulated between
earth and sky for eons.
We rely on the land
to purify the water
as it moves
through this cycle.

CHAPTER 1

LINKING PEOPLE AND ECOSYSTEMS

Try to imagine Earth without ecosystems. Ecosystems are the productive engines of the planet–communities of species that interact with each other and with the physical setting they live in. They surround us as forests, grasslands, rivers, coastal and deep-sea waters, islands, mountains–even cities. Each ecosystem represents a solution to a particular challenge to life, worked out over millennia; each encodes the lessons of survival and efficiency as countless species scramble for sunlight, water, nutrients, and space. Stripped of its ecosystems, Earth would resemble the stark, lifeless images beamed back from Mars by NASA cameras in 1997.

That image also underscores the difficulty of recreating the natural life-support systems that ecosystems provide, should we damage them beyond their capacity to rebound. The world's fertile soils, for instance, are a gift of millions of years of organic and inorganic processes. Technology can replicate the nutrients soils provide for crops and native flora, but on a global scale the costs would be prohibitive.

The fact is, we are utterly dependent on ecosystems to sustain us. From the water we drink to the food we eat, from the sea that gives up its wealth of products, to the land on which we build our homes, ecosystems yield goods and services that we can't do without. Ecosystems make the Earth habitable: purifying air and water, maintaining biodiversity, decomposing and recycling nutrients, and providing myriad other critical functions.

Harvesting the bounty of ecosystems roots our economies and provides us employment, particularly in low- and middle-income countries. Agriculture, forestry, and fishing are responsible for one of every two jobs worldwide and seven of ten jobs in sub-Saharan Africa, East Asia, and the Pacific. In a quarter of the world's nations, crops, timber, and fish still contribute more to the economy than industrial goods (World Bank 1999b:28–31, 192–195). Global agriculture alone produces US$1.3 trillion in food and fiber each year (Wood et al. [PAGE] 2000).

Ecosystems feed our souls as well, providing places for religious expression, aesthetic enjoyment, and recreation. In every respect, human development and human security are closely linked to the productivity of ecosystems. Our future rests squarely on their continued viability.

If our life on Earth is unimaginable without ecosystems, then we need to know how to live better within them. The world is large, nature is resilient, and humans have been altering the landscape for tens of thousands of years, all of which makes it easy to ignore warning signs that human activities might be damaging the capacity of an ecosystem to continue to deliver goods and services.

In fact, many nations and societies have completely altered the landscape, converting wetlands, prairies, and forests to other uses, and continue to prosper. What was once 200 Mha of tallgrass prairie in the heartland of the United States has been converted almost entirely to cropland and urban areas. The once-extensive forests of Europe have suffered much the same fate. These conversions have brought obvious benefits, such as stable food supplies and industrial production, that have made the United States and some European nations economic powerhouses. But they also impose costs—eroded topsoil, polluted wells and waterways, reduced fish yields, and lost wildlands and scenic places—that threaten to erode the wealth and quality of life these nations enjoy.

We don't have to look far to see how high the costs of degrading ecosystems can be. The rich waters of the Black Sea used to yield more than 700,000 tons of anchovy, sturgeon, bonito, and other valuable fish annually. But over the last 30 years, human pressures have radically altered the Black Sea ecology. Beginning in the 1970s, increasing pollution brought on frequent algal blooms. A rapid rise in fishing in the 1980s depleted key fish stocks. In 1982, the final blow came with the accidental introduction of a jellyfish-like creature, a ctenophore, that soon dominated the aquatic

In every respect, human development and human security are closely linked to the productivity of ecosystems. Our future rests squarely on their continued viability.

food web, directly competing with native fish for food. By 1992, the Black Sea fish catch had collapsed to one-third of its former volume (Prodanov et al. 1997:1–2). Now most fishers from the six nations surrounding the sea bring up nearly empty nets, and the once prominent fishing industry hemorrhages jobs and profits (Travis 1993:262–263).

Ecosystem degradation showed a different face to the Chinese living alongside the Yangtze River in 1998. In prior years, loggers had cut forests in the river's vast watershed, while farmers and urban developers drained lakes and wetlands and occupied the river's flood plains. In the meantime, little heed to soil conservation allowed 2.4 billion metric tons of earth to wash downstream each year, silting lakes and further reducing the buffers that formerly absorbed floodwaters (Koskela et al. 1999:342). When record rains fell in the Yangtze basin in the summer of 1998, these degrading practices amplified the flooding, which left 3,600 people dead, 14 million homeless, and $36 billion in economic losses (NOAA 1998; World Bank 1999a). The Chinese government is now trying to restore the ecosystem's natural flood-control services, but it could take decades and billions of dollars to reforest denuded slopes and reclaim wetlands, lakes, and flood plains.

How Viable Are Earth's Ecosystems?

In spite of the costs of degrading ecosystems and our dependence on their productivity, we know surprisingly little about the overall state of Earth's ecosystems or their capacity to provide for the future. We need to know: How viable are Earth's ecosystems today? How best can we manage ecosystems so that they remain healthy and productive in the face of increasing human demands?

This special millennial edition of the World Resources Report, *World Resources 2000–2001*, tries to answer these questions, focusing on ecosystems as the biological underpinning of the global economy and human well-being. It considers both predominantly natural ecosystems like forests and grasslands as well as human-constructed ecosystems like croplands, orchards, or other agroecosystems. Both ecosystem types are capable of producing an array of benefits, and both are crucial to human survival.

This chapter examines how people rely on ecosystems and surveys the factors that drive how people use, and often degrade, ecosystems. Chapter 2 assesses the current state of global ecosystems, presenting the results of a major new analysis of ecosystem conditions and pressures undertaken by World Resources Institute, the International Food Policy Research Institute, and many other collaborators. In Chapter 3, case studies illustrate trade-offs involved in managing ecosystems and ways that some communities responded as their local ecosystems declined. Chapter 4 considers the greater challenge of managing ecosystems in the 21st century to keep them productive and vital, even as our population and consumption grow.

All these chapters focus on the goods and services that ecosystems yield as fundamental measures of ecosystem health. This "goods and services" approach emphasizes how we depend on ecosystems on a daily basis.

Losing the Link?

It is easy to lose touch with our link to ecosystems, despite their importance. For the millions of us who depend directly on forests or fisheries for our survival, the vital importance of ecosystems is a fact of daily life. But for the millions of us who live in cities or suburbs and have transitioned from working the soil to working at computer keyboards, our link to ecosystems is less direct. We buy our food and clothing in stores and depend on technology to deliver water and energy. We take for granted that there will be food in the market, that transportation and housing will be available, and all at reasonable cost. Too often, we're only reminded of our link to natural systems when a fishery collapses, a reservoir goes dry, or air pollution begins to make us sick–when the flow of goods and services is disrupted. Then we suddenly become aware of the real value of these resources and the potential economic and biological costs of mismanagement.

Unfortunately, mismanagement of ecosystems abounds. Worldwide, human overuse and abuse of major ecosystems from rainforests to coral reefs to prairie grasslands have degraded or destroyed hectare upon hectare of once-productive habitat. This has harmed wildlife, to be sure, as the number of endangered species attests. But it has also harmed human interests by depleting the flow of the very goods and services we depend on.

Decline in the productive capacity of ecosystems can have devastating human costs. Too often, the poor are first and most directly affected by the degradation of ecosystems. Impoverished people are generally the most dependent on ecosystems for subsistence and cash, but usually exert the least control over how ecosystems are used or who reaps the benefits of that use.

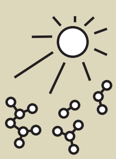
In many areas, declining agricultural productivity, diminished supplies of freshwater, reduced timber yields, and declining fish harvests have already taken a significant toll on local economies.

(continues on p. 10)

Box 1.1 History of Use and Abuse

Many of the challenges we face today—deforestation, soil erosion, desertification, salinization, and loss of biodiversity—were problems even in ancient times. What is different now is the scale, speed, and long-term nature of modern civilization's challenges to Earth's ecosystems. Before the industrial revolution, environmental degradation was much more gradual—occurring over hundreds or thousands of years—and relatively localized. The cumulative actions of rapidly growing and industrializing societies, however, have given rise to more complex problems. Acid rain, greenhouse gas emissions, ozone depletion, toxic waste, and large-scale industrial accidents are examples of such problems with global or regional consequences.

7000 BC–1800 BC 	Mesopotamia/Sumer *Salinization and waterlogging of Sumer's agroecosystem*	Around 7000 BC, people in this region (now, largely, Iraq) began to modify the natural environment. Lacking adequate rainfall, land had to be irrigated for cultivation, and the demand for food increased as the population grew. The irrigated land became salinized and waterlogged. Records noting "the earth turned white" with salt date back to 2000 BC. By 1800 BC, the agricultural system—the foundation of Sumerian civilization—collapsed.
2600 BC–present 	Lebanon *Overuse and exploitation of Lebanon's cedar forest*	At one time, Mount Lebanon was covered with a forest of cedars that were famous for their beauty and strength. Solomon's temple was built of cedar from this area as were many Phoenician ships. In the third millennium BC, Byblos grew wealthy from its timber trade. The Egyptians used cedar timber for construction and used the resin for mummification. The exploitation continued through the centuries. Only four small groves remain today.
2500 BC–900 	Mayan Empire *Soil erosion, loss of agroecosystem viability, and water siltation in Central America*	Mayans lived in what are now parts of Mexico, Guatemala, Belize, and Honduras. The agriculture techniques they used were creative and intensive—clearing hillsides of jungle, terracing fields to contain soil erosion, draining swamps by digging ditches and using the soil from the ditches to form raised fields. Eventually too much was demanded of this system. Soil erosion reduced crop yields, and higher levels of silt in rivers damaged the raised fields. Decreased food production and competition for the remaining resources may have led to that civilization's demise.
800 BC–200 BC 	Greece *Conversion and deforestation in the Mediterranean*	In Homeric times, Greece was still largely covered with mixed evergreen and deciduous forests. Over time the trees were cleared to provide land for agriculture, fuel for cooking and heating, and construction materials. Overgrazing prevented regeneration. The olive tree, favored for its economic value, began to flourish in ancient Greece because it grew well on the degraded land.
200 BC–present 	China *Desertification along the Silk Road*	The fortification of the Great Wall during the Han dynasty gave rise to intensive cultivation of farmland in northern and western China and to the growth of a major travel and trade route that came to be known as the Silk Road. Deserts began irreversibly expanding in this area as a result of the demands of a growing population and gradual climate changes.
50 BC–450 	Roman Empire *Desertification and loss of agroecosystem viability in North Africa*	The challenge of providing food for the population of Rome and its large standing armies plagued the empire. The North African provinces, once highly productive granaries, gradually became degraded as Roman demands for grain pushed cultivation onto marginal lands, prone to erosion. Scrub vegetation spread and some intensively cultivated areas became desertified. The irrigation systems the Romans used depended on watersheds that have since been deforested, and now yield less runoff, reducing the chance of restoring productivity.

1400–1600 	Canary Islands *Human and natural resource exploitation, degradation and extinctions in many regions*	Originally from North Africa, the Guanches were a people who inhabited the Canary Islands for more than 1,000 years before the Spanish arrived in the 1400s. The Spanish enslaved the Guanches, cleared the forests, and built sugar cane plantations. By 1600 the Guanches were dead, victims of Eurasian diseases and plantation conditions. As in the Canary Islands, regions in the Americas, Africa, and Asia where people were forced to grow and export cash crops such as sugar, tobacco, cotton, rubber, bananas, or palm oil, continue to suffer from deforestation, soil damage, biodiversity losses, and economic dependency instituted during colonization.
1800 	Australia and New Zealand *Loss of biodiversity and proliferating invasive species in island ecosystems*	There were no hoofed animals in Australia and New Zealand before Europeans arrived at the end of the 18th century and began importing them. Within 100 years there were millions of sheep and cattle. The huge increase in grazing animals killed off many of the native grasses that were not well adapted to intensive grazing. Island biodiversity worldwide suffered some of the most dramatic losses after nonnative plants and animals were introduced. Island flora and fauna had developed in isolation over millennia and thus lacked natural predators. Many island bird species, for example, were flightless and became easy prey for invaders. It is estimated that 90 percent of all bird extinctions occurred on islands.
1800 	North America *Conversion, loss of habitat, and unrestrained killing of wildlife in North America*	As land was cleared for settlement and cultivation around the world, animal habitats of almost every kind were reduced; animals were killed for food, hides, or recreation as commerce spread. In North America, herds of bison, totaling perhaps as many as 50 million, were hunted to near extinction by the end of the 19th century. Aquatic as well as terrestrial species became targets of exploitation and extincition. In the 19th century, whales were killed in large numbers to support industrializing economies in need of whale oil in great quantity, mainly for lighting and lubricants. On the northwest coast of North America, whale populations were on the verge of extinction by the 20th century.
1800–1900 	Germany and Japan *Industrial chemical poisoning of freshwater systems*	The industrial revolution had a profound impact on the waters of the world. Rivers that ran through industrial zones, like the Rhine in Germany, or rivers that ran through mining zones, like the Watarase in Japan, became heavily polluted in the 19th century. The German chemical industry poisoned the Rhine so badly that salmon, which had been plentiful as late as 1765, were rare by 1914. Japan's most important copper mine in the 1800s dumped mine tailings in the Watarase River, and sulfuric acid from smelters contaminated the water and killed thousands of hectares of forest trees and vegetation. Fish and fowl died and local residents became sick. The human birth rate dipped below the death rate in the nearby town of Ashio in the 1890s.
1900 	United States and Canada *Soil erosion and loss of biodiversity in the United States and Canada*	The Great Plains of the United States and Canada were ploughed in the late 19th and early 20th centuries and planted with new forms of drought-resistant wheat. Once the protective original grass cover was destroyed, drought in the 1930s enabled high, persistent wind storms to blow away much of the dry soil. Soil conservation methods were subsequently introduced such that when wind erosion again affected the area in the 1950s and in the 1970s, the consequences were less severe.
1928–present 	Worldwide *Industrial chemicals deplete the world's protective ozone layer*	Chlorofluorocarbons (CFCs) are a family of volatile compounds invented in 1928. Thought to be the world's first nontoxic, nonflammable refrigerants, their use grew rapidly. They also were used as industrial solvents, foaming agents, and aerosol propellants. CFC production peaked in 1974, the same year researchers noted that CFC emissions could possibily damage human health and the ozone layer. In 1985, the discovery of an "ozone hole" over the Antarctic coincided with a first-ever coordinated international effort to phase out production of CFCs and other ozone-depleting substances. Worldwide phase out of CFC production is scheduled for 2010.

Box 1.2 Linking Ecosystems and People

An urban professional in Tokyo reads a newspaper printed on pulped trees from North American forests. Her food and clothing come from plants and animals raised around the world—cotton and cashmere from Asia, fish from the Pacific and Indian oceans, beef from Australian and North American grasslands, fruits and vegetables from farmlands on four continents. The coffee she sips comes from tropical Central American plantations, but it is brewed with water from wells near the city.

In a Borneo village children get to school via river, poled in long boats handmade from local trees. In nearby paddies, families grow rice, their main dietary staple as well as a source of pepper, a cash crop, and wine.

The Shuar of Amazonian Ecuador find shelter in houses with thatched roofs made from the local palm leaves. They also use palm-leaf stems for weaving baskets and containers. They grow manioc, papaya, sweet potato, and other crops derived from the rainforest, for their own subsistence and for cash. The forest is also the source of their woodfuel and medicines, as well as fish and game.

Ecosystems sustain us. They are Earth's primary producers, solar-powered factories that yield the most basic necessities—food, fiber, water. Ecosystems also provide essential services—air and water purification, climate control, nutrient cycling, and soil production—services we can't replace at any reasonable price.

Primary Goods and Services Provided by Ecosystems

Ecosystem	Goods	Services
Agroecosystems 	■ Food crops ■ Fiber crops ■ Crop genetic resources	■ Maintain limited watershed functions (infiltration, flow control, partial soil protection) ■ Provide habitat for birds, pollinators, soil organisms important to agriculture ■ Build soil organic matter ■ Sequester atmospheric carbon ■ Provide employment
Coastal Ecosystems 	■ Fish and shellfish ■ Fishmeal (animal feed) ■ Seaweeds (for food and industrial use) ■ Salt ■ Genetic resources	■ Moderate storm impacts (mangroves; barrier islands) ■ Provide wildlife (marine and terrestrial) habitat ■ Maintain biodiversity ■ Dilute and treat wastes ■ Provide harbors and transportation routes ■ Provide human habitat ■ Provide employment ■ Provide for aesthetic enjoyment and recreation
Forest Ecosystems 	■ Timber ■ Fuelwood ■ Drinking and irrigation water ■ Fodder ■ Nontimber products (vines, bamboos, leaves, etc.) ■ Food (honey, mushrooms, fruit, and other edible plants; game) ■ Genetic resources	■ Remove air pollutants, emit oxygen ■ Cycle nutrients ■ Maintain array of watershed functions (infiltration, purification, flow control, soil stabilization) ■ Maintain biodiversity ■ Sequester atmospheric carbon ■ Moderate weather extremes and impacts ■ Generate soil ■ Provide employment ■ Provide human and wildlife habitat ■ Provide for aesthetic enjoyment and recreation
Freshwater Systems 	■ Drinking and irrigation water ■ Fish ■ Hydroelectricity ■ Genetic resources	■ Buffer water flow (control timing and volume) ■ Dilute and carry away wastes ■ Cycle nutrients ■ Maintain biodiversity ■ Provide aquatic habitat ■ Provide transportation corridor ■ Provide employment ■ Provide for aesthetic enjoyment and recreation
Grassland Ecosystems 	■ Livestock (food, game, hides, fiber) ■ Drinking and irrigation water ■ Genetic resources	■ Maintain array of watershed functions (infiltration, purification, flow control, soil stabilization) ■ Cycle nutrients ■ Remove air pollutants, emit oxygen ■ Maintain biodiversity ■ Generate soil ■ Sequester atmospheric carbon ■ Provide human and wildlife habitat ■ Provide employment ■ Provide for aesthetic enjoyment and recreation

■ In Canada's maritime provinces, collapse of the cod fishery in the early 1990s left 30,000 fishers dependent on government welfare payments and decimated the economies of 700 communities in Newfoundland alone (Milich 1999:628).

■ Urban water shortages in China–greatly aggravated by overextraction and pollution of nearby rivers and groundwater sources–cost urban economies an estimated US$11.2 billion per year in reduced industrial output and afflict nearly half of the nation's major cities (WRI et al. 1998:120).

■ Commercial cutting of India's forests and conversion of forests to agriculture have left the traditional system of village management of local forests in shambles. This has brought shortages of fuelwood and building materials to many of the 275 million rural Indians who draw on local forest resources (Gadgil and Guha 1992:113–145, 181–214; WCFSD 1999:59).

If this pattern holds, the loss of healthy ecosystems will ultimately act as a brake not just on local economies, but on national and global development as well.

An ecosystem is a community of interacting organisms and the physical environment they live in. Every hectare of the planet is part of an ecosystem.

Adopting a Human Perspective

All organisms have intrinsic value; grasslands, forests, rivers, and other ecosystems do not exist to serve humans alone. Nonetheless, *World Resources 2000–2001* deliberately examines ecosystems, and their management, from a human perspective because human use is the primary source of pressure on ecosystems today, far outstripping the natural processes of ecosystem change. In the modern world, virtually every human use of the products and services of ecosystems translates into an impact on those ecosystems. Thus, every use becomes either an opportunity for enlightened management or an occasion for degradation.

Responsible use of ecosystems faces fundamental obstacles, however. Typically, we don't even recognize ecosystems as cohesive units because they often extend across political and management boundaries. We look at them in pieces or concentrate on the specific products they yield. We miss their complexity, the interdependence of their organisms–the very qualities that make them productive and stable.

The challenge for the 21st century, then, is to understand the vulnerabilities and resilience of ecosystems, so that we can find ways to reconcile the demands of human development with the tolerances of nature. That requires learning to look at our activities through the living lens of ecosystems. In the end, it means adopting an ecosystem-oriented approach to managing the environment–an approach that respects the natural boundaries of ecosystems and takes into account their interconnections and feedbacks.

Sources of Wealth and Well-Being

Ecosystems are not just assemblages of species, they are systems combined of organic and inorganic matter and natural forces that interact and change. The energy that runs the system comes from the sun; solar energy is absorbed and turned into food by plants and other photosynthesizing organisms at the base of food chains. Water is the crucial element flowing through the system. The amount of water available, along with the temperature extremes and the sunlight the site receives, largely determine what types of plants, insects, and animals live there, and how the ecosystem is categorized.

Ecosystems are dynamic, constantly remaking themselves, reacting to natural disturbances and the competition among and between species. It is the complex, local interaction of the physical environment and the biological community that gives rise to the particular package of services and products that each ecosystem yields; it also is what makes each ecosystem unique and vulnerable.

Scale also is important. A small bog, a single sand dune, or a tiny patch of forest may be viewed as an ecosystem, unique in its mix of species and microclimate–a microenvironment. On a much larger scale, an ecosystem refers to more extensive communities–a 100 or 1,000 km^2 forest, or a major river system, each having many such microenvironments.

This edition of the World Resources Report examines ecosystems on an even larger scale. It considers five main types or categories of ecosystems: grasslands, forests, agroecosystems, freshwater systems, and coastal ecosystems. Together, these five major ecosystem types cover most of the Earth's surface and render the bulk of the goods and services people derive from ecosystems. Dividing ecosystems in this way allows us to examine them on a global scale and think in broad terms about the challenges of managing them sustainably.

Divisions between ecosystems are less important, however, than the linkages between them. Grasslands give way to savannas that segue into forests. Freshwater becomes brackish as it approaches a coastal area. Polar, island, mountain, and even urban ecosystems blend into and add to the mix. All these systems are tightly knit into a global continuum of energy and nutrients and organisms–the biosphere in which we live.

Direct and Indirect Benefits

The benefits that humans derive from ecosystems can be direct or indirect (Daily 1997:1–10; ESA 1997a:1–13). Direct benefits are harvested largely from the plants and animals in an ecosystem in the form of food and raw materials. These are the most familiar "products" an ecosystem yields–crops, livestock, fish, game, lumber, fuelwood, and fodder. Genetic resources that flow from the biodiversity of the world's ecosystems also provide direct benefits by contributing genes for improving the yield and disease resistance of crops, and for developing medicines and other products.

Indirect benefits arise from interactions and feedback among the organisms living in an ecosystem. Many of them take the form of services, like the erosion control and water purification and storage that plants and soil microorganisms provide in a watershed, or the pollination and seed dispersal that many insects, birds, and mammals provide. Other benefits are less tangible, but nonetheless highly valued: the scenic enjoyment of a sunset, for example, or the spiritual significance of a sacred mountain or forest grove (Kellert and Wilson 1993). Every year, millions of people make pilgrimages to outdoor holy places, vacation in scenic regions, or simply pause in a park or their gardens to reflect or relax. As the manifestation of nature, ecosystems are the psychological and spiritual backdrop for our lives.

Some benefits are global in nature, such as biodiversity or the storage of atmospheric carbon in plants and soils. Others are regional; watershed protection that prevents flooding far downstream is an example. But many ecosystem benefits are local, and these are often the most important, affecting people directly in many aspects of their daily lives. Homes, industries, and farms usually get their water supplies from local sources, for instance. Jobs associated with agriculture and tourism are local benefits as well. Urban and suburban parks, scenic vistas, and the enjoyments of backyard trees and wildlife are all local products that define our sense of place.

Because so many ecosystem goods and services are enjoyed locally, it follows that local inhabitants often suffer most when these benefits are lost. By the same token, it is local inhabitants who usually have the greatest incentive to preserve the ecosystems they depend on. In fact, local people hold enormous potential both for managing ecosystems sustainably and for damaging them through careless use. But local communities rarely exert full control over the ecosystems they inhabit; with the market for ecosystem goods becoming increasingly global, outside economic forces and government policies can overwhelm the best local intentions.

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Box 1.3 Water Filtration and Purification

At every stage of its journey between earth and sky, water can pick up pollutants and wastes—as it flows from a spring into streams, rivers, and the sea; as it pools into ponds and lakes; when it returns from the atmosphere as rain; when it soaks back into the soil after use on croplands or as effluent from sewage systems.

Fortunately, ecosystems can cleanse the water for us.

- Soils are inhabited by microorganisms that consume and recycle organic material, human and animal feces, and other potential toxins and pathogens. Deeper rocky layers of an aquifer may continue the cleansing process as water seeps through.
- Plants and trees hold soil in place as the water filters through. The vegetation interacts with fungi and soil microorganisms to generate many of soil's filtering capabilities.
- Freshwater bodies dilute pollutants where large quantities of municipal, agricultural, and industrial waters are drained or released.
- Wetlands intercept surface runoff, trap sediments from floodwaters, sequester metals, and excel at removing nitrogen and minerals from the water. A hectare of cattail marsh can consume three times as many nutrients as a hectare of grassland or forest (Trust for Public Land 1997:16).

In many places, however, we are straining nature's ability to filter and purify water. Where land is stripped of vegetation or overcultivated, rainwater flows downstream—unfiltered—over compacted and crusted soils. We have drained and converted half of all wetlands worldwide (Revenga et al. [PAGE] 2000), and we add levels of pollutants to watersheds that overwhelm their natural purification and dilution capacities.

To an extent, we can replace ecosystems' natural cleaning service with wastewater treatment plants, chlorination and other disinfectant processes, and artificial wetlands. But these options typically are expensive and do not provide the many other benefits supplied by forests and natural wetlands, such as wildlife habitat, open space, and flood protection.

The Costs of Clean Water

Here are some global and local indicators of our dependence on the water filtration and purification services that ecosystems provide. The human and economic costs of trying to replace them can be high.

- **Percentage of the world's population that lacks access to clean drinking water:**
  28 percent, or as many as 1.7 billion people (UNICEF 2000)
- **Number of people who die each year because of polluted drinking water, poor sanitation, and domestic hygiene:**
  5 million. Additionally, waterborne diseases such as diarrhea, ascariasis, dracunculiasis, hookworm, schistosomiasis, and trachoma cause illness in perhaps half the population of the developing world each year (WHO 1996).
- **Percentage of urban sewage in the developing world that is discharged into rivers, lakes, and coastal waters without any treatment:**
  90 percent (WRI et al. 1996:21)
- **Amount spent on bottled water worldwide in 1997:**
  $42 billion (Beverage Industry 1999)
- **Amount U.S. consumers spent on home water filtration systems in 1996:**
  $1.4 billion (Trust for Public Land 1997:24)
- **Cost incurred by households in Jakarta that must buy kerosene to boil the city's public water before use:**
  Rp 96 billion or US$52 million a year (1987 prices) (Bhatia and Falkenmark 1993:9)
- **Replacement cost of the water that would be lost if thirteen of Venezuela's National Parks that provide critical protection for urban water supplies were deforested:**
  $103 million to $206 million (net present value) (Reid forthcoming:6)
- **Typical cost to desalinize seawater:**
  $1.00–$1.50 per cubic meter (UNEP 1999:166)
- **Amount of open space and critical recharge area paved over every day in the United States:**
  11.7 km^2 (TPL 1997:3)
- **Estimated annual value of water quality improvement provided by wetlands along a 5.5-km stretch of the Alchovy River in Georgia, USA**
  $3 million (Lerner and Poole 1999:41)
- **Cost to construct wetlands to help process and recycle sewage produced by the 15,000 residents of Arcata, California:**
  $514,600 for a 40-ha system (Marinelli 1990). The city's alternative was to build a larger wastewater treatment plant at a cost of $25 million (Neander n.d.).

Box 1.4 Pollination

To many people, bees are known simply as prodigious honey makers and bats as cohorts of vampires and darkness. Rarely do we recognize that thousands of species of plants could not reproduce without their help. Wind pollinates some plants, but 90 percent of all flowering plants—including the great majority of the world's food crops—would not exist without animals and insects transporting pollen from one plant to another. Of the world's 100 most important crops, bees alone pollinate more than 70 percent (Nabhan and Buchmann 1997:136, 138). Besides food, pollinators help produce other agricultural products that enhance our lives, including dyes, fuelwood, tropical timbers, and textile fibers such as cotton and flax. The diets of many birds and mammals also are based on seeds and fruits produced by pollination.

No wonder, then, that agricultural specialists consider the current worldwide decline in pollinators a cause for alarm. Losses of pollinators have been reported on every continent except Antarctica. Some are on the verge of extinction; pesticides, mites, invasive species, and habitat loss and fragmentation are major killers. The consequences of continued pollinator declines could include billions of dollars in reduced harvests, cascades of plant and animal extinctions, and a less stable food supply.

Few studies have calculated the economic contribution of all pollinators, globally, to agricultural production and biodiversity, but

- The FAO recently estimated the 1995 contribution from pollination to the worldwide production of just 30 of the major fruit, vegetable, and tree crops (not including pasture or animal feeds) to be in the range of $54 billion (international dollars) per year (Kenmore and Krell 1998).

- Estimates of the value of pollination just for crop systems in the United States range from US$20 to $40 billion (Kearns et al. 1998:84).

Dependence of Selected U.S. Crops on Honey Bee Pollination

Crops	1998 Quantity Produced (metric tons)	Percentage of Crop Loss Without Honey Bee Pollination*
Temperate Fruits		
Almonds	393,000	90
Apples	5,165,000	80
Cherries	190,000	60
Oranges	12,401,000	30
Pears	866,500	50
Strawberries	765,900	30
Vegetables and Seeds		
Asparagus	92,800	90
Cabbage	2,108,200	90
Carrots	2,201,000	60
Cottonseed	7,897,000	30
Sunflowers	2,392,000	80
Watermelons	1,673,000	40

*Crop losses are estimates of loss if managed honey bee populations were eliminated in the United States, with no replacement of their services by alternative pollinators.
Sources: FAO 2000; Southwick and Southwick 1992.

Pollinators for the World's Flowering Plants (Angiosperms)

Pollinators	Estimated Number of Plant Species Pollinated	Total Percentage of Plant Species Pollinated*
Wind	20,000	8.30
Water	150	0.63
Bees	40,000	16.60
Hymenoptera	43,295	18.00
Butterflies/Moths	19,310	8.00
Flies	14,126	5.90
Beetles	211,935	88.30
Thrips	500	0.21
Birds	923	0.40
Bats	165	0.07
All Mammals	298	0.10
All Vertebrates	1,221	0.51
	351,923	

*Total percentage does not equal 100, reflecting pollination by more than one pollinator.
Source: Buchmann and Nabhan 1996:274.

Box 1.5 Biological Diversity

With an estimated 13 million species on Earth (UNEP 1995:118), few people take notice of an extinction of a variety of wheat, a breed of sheep, or an insect. Yet it is the very abundance of species on Earth that helps ecosystems work at their maximum potential. Each species makes a unique contribution to life.

- Species diversity influences ecosystem stability and undergirds essential ecological services. From water purification to the cycling of carbon, a variety of plant species is essential to achieving maximum efficiency of these processes. Diversity also bolsters resilience—an ecosystem's ability to respond to pressures—offering "insurance" against climate change, drought, and other stresses.

- The genetic diversity of plants, animals, insects, and microorganisms determines agroecosystems' productivity, resistance to pests and disease, and, ultimately, food security for humans. Extractions from the genetic library are credited with annual increases in crop productivity worth about $1 billion per year (WCMC 1992:433); yet the trend in agoecosystems is toward the replacement of polycultures with monocultures and diverse plant seed varieties with uniform seed varieties (Thrupp 1998: 23–24). For example, more than 2,000 rice varieties were found in Sri Lanka in 1959, but just five major varieties in the 1980s (WCMC 1992:427).

- Genetic diversity is fundamental to human health. From high cholesterol to bacteria fighters, 42 percent of the world's 25 top-selling drugs in 1997 were derived from natural sources. The global market value of pharmaceuticals derived from genetic resources is estimated at $75–$150 billion. Botanical medicines like ginseng and echinacea represent an annual market of another $20–$40 billion, with about 440,000 tons of plant material in trade, much of it originating in the developing world. Not fully captured by this commercial data is the value of plant diversity to the 75 percent of the world's population that relies on traditional medicine for primary health care (ten Kate and Laird 1999:1–2, 34, 101, 334–335).

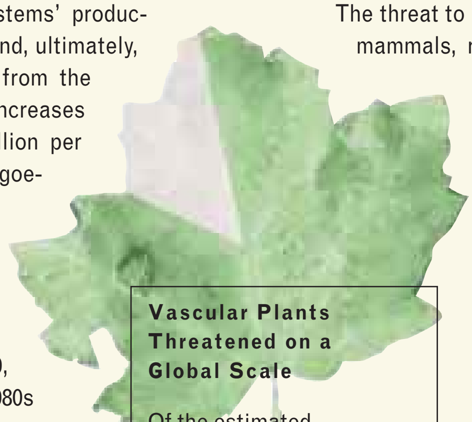
Origins of Top 150 Prescription Drugs in the United States of America

Origin	Total Number of Compounds	Natural Product	Semi-synthetic	Synthetic	Percent
Animal	27	6	21	—	23
Plant	34	9	25	—	18
Fungus	17	4	13	—	11
Bacteria	6	5	1	—	4
Marine	2	2	0	—	1
Synthetic	64	—	—	64	43
Totals	150	26	60	64	100

Source: Grifo et al. 1997:137.

The threat to biodiversity is growing. Among birds and mammals, rates may be 100–1,000 times what they would be without human-induced pressures—overexploitation, invasive species, pollution, global warming, habitat loss, fragmentation, and conversion (Reid and Miller 1989). Regional extinctions, particularly the loss of populations of some species in tropical forests, may be occurring 3–8 times faster than global species extinctions (Hughes et al. 1997:691).

Such localized extinctions may be just as significant as the extinction of an entire species worldwide. Most of the benefits and services provided by species working together in an ecosystem are local and regional. If a keystone species is lost in an area, a dramatic reorganization of the ecosystem can occur. For example, elephants disperse seeds, create water holes, and trample vegetation through their movements and foraging. The extinction of elephants in a piece of savanna can cause the habitat to become less diverse and open and cause water holes to silt up, which would have dramatic repercussions on other species in the region (Goudie 2000:67).



Vascular Plants Threatened on a Global Scale

Of the estimated 250,000–270,000 species of plants in the world, only 751 are known or suspected to be extinct. But an enormous number—33,047, or 12.5 percent—are threatened on a global scale. Even that grim statistic may be an underestimate because much information about plants is incomplete, particularly in the tropics.

Source: WCMC/IUCN 1998.

Box 1.6 Carbon Storage

Carbon is the basis of life, cycling through the oceans, atmosphere, vegetation, and soils. Through photosynthesis, plants take up carbon as carbon dioxide (CO_2) and convert it to sugar for energy; animals consume the plants; and when both plants and animals die, carbon is returned to the atmosphere as the organisms decay. But ever-increasing emissions of carbon from fossil fuel combustion and deforestation are unbalancing the global carbon cycle; there's less carbon in the soil and vegetation and more in the atmosphere. Because CO_2 in the atmosphere captures the sun's heat, increasing amounts destabilize the global climate.

It is estimated that prior to the 18th century, increases in atmospheric carbon were less than 0.01 billion metric tons of carbon (GtC) per year (Ciaias 1999). The Industrial Revolution and subequent global development greatly increased fossil fuel emissions, as did the clearing of forests and other land-use changes that release carbon. By 1998, there was approximately 176 GtC more carbon in the atmosphere than in 1850, an increase of nearly 30 percent (IPCC 2000:4). Today, human activities emit an estimated 7.9 GtC to the atmosphere annually (IPCC 2000:5). The oceans absorb slightly less than 30 percent of this carbon and terrestrial ecosystems absorb slightly more, but that leaves 40 percent of yearly emissions to accumulate in the atmosphere (IPCC 2000:5).

Reducing anthropogenic carbon emissions is one way to mitigate climate change. Other ways depend on maintaining the ability of ecosystems to absorb carbon. Through photosynthesis, plants provide the most effective and efficient way to recapture and store atmospheric carbon.

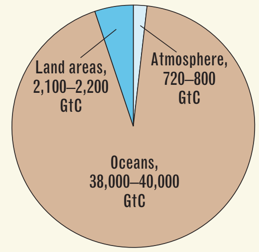
- Oceans are the major carbon reservoir or "sink." Through chemical and biological processes, including phytoplankton's growth and decay, oceans store roughly 50 times more carbon than is in the atmosphere, mostly as dissolved inorganic carbon (IPCC 2000:30).
- Soil and its organic layer store about 75 percent of total terrestrial carbon (Brown 1998:16). Most of the carbon released to the atmosphere in the last 2 centuries occurred as grasslands and forests were converted to agricultural uses.
- Forests are the most effective terrestrial ecosystem for recapturing carbon, but not all forests offer the same sequestration benefits. Faster-growing young trees absorb about 30 percent more carbon than mature wood, but an older forest stores more carbon overall in the soil and in above- and below-ground vegetation than a tree plantation of the same size. Latitude, climate, species mix, and other biological and ecosystem factors also affect carbon fluxes in forests (see Brown 1998:10).

Earth's Annual Carbon Budget, 1989–98

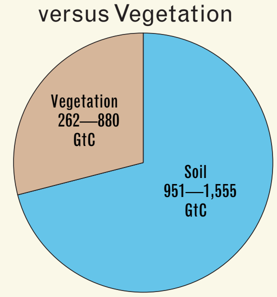
Type of emission or uptake	Gigatons of carbon per year
Human-induced emissions into the atmosphere	
Emissions from consumption and production (fossil fuel combustion and cement production)	6.3 ± 0.6
Net emissions from land use change (fires, deforestation, agriculture)	1.6 ± 0.8
Ocean and terrestrial capture from the atmosphere	
Net uptake by oceans (photosynthesis and ocean capture minus ocean release)	2.3 ± 0.8
Net uptake by terrestrial ecosystems (photosynthesis and terrestrial storage minus decay and respiration)	2.3 ± 1.3
Carbon added to the atmosphere each year	3.3 ± 0.2

Source: IPCC, 2000:5. Error limits correspond to an estimated 90 percent confidence interval. Emissions from consumption and production are calculated with high confidence. Net emissions from land use change are estimated from observed data and models. Uptake by oceans is based on models. Carbon added to the atmosphere each year is measured with high accuracy. Uptake by terrestrial ecosystems is an imputed amount (the difference between total emissions and estimated uptake by oceans and atmosphere).

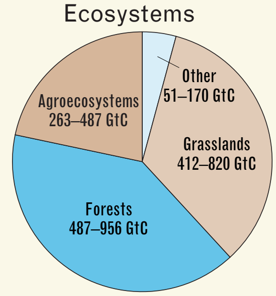
Global Carbon Storage



Carbon Stored in Soil versus Vegetation



Carbon Storage in Terrestrial Ecosystems



Sources: IPCC 1996:63; Matthews et al. [PAGE] 2000. Data on carbon stored in soil versus vegetation and in terrestrial ecosystems is derived from the International Geosphere-Biosphere Programme. Thus estimated share of carbon in each ecosystem varies slightly from PAGE results in Chapter 2, because PAGE definitions of ecosystems accommodate some overlap of transitional areas.

Managing Ecosystems: Trade-Offs and Costs

People often modify or manage ecosystems to enhance the production of one or more goods, such as crops or trees or water storage. The degree of modification varies widely. Some ecosystems are heavily affected, others remain relatively unaltered, and management ranges through various types of use–from nondestructive rubber tapping, to clear-cutting, and even to single-species tree plantations. Similarly, aquatic ecosystems can range from free-flowing rivers to artificial ponds for raising fish or shrimp.

Sometimes the dividing line between "natural" and "managed" ecosystems is clear. A farm is obviously a highly managed ecosystem–an *agroecosystem*. But often management is more subtle: a fence dividing a rangeland, a forest access road, a seawall protecting a private beach, a mountain stream diverted to supply a village with water. In any case, human influence, even if it is not intensive management, is pervasive among all ecosystem types.

The decision to manage or alter an ecosystem involves trade-offs. Not all benefits can be obtained at the same time, and maximizing one benefit may reduce or eliminate others. For example, converting a natural forest to a tree plantation may increase the production of marketable pulp or lumber, bringing high monetary returns per hectare, but it generally decreases biodiversity and habitat value compared with a natural forest. Likewise, damming a river may increase the water available for irrigation or hydroelectric power production and decrease the danger of floods, but it may also disrupt natural breeding cycles of fish and damage aquatic habitats downstream by diverting water or releasing it at inappropriate times.

To a certain extent, we accept these trade-offs as necessary to efficiently produce food, power, and the other things we need. Historically, we have been hugely successful at selectively increasing those ecosystem goods we value most. It is only recently that we have begun to focus on the dangers of such trade-offs.

The environmental awareness and knowledge we have gained over the last 30 years have taught us that there are limits to the amount of alteration that ecosystems can tolerate and still remain productive. The loss of a hectare of forest habitat or a single plant or insect species in a grassland may not affect the functioning of the system drastically or immediately, but it may push the system toward a threshold from which it cannot recover.

Biological thresholds remind us that it is the cumulative effects of human activities that factor most in ecosystem decline. A series of small changes, each seemingly harmless, can result in cumulative impacts that are irreversible; this is sometimes called the "tyranny of small decisions." The progressive conversion of a mangrove forest is a good example.

Mangroves serve as nurseries for many species of fish and shellfish that then leave the mangrove and are later caught in surrounding waters. The value of this seafood is often many times greater than the wood, crabs, and other fish harvested within the mangrove forest itself. But in regions where mangroves grow, raising shrimp is a profitable enterprise. Converting small sections of the mangrove to shrimp ponds may have little impact on the fish harvest in surrounding waters. But if shrimp growers gradually convert the entire mangrove to ponds, the local fishery will collapse at some point.

Determining the threshold between sustainability and collapse is no easy matter. This is one reason why it is difficult to manage ecosystems responsibly. Ecosystems are naturally resilient and can accommodate considerable disturbance. But how much? Our understanding of ecosystems, although it has increased rapidly, is still too limited to answer this crucial question. For most ecosystems, we have yet to master the details of how organisms and environment interact and connect, how changes in one element of the system reverberate through the whole, or what factors moderate the speed of change in an ecosystem. At a global level, we still lack even the most basic statistics on ecosystems–how much and where they have been modified, for example, or how their productivity has changed over time. So at both an individual ecosystem level and at a larger national or regional level, we find it nearly impossible to predict how close to the edge our management has brought us, or to determine the extent of the trade-offs we have already made.

How Are Ecosystems Degraded?

Human activities have put global ecosystems under siege:

- Some 75 percent of the major marine fish stocks are either depleted from overfishing or are being fished at their biological limit (Garcia and Deleiva In press).

- Logging and conversion have shrunk the world's forest cover by as much as half, and roads, farms, and residences are rapidly fragmenting what remains into smaller forest islands (Bryant et al. 1997:9).

- Some 58 percent of coral reefs are potentially threatened by destructive fishing practices, tourist pressures, and pollution (Bryant et al. 1998:6).

- Fully 65 percent of the roughly 1.5 billion ha of cropland worldwide have experienced some degree of soil degradation (Wood et al. [PAGE] 2000).

- Overpumping of groundwater by the world's farmers exceeds natural recharge rates by at least 160 billion m^3 per year (Postel 1999:255).

The pressures responsible for these declines continue to increase in most cases, accelerating ecosystem change (Vitousek et al. 1997:498). (See Chapter 2 for a detailed look at ecosystem conditions.)

In many instances, the principal pressure on ecosystems is simple overuse–too much fishing, logging, water diversion, or tourist traffic. Overuse not only depletes the plants and wildlife that inhabit the ecosystem, but also can fragment the system and disrupt its integrity–all factors that diminish its productive capacity.

Outright conversion of forests, grasslands, and wetlands to agriculture or other uses is a second principal pressure reshaping global ecosystems and the benefits they give. Invasive species, air and water pollution, and the threat of climate change are key ecosystem pressures as well.

AGRICULTURAL CONVERSION

When farmers convert a natural ecosystem to agriculture, they change both the composition of the ecosystem and how it functions. In agroecosystems, naturally occurring plants give way to a few nonnative crop species. Wildlife is pushed to the margins of the system. Pesticides may decimate insect populations and soil microorganisms. Soil compaction causes water to infiltrate the soil differently, and runoff and erosion may increase. The cycle of nutrients through the system shifts as fertilizers are applied and soil bacteria and vegetation change.

The result is a substantial change in benefits. Food production–clearly a boon–surges, but most other benefits suffer to some degree. Biodiversity and the benefits associated with it, such as production of a wide variety of wild plants and animals and the availability of diverse genetic material, often decline substantially. At the scale of conversion prevalent today, that can mean huge biodiversity losses in the aggregate. One study estimates that in the species-rich tropics, forest conversion commits two to five species of plants, insects, birds, or mammals to extinction each hour (Hughes et al. 1997:691).

Agriculture in converted areas may also increase pressures on surrounding ecosystems through the introduction of nonnative species that become invasive and displace indigenous species. Bioinvasions are second only to habitat loss, usually through conversion, as a threat to global biodiversity. In South Africa, nonnative tree species originally

(continues on p. 22)

Conversion represents the ultimate in human impact on an ecosystem, and the most abrupt change in the goods and services it produces.

Box 1.7 Linking People and Ecosystems: Human-Induced Pressures

Thousands of used tires are shipped into the United States from Asia for retreading and resale every year. Some have contained larvae of the Asian tiger mosquito. Already the mosquito has established itself in 25 states, feeding on mammals and birds. Some of the mosquitos carry the equine encephalitis virus, often fatal to horses and people.

Behind all the pressures impinging on ecosystems are two basic drivers: human population growth and increasing consumption.

A logging concessionaire in Gabon clear-cuts areas in its assigned tract, paying the government a sizable permit fee. Its contract with the government, which owns the tract, allows it to harvest timber at below market rates if it replants the area. The concessionaire plants seedlings but does nothing to stop the ensuing erosion of topsoil, the siltation of nearby streams, and the migration or loss of wildlife that depended on the mature forest.

Small-scale, artisanal miners from Venezuela illegally cross the unmarked border into Brazil deep in the Amazonian rainforest. Although they have no legal right to mine there for gold, they can eke out a living for their families if they keep their operation small and move frequently from place to place. To increase their chances of extracting gold, they add mercury to the sluice, although the toxic metal is technically banned. Like thousands of other independents in the area, they let the mixture run off directly into a tributary where it poisons local fish.

Primary Human-Induced Pressures on Ecosystems

Ecosystem	Pressures	Causes
Agroecosystems 	■ Conversion of farmland to urban and industrial uses ■ Water pollution from nutrient runoff and siltation ■ Water scarcity from irrigation ■ Degradation of soil from erosion, shifting cultivation, or nutrient depletion ■ Changing weather patterns	■ Population growth ■ Increasing demand for food and industrial goods ■ Urbanization ■ Government policies subsidizing agricultural inputs (water, research, transport) and irrigation ■ Poverty and insecure tenure ■ Climate change
Coastal Ecosystems 	■ Overexploitation of fisheries ■ Conversion of wetlands and coastal habitats ■ Water pollution from agricultural and industrial sources ■ Fragmentation or destruction of natural tidal barriers and reefs ■ Invasion of nonnative species ■ Potential sea level rise	■ Population growth ■ Increasing demand for food and coastal tourism ■ Urbanization and recreational development, which is highest in coastal areas ■ Government fishing subsidies ■ Inadequate information about ecosystem conditions, especially for fisheries ■ Poverty and insecure tenure ■ Uncoordinated coastal land-use policies ■ Climate change
Forest Ecosystems 	■ Conversion or fragmentation resulting from agricultural or urban uses ■ Deforestation resulting in loss of biodiver-sity, release of stored carbon, air and water pollution ■ Acid rain from industrial pollution ■ Invasion of nonnative species ■ Overextraction of water for agricultural, urban, and industrial uses	■ Population growth ■ Increasing demand for timber, pulp, and other fiber ■ Government subsidies for timber extraction and logging roads ■ Inadequate valuation of costs of industrial air pollution ■ Poverty and insecure tenure
Freshwater Systems 	■ Overextraction of water for agricultural, urban, and industrial uses ■ Overexploitation of inland fisheries ■ Building dams for irrigation, hydropower, and flood control ■ Water pollution from agricultural, urban, and industrial uses ■ Invasion of nonnative species	■ Population growth ■ Widespread water scarcity and naturally uneven distribution of water resources ■ Government subsidies of water use ■ Inadequate valuation of costs of water pollution ■ Poverty and insecure tenure ■ Growing demand for hydropower
Grassland Ecosystems 	■ Conversion or fragmentation owing to agricultural or urban uses ■ Induced grassland fires resulting in loss of biodiversity, release of stored carbon, and air pollution ■ Soil degradation and water pollution from livestock herds ■ Overexploitation of game animals	■ Population growth ■ Increasing demand for agricultural products, especially meat ■ Inadequate information about ecosystem condi-tions ■ Poverty and insecure tenure ■ Accessibility and ease of conversion of grass-

Box 1.8 Invasive Species

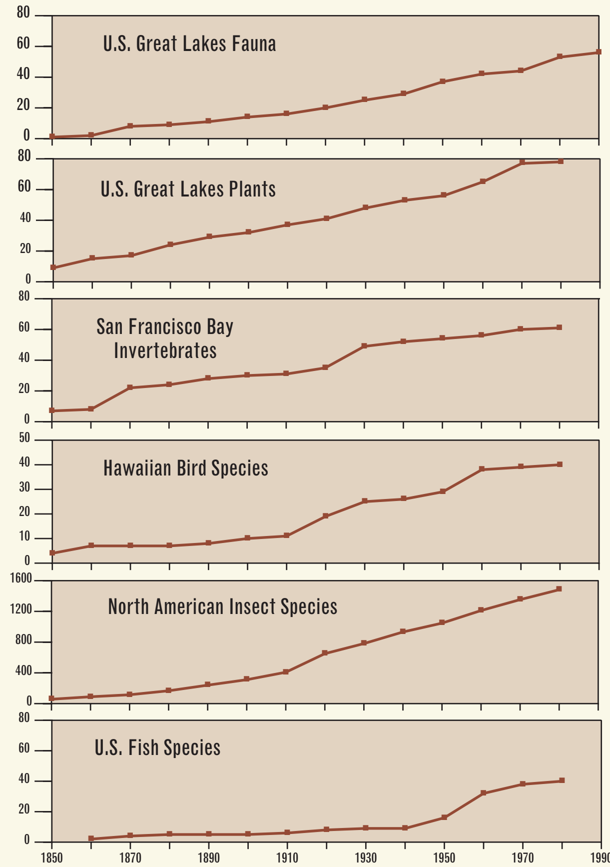
No ecosystem is immune to the threat of invasive species. They crowd out native plants and animals, degrade habitats, and contaminate the gene pools of indigenous species. Island ecosystems are particularly vulnerable because of their high levels of endemism and isolation; many island species evolved without strong defenses against invaders. On Guam, for example, the brown tree snake from Papua New Guinea has eaten twelve of the island's fourteen flightless bird species, causing them to become extinct in the wild. In New Zealand, roughly two-thirds of the land surface is covered by exotic plants (Bright 1998:115). Half of Hawaii's wild species are nonnative (OTA 1993:234).

Invasive species are a costly problem:

- Leidy's comb jellyfish, native to the Atlantic coast of the Americas, was pumped out of a ship's ballast tank into the Black Sea in the early 1980s. Its subsequent invasion has nearly wiped out Black Sea fisheries, with direct costs totaling $250 million by 1993 (Travis 1993:1366). Meanwhile, the zebra mussel, native to the Caspian Sea, was similarly dumped into the United States' Great Lakes in the late 1980s. Controlling this invader, which colonizes and clogs water supply pipes, costs area industries millions of dollars per year—perhaps $3–$5 billion total to date (Bright 1998:182).
- The Asian tiger mosquito, now spreading throughout the world, is a potential transmitter of 18 viral pathogens (Bright 1998:169). One of those pathogens is the West Nile virus. In 1999, a director with the U.S. Geological Survey noted that recent crow die-offs in Wisconsin suggest that the West Nile virus could be more deadly to North American bird species than to species in Africa, the Middle East, and Europe, where the virus is normally found (USGS 1999:1).
- In South Africa's Western Cape, invasive trees threaten to cut Cape Town's water supply by about a third in the next century. (See Chapter 3, "Working for Water.")

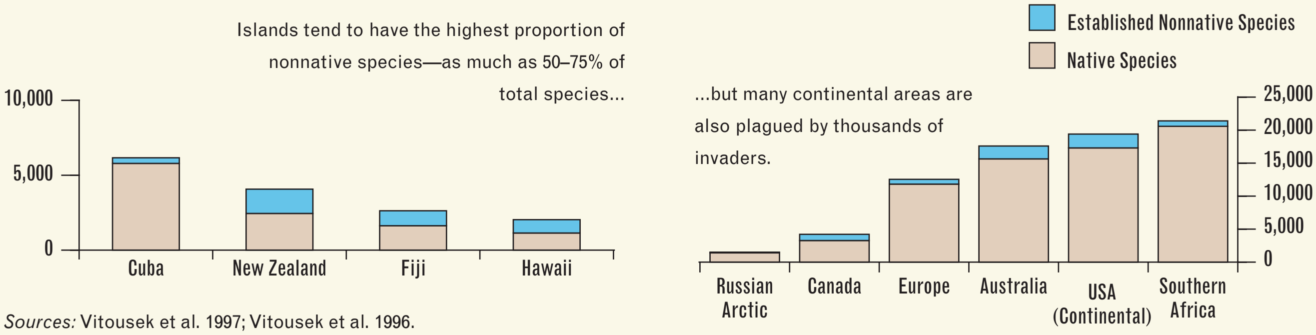
Regulation and control are complicated by the many modes of invasion. Some species find their way to new habitats by accident: they hitchhike in ships or planes, on traded goods or travelers. Other species are intentionally introduced for hunting, fishing, or pest control. Still other invasives "escape" their intended confines, like the seaweed *Caulerpa taxifolia*, which was originally intended for aquariums in Europe but now also carpets thousands of acres of French and Italian coastlines (MCBI 1998).

Cumulative Number of Nonnative Species in U.S. Regions by Decade of Introduction



Source: Ruesink et al. 1995:466.

Native vs. Nonnative Plant Species in Selected Regions



Sources: Vitousek et al. 1997; Vitousek et al. 1996.

Box 1.9 Trade-Offs: Lake Victoria's Ecosystem Balance Sheet

Trade-offs among various ecosystem goods and services are common in the management of ecosystems, although rarely factored into decision making. For example, farmers can increase food production by applying fertilizer or expanding the land they have under cultivation, but these strategies harm other goods and services from the land they farm, like water quality and biodiversity.

In very few cases do resource managers or policy makers fully weigh the various trade-offs among ecosystem goods and services. Why? In some cases, lack of information is the obstacle. Typically, not much is known about the likely impact of a particular decision on nonmarketed ecosystem services such as water purification or storm protection. Or, if such information does exist, it may not include estimates of the economic costs and benefits of the trade-offs. In other cases the obstacle is institutional. A government's Ministry of Agriculture naturally focuses primarily on its mission of food production and lacks the expertise or mandate to consider impacts of its actions on water quality, carbon sequestration, or coastal fisheries, for instance.

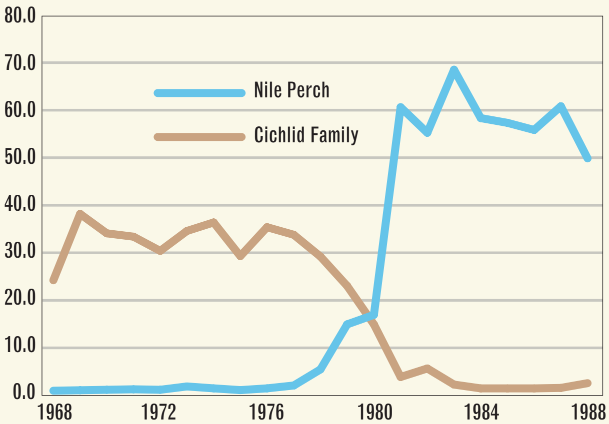
The example of Africa's Lake Victoria illustrates how profound and unpredictable trade-offs can be when management decisions are made without regard to how the ecosystem will react. Lake Victoria, bounded by Uganda, Tanzania, and Kenya, is the world's largest tropical lake and its fish are an important source of food and employment for the region's 30 million people. Before the 1970s, Lake Victoria contained more than 350 species of fish from the cichlid family, of which 90 percent were endemic, giving it one of the most diverse and unique assemblages of fish in the world (Kaufman 1992:846–847, 851). Today, more than half of these species are either extinct or found only in very small populations (Witte et al. 1992:1, 17).

The collapse in the lake's biodiversity was caused primarily by the introduction of two exotic fish species, the Nile perch and Nile tilapia, which fed on and outcompeted the cichlids for food. But other pressures factored in the collapse as well. Overfishing depleted native fish stocks and provided the original impulse for introducing the Nile perch and tilapia in the early 1950s. Land-use changes in the watershed dumped pollution and silt into the lake, increasing its nutrient load and causing algal blooms and low oxygen levels in deeper waters—a process called eutrophication. The result of all these pressures was a major reorganization of the lake's fishlife. Cichlids once accounted for more than 80 percent of Lake Victoria's biomass and provided much of the fish catch (Kaufman 1992:849). By 1983, Nile perch made up almost 70 percent of the catch, with Nile tilapia and a native species of sardine making up most of the balance (Achieng 1990:20).

Although the introduced fishes devastated the lake's biodiversity, they did not not destroy the commercial fishery. In fact, total fish production and its economic value rose considerably.

Trading Biodiversity for Export Earnings

Percentage Contribution to Lake Victoria Fish Catch (Kenya Only), 1968–1988



Source: Achieng 1990:20, citing Fisheries Department of Kenya, *Statistical Bulletin.*

Today, the Nile perch fishery produces some 300,000 metric tons of fish (FAO 1999), earning $280–$400 million in the export market—a market that did not exist before the perch was introduced (Kaufman 2000). Unfortunately, local communities that had depended on the native fish for decades did not benefit from the success of the Nile perch fishery, primarily because Nile perch and tilapia are caught with gear that local fishermen could not afford. And, because most of the Nile perch and tilapia are shipped out of the region, the local availability of fish for consumption has declined. In fact, while tons of perch find their way to diners as far away as Israel and Europe, there is evidence of protein malnutrition among the people of the lake basin (Kaufman 2000).

The sustainability of the Nile perch fishery is also a concern. Overfishing and eutrophication are major threats to the fishery, and the stability of the entire aquatic ecosystem—so radically altered over a 20-year span—is in doubt. The ramifications of the species introductions can even be seen in the watershed surrounding Lake Victoria. Drying the perch's oily flesh to preserve it requires firewood, unlike the cichlids, which could be air-dried. This has increased pressure on the area's limited forests, increasing siltation and eutrophication, which, in turn, has further unbalanced the precarious lake ecosystem (Kaufman 1992:849–851; Kaufman 2000).

In sum, introducing Nile perch and tilapia to Lake Victoria traded the lake's biodiversity and an important local food source for a significant—although perhaps unsustainable—source of export earnings. When fisheries managers introduced these species, they unknowingly altered the balance of goods and services the lake produced and redistributed the economic benefits flowing from them. Knowing the full dimensions of these trade-offs, would they make the same decision today?

imported for forest plantations have invaded a third of the nation's mountain watersheds. The invading plants have depleted freshwater supplies, displaced thousands of native plants, and altered animal habitats, precipitating a countrywide eradication program (see Chapter 3, Working for Water).

Not all agricultural conversions are equal. Some may retain or carefully harbor aspects, and services, of the original ecosystem. In Sumatra, some traditional agroforestry systems (where trees and crops are mixed) contain as much as half the species diversity found in the neighboring forest. Traditional Central American coffee plantations raise their coffee plants in the shade of native trees that provide essential bird habitat and a range of secondary products. Even many modern agricultural systems include careful tillage practices aimed at preventing erosion and preserving the soil's water-holding properties and beneficial soil organisms.

URBAN AND INDUSTRIAL CONVERSION

Unfortunately, conversion to urban or industrial uses is usually not so benign. Radical changes in ecosystem benefits occur as structures and paved surfaces replace native plant and animal communities. As city dwellers cover permeable soil surfaces with concrete and asphalt, watershed functions decline. With few places to sink in, rainfall runs off quickly and local flooding can ensue. Still, the more simplified ecosystems in parks, backyards, and vacant lots do provide important services–shade, areas for relaxation, removal of air pollutants, and even some wildlife habitat–that city dwellers enjoy.

POLLUTION AND CLIMATE CHANGE

The effects of pollution put indirect pressures on ecosystems. Acid rain, smog, wastewater releases, pesticide and fertilizer residues, and urban runoff all have toxic effects on ecosystems–sometimes at great distances from the activities that gave rise to the pollution. For example, nitrogen releases from industry, transportation, and agriculture have seriously altered the global nitrogen cycle, affecting the function of both terrestrial and aquatic ecosystems.

Biologically active, or "fixed," nitrogen is an essential nutrient for all plants and animals. But nitrogen releases from human sources like fertilizers and fossil fuels now exceed those from natural sources, leaving ecosystems awash in fixed nitrogen. The impacts include an overgrowth of algae in waterways, caused by the fertilizing effect of excess nutrients; acidification of soils and loss of some soil nutrients; loss of plants adapted to natural low-nitrogen conditions; and more smog and greenhouse warming from higher levels of nitrogen oxides in the atmosphere (ESA 1997b:1–14).

Climate change from the buildup of greenhouse gases provides an even more profound example of the potential for pollution to inadvertently disrupt ecosystems on a global scale. Scientists warn that global ecosystems could undergo a major reorganization as Earth's vegetation redistributes itself to accommodate rising temperatures, changes in rainfall patterns, and the potential fertilizing effects of more carbon dioxide (CO_2) in the atmosphere. Computer models estimate that doubling atmospheric CO_2 levels from preindustrial levels, which will likely happen within the next century, could trigger broad changes in the distribution, species composition, or leaf density of roughly one-third of global forests. Tundra areas could also shrink substantially and coastal wetlands shift markedly, among many other effects. It is not at all clear how present ecosystems would weather such significant changes or how these changes might affect their productivity (Houghton et al. 1997:30).

What Drives Degradation?

Behind all the pressures impinging on ecosystems are two basic drivers: human population growth and increasing consumption. Closely related are a suite of economic and political factors–market forces, government subsidies, globalization of production and trade, and government corruption–that influence what and how much we consume, and where it comes from. Issues of poverty, land tenure, and armed conflict are also significant factors in how people treat the ecosystems they live in and extract goods and services from.

DEMOGRAPHICS AND CONSUMPTION

Population growth is in many ways the most basic of environmental pressures because everyone requires at least some minimum of water, food, clothing, shelter, and energy–all ultimately harvested directly from ecosystems or obtained in a way that affects ecosystems. Over the next 50 years, demographers expect the world's population to grow from the current 6 billion to 9 billion or so, with most of this growth taking place in developing nations (UN Population Division 1998:xv). Simple arithmetic dictates this will increase the demand for ecosystem products and increase the pressure on global food and water supplies.

Increasing pressure on ecosystems is not simply a matter of population growth, however. In fact, it is more a matter of how much and what we consume. Global increases in consumption have greatly outpaced growth in population for decades. From 1980 to 1997, the global economy nearly tripled to some US$29 trillion, yet the world population increased only 35 percent (World Bank 1999b:194; UN Population Division 1998:xv). Per capita consumption levels are rising quickly in many nations as their economies develop; and consumption levels in most industrialized nations are already remarkably high. This higher consumption of everything from paper to refrigerators to computers to oil is the result of greater wealth. Personal-income levels have climbed steadily in developed nations and a number of rapidly developing countries such as China, India, and Thailand; and consumption has increased accordingly.

At the same time, the world's economy has become more integrated. Trade has made consumer markets more global. Industries have become more international and less tied to a single place or production facility. This "globalization" means that consumers derive goods and services from ecosystems around the world, with the costs of use largely separated from the benefits. This tends to hide the environmental costs of increased consumption from those doing the consuming.

For example, a housing contractor in Los Angeles installs copper plumbing but has no way of knowing whether the copper has come from the infamous Ok Tedi mine in Papua New Guinea. The giant mine, which is owned by an international consortium of companies, dumps 80,000 tons per day of untreated tailings into the Ok Tedi River, destroying much of the river's aquatic life and disrupting the subsistence lifestyle of the local Wopkaimin people. Globalization means the eventual homeowners who benefit from the copper have no knowledge of their link with the damaged Ok Tedi watershed and don't suffer the environmental costs (Da Rosa and Lyon 1997:223–226).

It's not surprising that those doing the most consuming live in developed countries, but the unevenness of consumption of ecosystem goods and services worldwide is striking. It takes roughly 5 ha of productive ecosystem to support the average U.S. citizen's consumption of goods and services versus less than 0.5 ha to support consumption levels of the average citizen in the developing world (GEF 1998:84). Annual per capita CO_2 emissions are more than 11,000 kg in industrial countries, where there are far more cars, industries, and energy-consuming appliances. This compares with less than 3,000 kg in Asia (UNDP 1998:57). On average, someone living in the developed world spends nearly $16,000 (1995 international dollars) on private consumption each year, compared with less than $350 spent by someone in South Asia and sub-Saharan Africa (UNDP 1998:50).

Of course, greater consumption of nutritious food, safe housing, clean water, and adequate clothing is absolutely necessary to relieve poverty in many nations, particularly in the developing world. In the words of the UN's 1948 Universal Declaration of Human Rights, "Everyone has the right to a standard of living adequate for the health and well-being of himself and of his family" (Article 25). Accommodating such basic human development, however, is far from the

(continues on p. 30)

Box 1.10 Domesticating the World: Conversion of Natural Ecosystems

Since the dawn of settled agriculture, humans have been altering the landscape to secure food, create settlements, and pursue commerce and industry. Croplands, pastures, urban and suburban areas, industrial zones, and the area taken up by roads, reservoirs, and other major infrastructure all represent conversion of natural ecosystems.

These transformations of the landscape are the defining mark of humans on Earth's ecosystems, yielding most of the food, energy, water, and wealth we enjoy, but they also represent a major source of ecosystem pressure.

Conversion alters the structure of natural ecosystems, and how they function, by modifying their basic physical properties—their hydrology, soil structure, and topography—and their predominant vegetation. This basic restructuring changes the complement of species that inhabits the ecosystem and disrupts the complex interactions that typified the original ecosystem. In many cases, the converted ecosystem is simpler in structure and less biologically diverse. In fact, habitat loss from conversion of natural ecosystems represents the primary driving force in the loss of biological diversity worldwide (Vitousek et al. 1997:495).

Historically, expansion of agriculture into forests, grasslands, and wetlands has been the greatest source of ecosystem conversion. Within the last century, however, expansion of urban areas with their associated roads, power grids, and other infrastructure, has also become a potent source of land transformation.

- Worldwide, humans have converted approximately 29 percent of the land area—almost 3.8 billion ha—to agriculture and urban or built-up areas (WRR calculations).

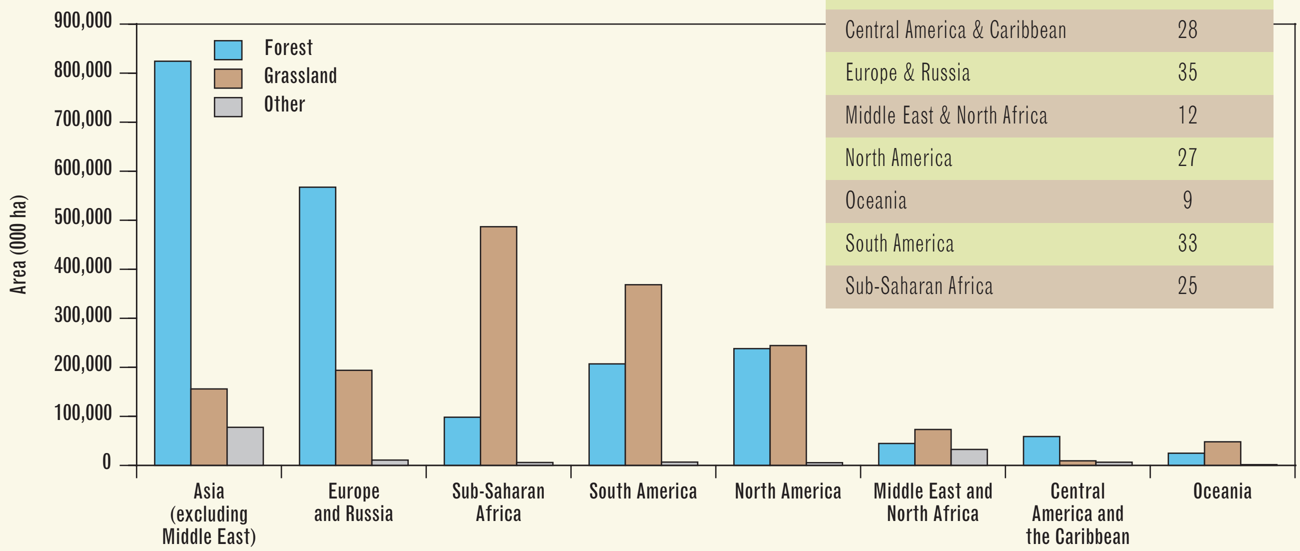
- Agricultural conversion to croplands and managed pastures has affected some 3.3 billion ha—roughly 26 percent of the land area. All totaled, agriculture has displaced one-third of temperate and tropical forests and one-quarter of natural grasslands. Agricultural conversion is still an important pressure on natural ecosystems in many developing nations; however, in some developed nations agricultural lands themselves are being converted to urban and industrial uses (WRR calculations).

- Urban and built-up areas now occupy more than 471 million ha—about 4 percent of land area. Almost half the world's population—some 3 billion people—live in cities. Urban populations increase by another 160,000 people daily, adding pressure to expand urban boundaries (UNEP 1999:47). Suburban sprawl magnifies the effect of urban population growth, particularly in North America and Europe. In the United States, the percentage of people living in urban areas increased from 65 percent of the nation's population in 1950 to 75 percent in 1990, but the area covered by cities roughly doubled in size during the same period (PRB 1998).

- Future trends in land conversion are difficult to predict, but projections based on the United Nations' intermediate-range population growth model suggest that an additional one-third of the existing global land cover could be converted over the next 100 years (Walker et al. 1999:369).

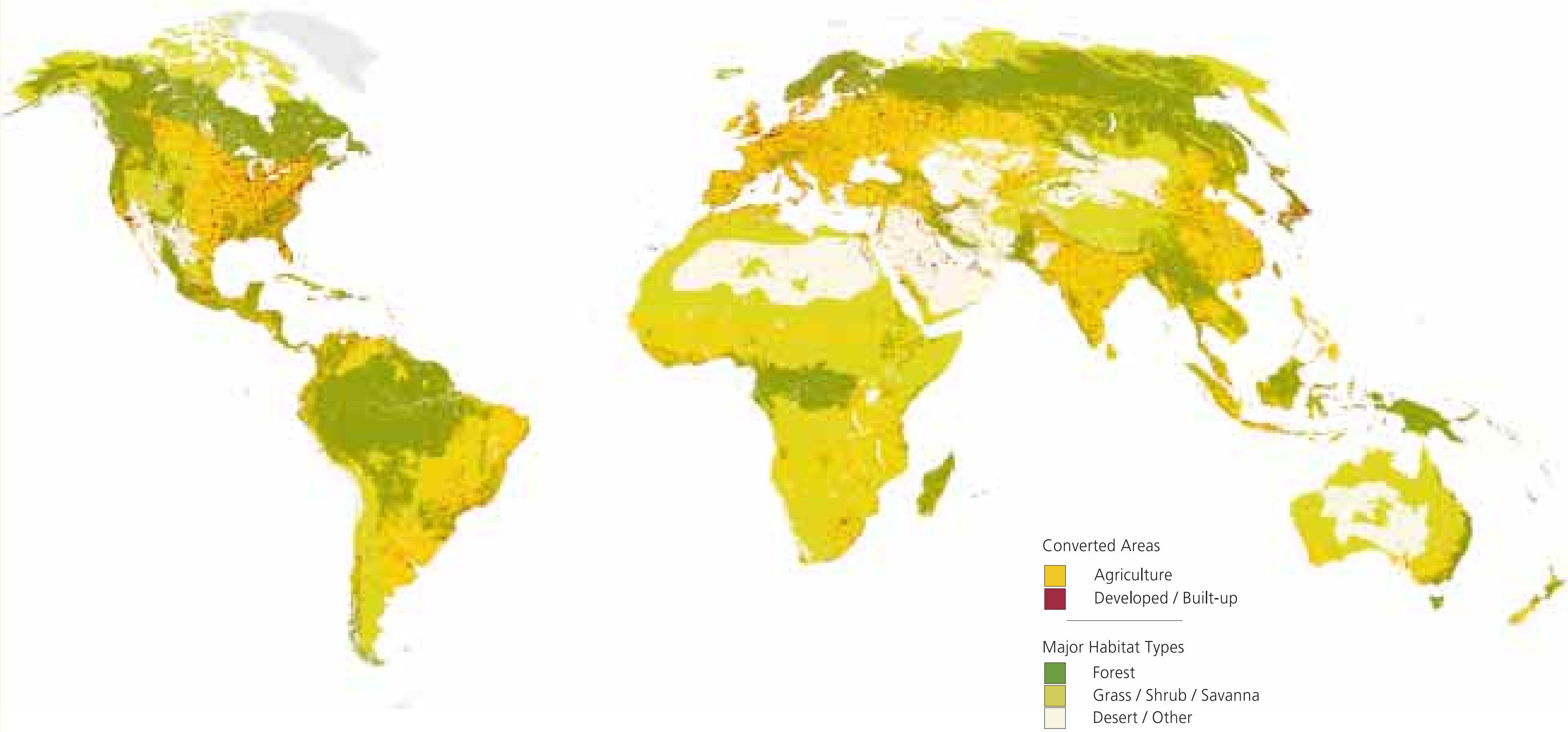
Region	Percentage of Land Converted
Asia (excl. Middle East)	44
Central America & Caribbean	28
Europe & Russia	35
Middle East & North Africa	12
North America	27
Oceania	9
South America	33
Sub-Saharan Africa	25

Area Converted by Region



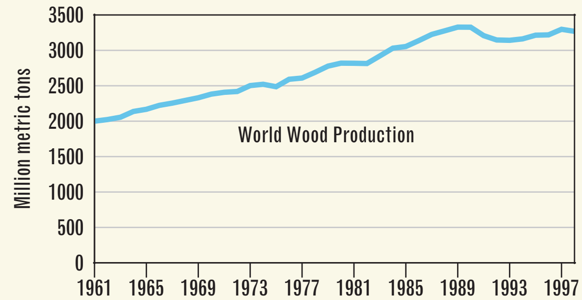
Source: WRR calculations.

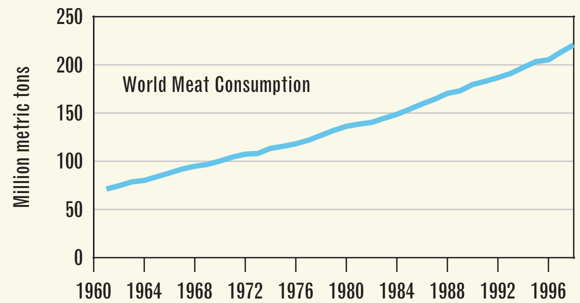
Global Map of Converted Areas

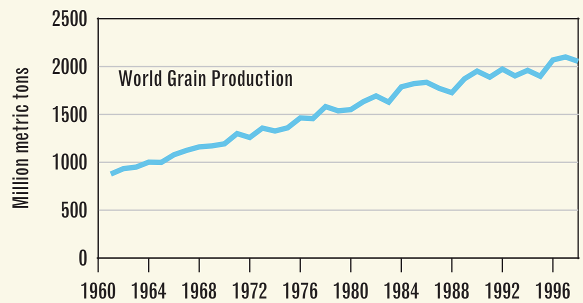


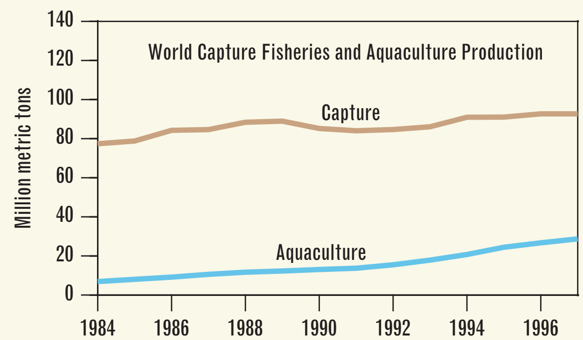
Source: Created for this publication by S. Murray [PAGE] based on data from Global Land Cover Characteristics Database Version 1.2 (Loveland et al. 2000); NOAA-NGDC (1998); WWF (1999).

Box 1.11 How Much Do We Consume?









Sources: FAO 1999; FAO 2000.

Humans consume goods and services for many reasons: to nourish, clothe, and house ourselves, certainly. But we also consume as part of a social compact, since each community or social group has standards of dress, food, shelter, education, and entertainment that influence its patterns of consumption beyond physical survival (UNDP 1998:38–45).

Consumption is a tool for human development—one that opens opportunities for a healthy and satisfying life, with adequate nutrition, employment, mobility, and education. Poverty is marked by a lack of consumption, and thus a lack of these opportunities. At the other extreme, wealth can—and often does—lead to excessive levels of material and nonmaterial consumption.

In spite of its human benefits, consumption can lead to serious pressure on ecosystems. Consumption harms ecosystems directly through overharvesting of animals or plants, mining of soil nutrients, or other forms of biological depletion. Ecosystems suffer indirectly through pollution and wastes from agriculture, industry, and energy use, and also through fragmentation by roads and other infrastructure that are part of the production and transportation networks that feed consumers.

Consumption of the major commodities ecosystems produce directly—grains, meat, fish, and wood—increased substantially in the last 4 decades and will continue to do so as the global economy expands and world population grows. Plausible projections of consumer demand in the next few decades suggest a marked escalation of impacts on ecosystems (Matthews and Hammond 1999:5).

- Global wood consumption has increased 64 percent since 1961. More than half of the 3.4 billion m^3 of wood consumed annually is burned for fuel; the rest is used in construction and for paper and a variety of other wood products. Demand for lumber and pulp is expected to rise between 20 and 40 percent by 2010. Forest plantations produce 22 percent of all lumber, pulp, and other industrial wood; old-growth and secondary-growth forests provide the rest (Matthews and Hammond 1999:8, 31; Brown 1999:41).

- World cereal consumption has more than doubled in the last 30 years, and meat consumption has tripled since 1961 (Matthews and Hammond 1999:7). Some 34 percent of the world's grain crop is used to feed livestock raised for meat (USDA 2000). A crucial factor in the rise in grain production has been the more than fourfold increase in fertilizer use since 1961 (Matthews and Hammond 1999:14). By 2020, demand for cereals is expected to increase nearly 40 percent, and meat demand will surge nearly 60 percent (Pinstrup-Andersen et al. 1999:11).

- The global fish catch has grown more than sixfold since 1950 to 122 million metric tons in 1997. Three-fourths of the global catch is consumed directly by humans as fresh, frozen, dried, or canned fish and shellfish. The remaining 25 percent is reduced to fish meal and oil, which is used for both livestock feed and fish feed in aquaculture. Demand for fish for direct consumption is expected to grow some 20 percent by 2010 (FAO 1999:7, 82; Matthews and Hammond 1999:61).

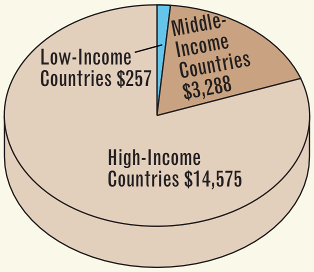
The Unequal Geography of Consumption

While consumption has risen steadily worldwide, there remains a profound disparity between consumption levels in wealthy nations and those in middle- and low-income nations.

- On average, someone living in a developed nation consumes twice as much grain, twice as much fish, three times as much meat, nine times as much paper, and eleven times as much gasoline as someone living in a developing nation (Data Table ERC.3; Laureti 1999:50, 55).

- Consumers in high-income countries—about 16 percent of the world's population—accounted for 80 percent of the money spent on private consumption in 1997—$14.5 trillion of the $18 trillion total. By contrast, purchases by consumers in low-income nations—the poorest 35 percent of the world's population—represented less than 2 percent of all private consumption. The money spent on private consumption worldwide (all goods and services consumed by individuals except real estate) nearly tripled between 1980 and 1997 (World Bank 1999:44, 226).

Global Share of Private Consumption, 1997 (in billlions)



Disparities in Consumption: Annual per Capita Consumption in Selected High-, Medium-, and Low-Income Nations

Country	Total Value of Private Consumption* (1997)	Fish (kg) (1997)	Meat (kg) (1998)	Cereals (kg) (1997)	Paper (kg) (1998)	Fossil Fuels (kg of oil equivalent) (1997)	Passenger Cars (per 1,000 people) (1996)
United States	$21,680	21.0	122.0	975.0	293.0	6,902	489.0
Singapore	$16,340	34.0	77.0	159.0	168.0	7,825	120.0
Japan	$15,554	66.0	42.0	334.0	239.0	3,277	373.0
Germany	$15,229	13.0	87.0	496.0	205.0	3,625	500.0
Poland	$5,087	12.0	73.0	696.0	54.0	2,585	209.0
Trinidad/Tobago	$4,864	12.0	28.0	237.0	41.0	6,394	94.0
Turkey	$4,377	7.2	19.0	502.0	32.0	952	55.0
Indonesia	$1,808	18.0	9.0	311.0	17.0	450	12.2
China	$1,410	26.0	47.0	360.0	30.0	700	3.2
India	$1,166	4.7	4.3	234.0	3.7	268	4.4
Bangladesh	$780	11.0	3.4	250.0	1.3	67	0.5
Nigeria	$692	5.8	12.0	228.0	1.9	186	6.7
Zambia	$625	8.2	12.0	144.0	1.6	77	17.0

*Adjusted to reflect actual purchasing power, accounting for currency and cost of living differences (the "purchasing power parity" approach).

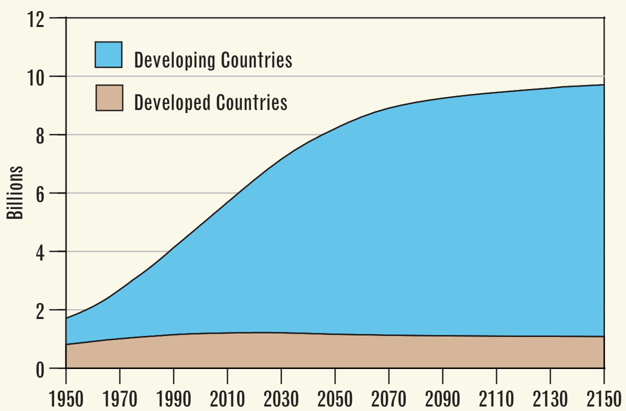
Sources: Total Private Consumption (except China and India): World Bank 1999: Table 4.11; (fish) Laureti 1999: 48–55; (meat) WRI et al. 2000a: Agriculture and Food Electronic Database; (paper) WRI et al. 2000b: Data Table ERC.5; (fossil fuels) WRI et al. 2000b: Data Table ERC.2; (passenger cars) WRI et al. 2000b: Data Table ERC.5.

Box 1.12 The Human Population

Population growth stresses ecosystems because it contributes to increases in both consumption and conversion. Each year, the human population grows by approximately 80 million. Although global fertility rates decreased since the 1950s from 5.0 to 2.7 births per woman (UN Population Division 1998b:514–515), the population will continue to grow. Past high fertility rates created today's pool of more than 1.5 billion people at the prime reproductive age—between 15 and 29 years old; another 1.9 billion are younger than 15 (UN Population Division 1998a). An adjunct to population growth is the significant decrease in mortality. Since the 1950s the global mortality rate has dropped from about 20 to fewer than 10 deaths per year per 1,000 people (UNFPA 1999). In contrast, the seven African countries hardest hit by the AIDS epidemic have actually experienced a decrease in life expectancy because of the high number of deaths caused by the disease (UN Population Division 1998a).

- Growth is fastest in less developed nations, among populations most dependent on ecosystems for a subsistence living. Demographers expect 97 percent of all population growth in the next 5 decades to occur in developing countries.

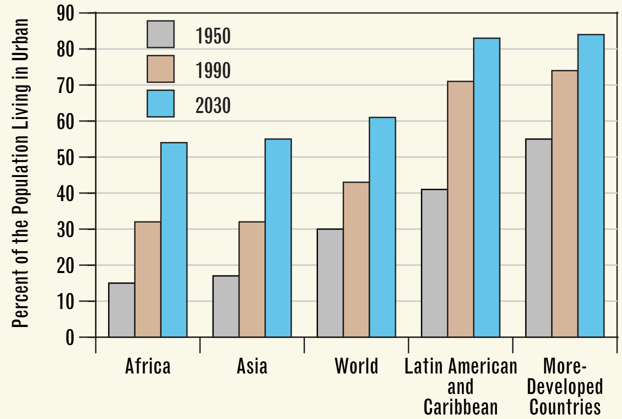
World Population Growth



Source: UN Population Division (1998a).

- In both more and less developed nations, cities are drawing people into ever greater concentrations. Urban regions tend to offer more opportunities for economic development as well as better education and health resources. Although urban areas occupy only about 4 percent of the Earth's land area, they are home to nearly half the world's population (UNEP 1999:47; Wood et al. [PAGE] 2000). Currently cities are expansive consumers of ecosystem goods and services and prolific generators of ecosystem-damaging wastes—essentially concentrated centers of ecosystem pressures. By 2030, more than 60 percent of all people are likely to be living in urban areas. In industrial countries and Latin America, the share is expected to exceed 80 percent (UN Population Division 1998a).

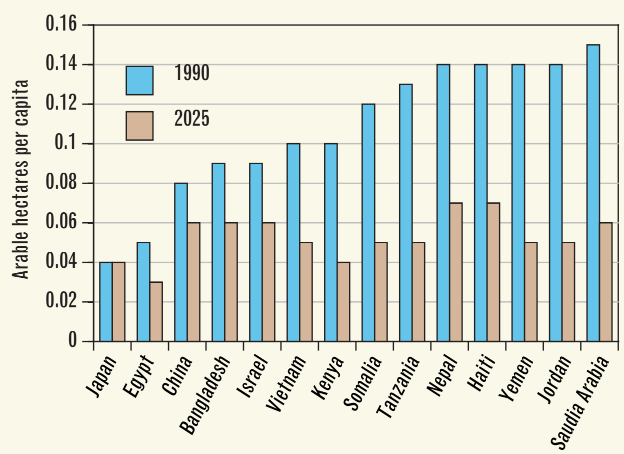
Trends in Urbanization



Source: UN Population Division 1998a.

- As the population grows in the next quarter century, pressures will increase, especially in countries where arable land is in short supply. In 14 countries, arable land per capita is expected to be less than 0.07 ha—equivalent to an area about 0.25 km^2—to sustain each human life (WHO 1997:59). Richer countries may supplement their food resources with imports, but poorer countries will have a more difficult time following such a strategy to feed their hungry populations.

Available Arable Land per Capita in 2025 for Selected Countries



Source: WHO 1997:59.

Box 1.13 Pollution and Ecosystems

In the last century, a growing and rapidly industrializing world has produced greater quantities of common pollutants like household garbage and sewage, and more toxic and persistent contaminants like pesticides, polychlorinated-biphenyls (PCBs), dioxins, heavy metals, and radioactive wastes. The environmental costs of contemporary society's pollutant load are difficult to quantify, both because there is little comprehensive data on pollution emissions on a global scale and because the effects of pollutants on ecosystems are often hard to measure. But the problem is surely growing.

Pollutants affect ecosystems in a variety of ways. Pesticides and heavy metals may harm exposed orgnisms by being acutely toxic or by accumulating in plant and animal tissue through repeated exposures. Pollutants like acid rain can act at a system-wide level, disrupting soil acidity and water chemistry—both critical environmental factors that affect the nutrition and physical development of plants and aquatic life. Multiple pollutants can create a toxic synergy that weakens organisms and gradually reduces an ecosystem's productivity and resilience. All of these effects on ecosystems are much in evidence.

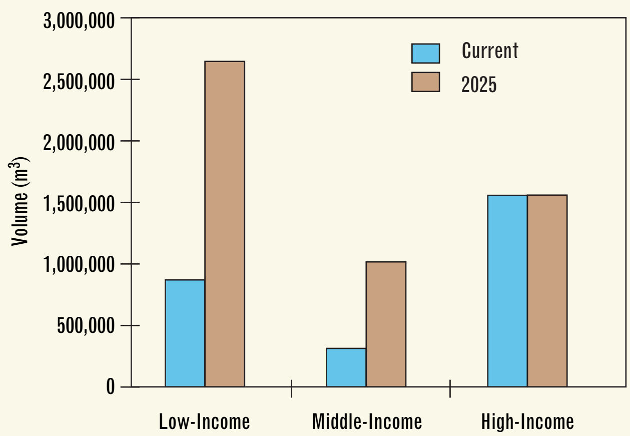
- Although there is greater awareness today of the dangers associated with toxic materials, toxic emissions continue to be significant. For example, the US$37 billion global pesticide market dispenses 2.6 billion kg of active ingredients (pesticides excluding solvents and dilutants) on the world's farms, forests, and household gardens, with a variety of collateral effects on wildlife and human health (Aspelin and Grube 1999:10).

- Accidental releases of toxic substances like mining wastes, or of oil or industrial chemicals, occur routinely and with devastating effect. In January 2000, 99,000 m^3 of cyanide-laden wastes escaped a Romanian gold mine when an earthen tailings dam collapsed; the toxic plume wiped out virtually all aquatic life along a 400-km stretch of the Danube and its tributaries (D'Esposito and Feiler 2000:1,4). In 1997, more than 167,000 tons of oil spilled from pipelines, storage vessels, tankers, and other carriers and sources to contaminate the world's marine and inland environments (Etkin 1998:5)

- Air pollution from sulfur dioxide (SO_2), nitrogen oxides (NO_x) and ground-level ozone still exceeds the "critical load"—the amount an ecosystem can absorb without damage—over wide areas of Europe, North America, and Asia, with documented effects on crops, forests, and freshwater ecosystems from acid rain. For example, the fraction of healthy Norway spruce, one of the most common conifers in European forests, decreased from 47 percent in 1989 to 39 percent in 1995—an indicator of the continued stress air pollution imposes on Europe's forest ecosystems (EEA 1999:144–145).

- Fertilizer runoff, human and animal sewage, and inadequately treated industrial wastes can add nutrients to freshwater and coastal ecosystems, stimulating algal blooms and depleting the water of oxygen—a process called eutrophication. Oxygen-depleted waters can't support aquatic life. Eutrophication is a growing problem worldwide. A roughly 18,000 km^2 "dead zone" of oxygen-depleted waters in the northern Gulf of Mexico stems from a tripling of the nutrient pollution carried to the coast by the Mississippi River over the last 40 years (Rabalais and Scavia 1999; NOAA 2000).

Total Waste Volumes Generated by Low-, Middle-, and High-Income Countries (per day)



Source: Hoornweg and Thomas 1999:11.

Excess Nutrients Translate to Water Pollution

Country	Total Nitrogen Supply from Fertilizer and Manure (1,000 tons)	Nitrogen Uptake by Crops	Residual Nitrogen	Residual Equivalence per Hectare (kg)
Belgium and Luxembourg	580	211	369	240
Denmark	816	287	529	187
Netherlands	1255	285	970	480

Note: Because some nitrogen is lost to the atmosphere, only a part of the residual nitrogen stays in the soil for possible nitrate leaching.
Source: Matthews and Hammond 1999.

predominant pressure on ecosystems today. Even considering that almost four times as many people live in developing countries as in developed ones, the greatest burden on ecosystems currently originates with affluent consumers in developed countries, as well as wealthy elites in developing countries. It is the pattern of excessive consumption that often accompanies wealth that brings a disproportionate impact on ecosystems.

DISTORTED PRICES, UNDERVALUED SERVICES

People don't generally consciously decide to damage ecosystems, but many of the things we do have that effect. Given that ecosystems provide so many benefits, why do people do things that jeopardize these benefits?

Economic signals–reflected in prices and government policies–are one of the prime factors determining how we treat ecosystems. They are behind our choices of what to consume and how to manage our lands and our businesses. A farmer deciding what crops to plant and what farm chemicals to use, or whether to increase the cultivated area by clearing adjacent forests, is guided by calculating commodity and pesticide prices as well as many other farm costs. Similarly, a developer's choice of where to locate a tract of housing or a factory, or a fisher's decision on what type of fishing gear to use and how many days to spend at sea are driven largely by economic factors–the price of land or boat, of labor or fishing licenses, of the finished house or the harvested fish.

But prices all too frequently send us the wrong signals. In most cases, they don't reflect the real costs to the environment of harvesting ecosystem goods and services. The problem is, many of the less tangible aspects of ecosystems, particularly the services they provide, are not bought or sold in the marketplace and are therefore harder to assign a value. How much is carbon storage in a forest worth? What price tag can be put on flood protection provided by the wetlands along a river?

The connection between these services and the more tangible marketable goods–timber or fish or crops–is not always obvious to those exploiting these goods and services. The value of biodiversity to the future of food crops is, for example, of little immediate import to an individual farmer trying to maximize his or her profit. The result is that most ecosystem services have been undervalued in the past and neglected in decisions about whether to exploit or alter an ecosystem. The market has failed to register the real worth of these services in its price system–a "market failure."

Consider the case of deciding whether to clear native forests for a new agricultural settlement. The potential farmers will take into account the cost of the labor needed to clear land, the fertilizers used to increase yields, and the construction materials required to build houses or roads. They may even factor in some reductions in ecosystem services. For example, they may consider the cost of forgoing the benefits of using the forest as a source of fuelwood and the loss of wild animals and plants.

It is, nonetheless, very likely that they won't take into full account the many environmental costs of forest clearing. Cutting down forests might increase downstream flooding and sedimentation, for example, but since these costs are borne by people living far downstream, they will often be ignored by the upstream farmers. The result is that more forest is cleared than would make sense from an overall economic standpoint, and the forest ecosystem suffers needless damage, as may the downstream populations. Extending this argument to the global level, a better accounting of all the costs and benefits of forest conversion would not necessarily mean that all forest is preserved, but it would certainly result in a lower rate of deforestation than is occurring now.

SUBSIDIES AND OTHER POLICY FAILURES

Government policies often contribute to ecosystem decline through their effect on prices. Fiscal policies affect prices through taxes and subsidies. Tariffs increase the price of imported goods directly and import quotas increase them indirectly. Exchange-rate policies affect the value of all tradable commodities. Government agencies also actively buy and sell farm commodities, often at predetermined prices. All of these actions can influence the decisions of farmers, fishers, developers, timber and mining companies, and others who use the land and sea, harvest from it, or impact it through pollution.

Subsidies. Government subsidies contribute importantly to current pressures on ecosystems, often encouraging damaging activities–such as overfishing or the liberal use of coal or other fossil fuels–that would not otherwise be economically viable. Generous loans to build fishing boats, agricultural price supports, depletion allowances for timber and oil producers, and outright grants for road construction are just a few of the ways that governments subsidize activities that can damage ecosystems. One recent analysis reported that government expenditures on environmentally damaging subsidies in just four sectors–water, agriculture, energy, and road transportation–totaled some $700 billion per year worldwide (de Moor and Calamai 1997:1).

Subsidies often promote laudable social goals–employment, higher productivity, economic development–when first instituted, but these goals are often subverted over time through unintended consequences such as environmental impacts. For example, governments have subsidized the use of various farm inputs, such as pesticides and fertilizers, partly to boost agricultural production and partly to support the industries producing these chemicals. Pesticide subsidies, in particular, have been common in developing countries. In the mid-1980s, Indonesia was spending about $150 million annually on pesticide subsidies, mostly to protect the rice crop. This led to considerable overuse. Rather than reducing crop-damaging insects, however, this liberal pesticide use actually triggered periodic outbreaks by reducing natural predators and prompting pesticide resistance among target insects. It also caused substantial downstream pollution and adversely affected the health of farmers. When the government ended its subsidies, pesticide use dropped, the government saved money, and rice production continued to increase (World Bank 1997:26).

Subsidizing irrigation projects is another common practice that has seriously harmed aquatic ecosystems. Throughout the world, government support has typically allowed water utilities to sell irrigation water for far less than the cost of supplying it, which has inevitably led to overuse. In arid Tunisia, for example, farmers pay no more than one-seventh the cost of water they use to irrigate their fields. Similar practices of underpricing irrigation water in the western United States cost U.S. taxpayers an estimated US$2–$2.5 billion per year (de Moor and Calamai 1997:14–15). With water costs low, farmers have little incentive to use water efficiently or to restrict its use to high-value crops. Direct water diversions and overpumping from irrigation wells often rob streams of much of their normal flow. Too often pesticide and fertilizer runoff pollutes what flow remains.

Regulations. Beyond their effect on prices, government policies can also impact ecosystems more directly, through such mechanisms as zoning ordinances, pollution standards, or other regulations that affect land use and business practices. Programs to promote economic development may foster "grow now, clean up later" policies that encourage industrialization no matter what the environmental costs. China's dramatic industrialization after economic reforms in 1978 followed this pattern, and by the early 1990s, the nation was estimating that economic costs associated with ecological destruction and pollution had reached as high as 14 percent of its gross national product (WRI et al. 1998:115–116). Hoping to reverse its environmental losses and reduce the health impacts of polluted air and water, China has recently begun a costly effort to tighten and enforce its environmental regulations.

Sectoral Divisions. Other government-related factors also affect the use of ecosystems. Government institutions, for example, are routinely divided along sectoral lines–the Ministry of Agriculture, the Forest Department, the Environment Agency, and so on. This works against adopting any integrated view of ecosystems or their management. The Ministry of Agriculture's prime concern, for instance, will be farm production. Like an individual farmer, the Ministry will likely see preserving biodiversity or minimizing forest conversion as peripheral to its mission. It may even

(continues on p. 33)

Economic signals—reflected in prices and government policies—are one of the prime factors determining how we treat ecosystems. Subsidies often encourage damaging activities that would not otherwise be economically viable.

Box 1.14 Valuing the Invaluable

The economic values we assign to our work and the fruits of our labor are important factors in our behavior and the decisions we make about our assets. Similarly, the values we assign to *ecosystem* assets—goods and services like pollination, water purification, nitrogen fixation, and carbon storage—are an important factor in how we treat ecosystems. Yet because these services are not routinely bought and sold in markets, there's no easy way to calculate their worth. Too often, decision makers and traditional economists simply ignore their value, essentially treating ecosystem goods and services as though they will always be in profuse supply. A result is that loggers may harvest a patch of forest for the value of its timber alone, ignoring the value the forest provides in terms of flood control, water purification, or habitat for migratory songbirds.

How does one assign a monetary value to all the ecological amenities of an ecosystem? As the state of the art of economic analysis has improved, economists have identified a variety of tools to quantify direct—and even some indirect and intangible—ecosystem services.

Where possible, actual market values are used. For example, the price of fish and shellfish harvested in an estuary provides one value for direct goods provided by that ecosystem. Another way to estimate value is to calculate the cost of replacing an ecosystem service. For New York City, natural habitats in its upstate watershed were shown to provide the same water purification services as a new water filtration plant. The $3–$8 billion price tag (Ryan 1998) for the proposed filtration plant is a good base estimate of the value of the water purification service that the intact ecosystem provides—although it does not capture the value of the other watershed services including carbon sequestration, recreational opportunities, and support for biodiversity.

Similarly, the price difference between two comparable houses, one near a shoreline and one inland, is thought to capture the aesthetic value of the shore. Still another market-based method of calculating a lake's or a park's or a wilderness area's value, both as a scenic and a recreational site, is to calculate how much money and time visitors spend to travel there.

When market data are not available, or to supplement them, researchers resort to other means. They ask people what they'd pay, for example, to keep a wetland from being filled and developed or to prevent a wilderness area from being mined. Properly done, such "contingent valuation" surveys can go beyond measuring the practical benefits humans extract from nature to encompass the ethical and spiritual values they attach. But surveys can be unreliable and subject to bias, especially when people are queried about paying to minimize the effects of something as complex as climate change.

Valuation exercises can be a useful policy tool in educating audiences about the many ways we depend on and profit from ecosystem services. Ultimately, however, creating financial incentives for ecosystem conservation is more important than finding an accurate market value for any or all ecosystem services. Incentives for conservation may come from creating markets for ecosystem services where none exist, or finding other ways for landowners to gain financially from the services their land provides. Auctioning permits to emit carbon or compensating countries or companies that reforest land to sequester carbon are examples of ways to create such markets.

Ecotourism, where the beauty and unspoiled quality of an ecosystem is marketed directly, may be another incentive to conserve. In South Africa, a private enterprise called Conservation Corporation negotiated with farmers to return 168 km^2 of their land to its original habitat and stock it with big-game animals. Open for business as a safari destination, the land is now yielding $200–$300 per hectare annually from visitor fees instead of $21–$68 from ranching or farming, and providing a biologically diverse resource base to support the large game (Anderson 1996:207; Honey 1999:374). In the Maldives, a government study determined that a single live shark yields approximately US$33,500 annually in tourist revenue, compared to US$32 when caught and sold by a fisherman. This and other studies supplied the incentive for the Maldives to make sharks, turtles, and dolphins protected species (Sweeting et al. 1999:66, citing WTO 1997).

In some ways, "priceless" may be the most accurate value that we can ever place on intangible ecosystem goods and services such as a coastal area's beauty or a mountain range's spiritual importance. But used as one of many measures of an ecosystem's worth, and with recognition of its limitations, environmental economics offers a powerful ecosystem management tool in a political world. Until we fully understand ecosystem values, we are handicapped in deciding what to use and what to save.

see the Forest or Environment Departments as competitors for budget and administrative control, reducing the chances of cooperation between agencies that manage ecosystems. This limited focus makes it unlikely that agencies as now configured will recognize or account for the environmental trade-offs that their policies promote.

Corruption. Government corruption is another common institutional failure that allows unchecked exploitation of ecosystems—often by a small elite. Even when laws and management policies are sound, they may be undermined by government officials who turn a blind eye to illegal harvesting or themselves take part in the plunder through sweetheart deals or insider investments. The scale of corruption in the forest sector, for example, is staggering. In Indonesia, illegal logging accounts for more than half of the nation's timber production, with timber smuggling taking place in some national parks in full view of park authorities (EIA and Telepak 1999:4). As a result, the government loses an estimated US$1–$3 billion per year in timber royalties, and the forests suffer from haphazard cutting (WCFSD 1999:36). Similarly, the Russian government collected only a fraction—estimated at 3–20 percent—of the timber revenues it was due in 1994 (WCFSD 1999:36). The rest was lost to theft and fraud.

Who Owns Ecosystems?

Ownership is a crucial factor in how we manage ecosystems. The question of who owns the land or has the right to use its resources is key in determining what services or products are reaped from an ecosystem, how they are harvested, and who gains the benefits. Some patterns of ownership can work against good management of ecosystems, as when property rights are concentrated in the hands of those whose economic interests may favor unsustainable harvest levels or extensive development.

PROPERTY RIGHTS

In 1985, Maxxam Corporation acquired the locally based Pacific Lumber Company in Northern California, owner of the state's largest remaining tract of mature redwood forest. For years, Pacific Lumber had managed its forests to maintain their long-term productivity, emphasizing moderate harvest levels that could continue to feed its lumber mills indefinitely. Maxxam quickly abandoned Pacific Lumber's modest but sustainable harvest practices, more than doubling the harvest rate to help pay off its large corporate debt. Maxxam stockholders reaped the benefits of this short-term approach, with little regard for its long-term effects on the

(continues on p. 40)

The challenge for the 21st century is to understand the vulnerabilities and resilience of ecosystems, so that we can find ways to reconcile the demands of human development with the tolerances of nature.

Box 1.15 Ecotourism and Conservation: Are They Compatible?

From African wildlife safaris, to diving tours in the Caribbean's emerald waters and coral reefs, to guided treks in Brazil's rainforests, nature-based tourism is booming. The value of international tourism exceeds US$444 billion (World Bank 1999:368); nature-based tourism may comprise 40–60 percent of these expenditures and is increasing at 10–30 percent annually (Ecotourism Society 1998).

This burgeoning interest in traveling to wild or untrammeled places may be good news, especially for developing countries. It offers a way to finance preservation of unique ecosystems with tourist and private-sector dollars and to provide economic opportunities for communities living near parks and protected areas. For Costa Rica, tourism generated $654 million in 1996, and for Kenya $502 million in 1997, much of it from nature and wildlife tourism (Honey 1999:133, 296). Tourism has been influential in helping to protect Rwanda's mountain gorillas and their habitat in Volcanoes National Park. Prior to the outbreak of civil war, tourist visits provided $1.02 million in direct annual revenues, enabling the government to create antipoaching patrols and employ local residents (Gossling 1999:310).

But the reality of nature-based travel is that it can both sustain ecosystems and degrade them. Much nature-based tourism falls short of the social responsibility ideals of "ecotourism," defined by the Ecotourism Society as "travel to natural areas that conserves the environment and sustains the well-being of local people" (Ecotourism Society 1998). Destinations and trips marketed as ecotourism opportunities may focus more on environmentally friendly lodge design than local community development, conservation, or tourist education. Even some ecosystems that are managed carefully with ecotourism principles are showing signs of degradation.

Ecotourism's Costs and Benefits

At first glance, Ecuador's Galápagos Islands epitomize the promise of ecotourism. Each year the archipelago draws more than 62,000 people who pay to dive, tour, and cruise amidst the 120 volcanic islands and the ecosystem's rare tropical birds, iguanas, penguins, and tortoises. Tourism raises as much as $60 million annually, and provides income for an estimated 80 percent of the islands' residents. The tenfold increase in visitors since 1970 has expanded the resources for Ecuador's park service. Tour operators, naturalist guides, park officials, and scientists have worked together to create a model for low-impact, high-quality ecotourism (Honey 1999:101, 104, 107).

But closer examination reveals trade-offs: a flood of migrants seeking jobs in the islands' new tourist economy nearly tripled the area's permanent population over a 15-year period, turned the towns into sources of pollution, and added pressure to fishery resources (Honey 1999:115, 117). Only 15 percent of tourist income directly enters the Galápagos economy; most of the profits go to foreign-owned airlines and luxury tour boats or floating hotels—accommodations that may lessen tourists' environmental impacts, but provide little benefit to local residents (Honey 1999:108, citing Epler 1997). The hordes of tourists and immigrants have brought new animals and insect species that threaten the island's biodiversity (Honey 1999:54).

The Galápagos Islands well illustrate the complexities of ecotourism, including the potential to realize financial benefits nationally, even as problems become evident at the local or park scale. For example, to a government that is promoting ecotourism, more visitors means more income. But more visitors can translate into damage to fragile areas. Park officials often complain of habitat fragmentation, air pollution from vehicle traffic, stressed water supplies, litter, and other problems. In Kenya's Maasai Mara National reserve, illegal but virtually unregulated off-road driving by tour operators has scarred the landscape (Wells 1997:40).

These impacts can be minimized with investments in park management, protection, and planning. However, developing countries often lack the resources to monitor, evaluate, and prevent visitor impacts, and infrastructure and facilities may be rudimentary or nonexistent.

Low entrance fees are part of the problem; they often amount to just 0.01-1 percent of the total costs of a visitor's trip (Gossling 1999:309). Setting an appropriate park entry fee—one that covers the park's capital costs and operating costs, and ideally even the indirect costs of ecological damage—is one way that management agencies can capture a larger share of the economic value of tourism in parks and protected areas. Most parks have found that visitors are willing to pay more if they know their money will be used to enhance their experience or conserve the special area. To ensure broad affordable access to parks, Peru, Ecuador, Kenya, Jordan, Costa Rica, and several other countries have raised fees for foreigners while maintaining lower fees for residents.

Unfortunately, tourism revenues are not always reinvested in conservation. Of the US$3 million that Galápagos National Park generates each year, for example, only about 20 percent goes to the national park system. The rest goes to general government revenues (Sweeting et al. 1999:65). This is typical treatment of park income in many countries, but it undermines visitors' support for the fees and destroys the incentive for managers to develop parks as viable ecotourism destinations. Fortunately, some countries are using special fees and tourism-based trust funds to explicitly channel tourist dollars to conservation. Belize, for example, raises funds for conservation through a US$3.75 tourist tax levied on every foreign visitor as they depart the country, generating about US$750,000 per year (Sweeting et al. 1999:69).

Well-planned and -managed ecotourism offers greater potential to bolster local and rural economic development than traditional tourism, in which most of the economic benefits linked to tourist expenditures "leak" back to commercial tour operators in the richer countries (where most tourists originate) or are captured by large cities of the host countries (Wells 1997:iv). But increasing prices for land, food, and other products can coincide with the growing popularity of a tourist or ecotourist haven, to the detriment of local residents. In Zanzibar, villagers and townspeople have been enticed into selling their property to tourism investors who do not guarantee any profit sharing, joint ownership, or other form of sustained benefit (Honey 1999:287). In Tonga, tourism-driven inflation has caused shortages of arable land (Sweeting et al. 1999:29).

Some countries have introduced policies that help reimburse local residents for the direct and indirect costs of establishing a protected area. Kenya, for example, aims to share 25 percent of revenue from entrance fees with communities bordering protected areas (Lindberg and Huber 1993:106). Ecotourism planners also advocate sales of local handicrafts in gift stores, patronage of local lodges, use of locally grown food in restaurants and lodges, and training programs to enable residents to fill positions as tour guides, hotel managers, and park rangers. Both tour operators and visitors have a role to play by screening trips carefully and committing to ecotourist principles. Developers can choose sites based on environmental conditions and local support, and use sustainable design principles in building and resort construction.

Poorly planned, unregulated ecotourism can bring marginal financial benefits and major social and environmental costs. But with well-established guidelines, involvement of local communities, and a long-term vision for ecosystem protection rather than short-term profit by developers, ecotourism may yet live up to its promise.

Box 1.16 Uprooting Communal Tenure in Indonesian Forests

Many communities on the outer islands of Indonesia, and elsewhere in the developing world, use traditional systems of community-based, group tenure rights to manage forest resources. Many of these management systems are generations old and meet local economic needs while maintaining vital ecosystem functions, including protection of biodiversity (Lynch and Alcorn 1994:374, 381). Unfortunately, most of these systems are threatened by legal and development pressures.

In Indonesia, traditional community-based property rights are called *adat* rights. Across the Indonesian archipelago, communities adapt adat rights to their specific economic and environmental needs. Agroforests in Sumatra and Kalimantan, for example, are managed for rubber, durian fruits, illepe nuts, resins, and rattan.

Between 12 and 60 million people depend on Indonesia's forests, with a substantial proportion practicing traditional agroforestry (Poffenberger et al. 1997:22). Detailed information is lacking, but research suggests much of this land is managed under adat rights.

Threats to Group Tenure

Adat rights in Indonesia face four significant threats:

- Adat rights are not meaningfully recognized by the state, despite their widespread importance. The Indonesian Ministry of Forestry manages and claims exclusive ownership of 131 Mha of forest land—68 percent of Indonesia's land area, including 90 percent of the Outer Islands. Even though government planners admit knowledge of adat tracts is important in formulating sustainable resource management plans, the government does not know how much of this land is also claimed under traditional group tenure regimes (Fox and Atok 1997:32; Peluso 1995:390–391).

- State-sponsored development activities constantly override adat rights. Where 20-year timber concessions have been granted, forest-based communities find their traditional rights of use and access usurped (Lynch and Talbott 1995:52–54). Government-directed development plans—including mining, transmigration settlements, and conver-

sion of forests to timber or oil palm plantations—degrade or destroy these ecosystems (Michon and de Foresta 1995:103–104). In East Kalimantan province, 30 percent of Long Uli village land was lost to a government nature reserve, and 20 percent (including half of the village's cultivated land) was included in a timber concession, all without the consent of or consultation with the villagers (Sirait et al. 1994:416). Over the protests of villagers in eastern Maluku province, local government officials signed agreements with timber companies granting them access to the village's resin-producing agroforests, which were then destroyed without adequate compensation, thus undermining environmental sustainability and local economic stability (Zerner 1992:31–33).

- The imminent nature of state-sponsored development projects provokes communities to overexploit their resource base. Faced with irretrievably losing control of their lands and resources, some forest-dependent communities will incautiously reap maximum harvests and, in the process, destroy the resource base (Lynch and Talbott 1995:98; Sirait et al. 1994:416).

- Government policies that disproportionately reward agricultural production can also promote forest degradation. More favorable prices for agricultural commodities, relative to nontimber forest products, encourage farmers to pursue less sustainable forms of agriculture than those used by traditional agroforestry systems (Padoch and Pinedo-Vasquez 1996:113).

New Approaches

Many conflicts would be mitigated if adat rights were legally recognized and granted political legitimacy. In 1998, before the fall of the Suharto government, the Indonesian Ministry of Forestry issued a decree that created a new land-use category, the *kawasan dengan tujuan istemewa*, or "area of special/extraordinary objective," for 60 resin-producing agroforest villages in the vicinity of Krui, Sumatra. The decree established a process for granting official use and management rights to local villages covering 29,000 ha of forest. The regulation was the first ever to grant legally recognized management rights to community agroforesters.

Other important political and legal changes include President Habibie's emphasizing the importance of civil society and governmental accountability. The Basic Forest Law of 1999 acknowledges that local people have a key role in sustainable forest management; however, it fails to recognize adat rights. Within the Forestry Ministry, a new regulation currently being considered would authorize the demarcation of indigenous territories within areas designated as state forestland. The Ministry of Agrarian Affairs, in a related vein, has issued a decree providing for delineation and registration of community-based adat rights in some forested areas (Lynch 2000).

Wider legal recognition of traditional community rights of access to and management of forests in Indonesia could follow these important developments (Campbell 1998). Still needed, however, are clearer policies on adat rights that also define local and state rights and responsibilities (Bromley and Cernea 1989:52; Lynch and Alcorn 1994:376–377).

Current progress toward wider legal recognition of local tenure by the Indonesian government, however, is fragile in light of the country's recent economic and political turmoil. Similar efforts to promote legal recognition of group tenure in Thailand and the Philippines are also at precarious stages.

At current population growth rates, tensions between development and sustainability are sure to continue. An additional 15–33 Mha of forest in Indonesia is expected to suffer deforestation by 2020 (Lynch 2000). Plans are already under way to create more pulp, paper, and oil palm plantations, all of which replace natural forests (Barber 1997:74).

Logged-over areas of natural forest currently provide forest-dependent communities space for agriculture, grazing, and collection of forest products such as timber, rattan, and rubber. Converting these areas to intensively managed pulp and oil palm plantations will permanently exclude local populations; their claims to resources, which had tenuous legitimacy before, will be made irrelevant (Barber 1997:75). Securing the community-based property rights of Indonesia's forest-dependent communities would help to both protect the interests of Indonesia's rural inhabitants and promote environmental sustainability.

Box 1.17 Rural Poverty and Adaptation

Near a rural Bengali village, peasant families searching for firewood pick a local forest patch clean. A refugee from war-torn Rwanda flees to Tanzania where he poaches game in a national park to feed his family. A poor Kenyan family continues to cultivate their small farm plot in spite of severe erosion and exhausted soil. These are the typical images of the rural poor—people hugely dependent on ecosystems, unable to afford sound management practices, and caught in a vicious cycle of overusing already fragile and degraded resources.

A more nuanced view has emerged, however, that recognizes that the poor may have limited resources and great dependence on the environment, but they also have considerable ability to protect their ecosystems, when given the opportunity. Research is bringing to light abundant examples of *adaptation*—strategies that the poor use to lessen the impacts of environmental, economic, or social change on their resources. Adaptive measures include innovative land-use practices, the adoption of new technologies, economic diversification, and changes in social organization (Batterbury and Forsyth 1999:8).

Who Are the Poor?

Approximately 1.3 billion people, one-quarter of the world's population, live on about $1 a day (World Bank 1999:117). In addition to encompassing insufficient financial assets, poverty often means a lack of education, mobility, employment opportunities, or access to basic services such as safe water, and physical isolation in remote villages. Limited access to land is another key aspect of poverty; 52 percent of the rural poor have landholdings too small to provide an adequate income, and 24 percent are landless (UNCHS 1996:109).

The vulnerability of the poor is often exacerbated by a lack of political power to defend their rights to environmental resources or defend themselves against outright oppression. In South and Southeast Asian countries, for example, many governments consider forest-dependent people to be squatters who are illegally using state-owned resources. They can be arbitrarily displaced, often with state sanction, no matter how long they have occupied the forest (Lynch and Talbott 1995:21). War and civil conflict in Central and Eastern Europe, Somalia, the Congo, Lebanon, and other countries have torn people from their land and plunged them into poverty.

Urban poverty is a growing phenomenon, but the largest numbers of poor people in developing countries still live in rural areas—as much as 80 percent in 1988 (Jazairy et al. 1992:1). Many struggle to subsist on lands variously described as "poverty traps," "less favored," or "marginal." These tend to be areas of high ecological vulnerability (such as subtropical drylands or steep mountain slopes) or low levels of biological or resource productivity combined with high human demands. There may be almost twice as many poor living on marginal lands as on favored lands in developing countries—630 million compared to 325 million (CGIAR et al. 1997). If current trends in poverty and natural resource degradation persist, by 2020 more than 800 million people could be living on less favored lands, places like the upper watersheds of the Andes and the Himalayas, the East African highlands, and the Sahel (Hazell and Garrett 1996).

Protecting Their Ecosystems

It is increasingly evident that the poor can fight back against environmental degradation. In some places, they have been fighting back for centuries, using adaptive measures whenever ecosystem changes have demanded them.

One example of adaptation can be found in the highlands of Papua New Guinea, where the Wola people grow crops on slopes cleared of native forests by means of slash and burn techniques. Instead of accelerating soil exhaustion and furthering deforestation, as traditional models would predict, the Wola have maintained soil fertility by constructing mounds of soil using rotting vegetation as compost. They select strategically what crops to plant, using a variety of crops in the first years of cultivation when soils are rich. In later years when soil fertility declines, the Wola plant only sweet potatoes, a crop that can thrive without many nutrients (Batterbury and Forsyth 1999:8, citing Sillitoe 1998 and Sillitoe 1996).

The Mossi people in Burkina Faso offer other examples of successful adaptation. As rapid population growth and frequent droughts have degraded their soils, Mossi farmers have responded by creating compost pits and building *diguettes*—semipermeable lines of stone placed at right angles to the slope to prevent erosion (Batterbury and Forsyth 1999:9–10). The significant number of Mossi who have migrated to cities or the neighboring country of Cote d'Ivoire for wage employment during the dry season is also an adaptive response that reduces pressures on the land and food supply, provides remittances for families, and diversifies income sources. Like all adaptations, however, these local strategies have their limitations. Severe drought or a shortage of nonfarm job opportunities can undermine the Mossi's successes.

A third adaptation example comes from the forest-savanna zone of Guinea in West Africa. For 200 years, researchers erroneously blamed the Kissi and Kuranko people for the deforestation of a large forest in the Kissidougou province. Research into historical land-cover patterns eventually revealed that the Kissi and Kuranko had actually *created* patches of forest on relatively treeless savannas through targeted burning to reduce the risk of fire and to increase soil fertility, and by tethering animals and promoting fast-growing tree species (Batterbury and Forsyth 1999:10–11, citing Fairhead and Leach 1996).

Examples of Indigenous Soil and Water Conservation Techniques in Selected West African Countries

Country	Rainfall (mm)	Population Density (per km^2)	Indigenous Soil and Water Conservation Techniques
Burkina Faso	1,000–1,100	35	Stone bunds in slopes network of earth bunds and drainage channels in lowlands
	1,000	35–80	Contour stone bunds on slopes, drainage channels
	400–700	29	Stone lines, stone terraces, planting pits
Cameroon	800–1,100	80–250	Bench terraces (0.5–3 m high), stone bunds
Cape Verde	400–1,200 (uplands)	>100	Dry stone terraces (walls 1–2 m high), rectangular basins (approx. 2 m x 4 m)
Chad	250–650	5–6	Water harvesting in drier regions: various earth bunding systems with upslope wingwalls and catchment area
Niger	300–500		Stone lines, planting pits
Nigeria	1,000–1,500	110–450	Stepped, level benched stone terraces, rectangular ridges, mound cultivation
Mali	400	20–30	Pitting systems
	500–650	13–85	Cone shaped mounds, planting holes, terraces square basins, stone lines, bunds or low walls
Sierra Leone	2,000–2,500	38	Sticks and stone bunding on fields and drainage techniques in gullies
Togo	1,400	80	Bench terraces and contour bunds, (rectangular) mound cultivation

Source: IFAD 2000.

Adaptation is not confined to rural areas. In cities the poor supplement their diets and income by transforming vacant lots, rooftops, and the lands along roadsides and other rights-of-way into highly productive plots of vegetables, fruits, and trees. As food and fuel are the largest household expenses for low-income urban populations, urban agriculture can be a first line of defense against hunger and malnutrition. Shantytown dwellers who mobilize to secure access to water and sanitation and improve their environments are engaging in another form of adaptation. But adaptation can be more difficult in cities, where a community's response may be more dependent on access to and support from local and state governments, corporations, or international agencies. In addition, many environmental risks are relatively new or beyond the experience of the urban poor, or difficult to detect, such as solvent or lead poisoning (Forsyth and Leach 1998:26).

How a community adapts to ecosystem decline depends on the knowledge that individuals have and the local biophysical environment, such as rainfall and soil conditions. Economic and political factors such as the availability of labor and access to markets also are crucial.

Governments, NGOs, and development agencies can help the poor respond positively to natural resource management challenges by working with local residents—supporting locally designed adaptations and community-based institutions, creating employment opportunities, and providing new knowledge, technical and marketing assistance, training, and credit. Those institutions also can hinder adaptations and progress against poverty. Limiting the voice of the poor in resource management decisions or denying local people security of tenure and rights of access to resources are among the most detrimental factors. Without recognition of traditional tenure rights and grants of control over resources, the poor have less incentive and capacity to adapt.

Experiences of the people of Sukhomajri, India, illustrate the difference that stable tenure systems can make in the health of an ecosystem. Twenty years ago, the forest department granted villagers the right to harvest the grass in the watershed for a nominal fee, rather than auctioning the grass to a contractor who, in turn, would charge the villagers high rates for the grass (Agarwal and Narain 1999:16). With the assurance that they would reap the benefits of increased biomass production, villagers identified ways to protect the watershed—regulating livestock grazing, investing in the construction of water tanks for increased crop production, and sustainably harvesting wood from the forest that lies within the catchment. By the mid-1980s, Sukhomajri was no longer importing food but exporting it. Between 1979 and 1984, household income increased from Rs 10,000 to Rs 15,000. The village also earns about Rs 350,000 annually from the sale of milk, and another Rs 100,000 from the sale of *bhabhar*—a fibrous grass that can be used as fodder and sold to paper mills (Agarwal and Narain 1999:16). The result—a once degraded watershed is today a wetter, greener, more productive and prosperous area.

local economy or the health and productivity of the forest (Harris 1996:130–135, 170–171; LOE 1996:12–18).

Lack of ownership can also be a problem. Many of the world's poor lack legal property rights–tenure–over the lands they live on. A poor farmer without secure land tenure may not feel much incentive to consider long-term productivity because he or she has no assurance of being able to stay and capitalize on any investments in good soil or water management. In fact, lack of legal title tends to discourage some land uses, like agroforestry, that are relatively benign to ecosystems but require long periods to reach peak productivity (Scherr 1999). In addition, landless immigrants, often fleeing unemployment and poverty or civil strife in more populated regions, have been important contributors to deforestation in frontier areas as they clear forest plots for subsistence farming. In some instances, clearing forest areas is actually a means to gain land title, since it converts the land to agriculture–a legally recognized land use.

Sometimes, modern systems of private or state ownership can conflict with more traditional forms of group or community ownership, with the environment suffering as a consequence. Cultures around the world have developed systems of communal management of shared resources to control overharvesting. Forests in Indonesia, rangelands in Mongolia, and coastal fishing areas in the Philippines are all current examples. An extensive literature documents that these traditional systems of property rights and communal management can be very effective at preserving ecosystems over the long term even as they are routinely harvested. Nonetheless, governments often ignore these traditional forms of ownership, denying them legal recognition.

POVERTY

The question of who owns ecosystems and their benefits ultimately becomes a question of equity. Those with property rights or with the money to buy consumer items are most likely to control the goods and services that ecosystems produce and to influence how ecosystems are managed. Yet it is the poor who are most directly dependent on ecosystems for their immediate survival and therefore most vulnerable when ecosystems decline. Subsistence farmers and others who cannot afford fertilizers depend on natural soil fertility; and subsistence fishers depend on the continued productivity of lakes, rivers, estuaries, and coastal wetlands. When these systems are depleted, impoverished people can't insulate themselves from the effects as the wealthy can. They must bear the costs of lost ecosystem services directly.

The connection between poverty and the environment is complex. In many instances, poverty contributes to pressures on ecosystems. Roughly half of the world's poorest people live on marginal lands–arid areas, steep slopes, and the like–that are prone to degradation (UNDP 1998:66). Even when the slope erodes, or the fish harvest tapers off, the poor often have no choice but to keep depleting the resource or to convert other vulnerable areas for use.

But this isn't always the case. In fact, the poor can be a source of conservation and environmental protection as well (Scherr 1999). Many people around the world have learned to extract goods from marginal systems without further degradation. For instance, the Mien people of the northern highlands of Thailand center their cultivation on the least erosive slopes, allowing local forests to remain intact and even expand (Batterbury and Forsyth 1999:8). Similar successes, as a result of diversifying both crops and income-generating activities, are taking place in the Machakos region of Kenya (see Chapter 3, Regaining the High Ground: Reviving the Hillsides of Machakos), the drylands and forests of West Africa, and other areas.

Managing for Ecosystem Health

Well-managed ecosystems can provide a range of benefits over the long term. We can choose to emphasize one or a few benefits over others–timber production over scenery, more food over unbroken forests, hydropower over fish harvests–but each choice has a consequence. Poor management choices in the past have often needlessly degraded ecosystems, yielding fewer goods and services today when demand is rising quickly. Retaining the productive capacity of ecosystems in the face of the trade-offs we make marks the difference between good and poor management.

But what does it take to manage ecosystems so that they remain resilient and productive, so that they retain–or recover–their health? We are still struggling to find out. There is no standard measure of ecosystem health or resilience. How much productivity should we expect from ecosystems, and how much degradation can we tolerate? How much can we repair what we have broken, and how much will it cost?

Certainly, answering these questions requires a fundamental knowledge of ecosystem processes and the relationship between various goods and services. Yet these are not scientific questions alone. They are also matters of societal judgment, of economics, and even of ethics. We may choose to forgo harvesting a tract of old-growth forest simply because it is a beautiful and rare habitat, or we may deem it more beneficial used as lumber for housing and left to regenerate as second growth. In either case, the forest may persist in a vital state, but deliver a very different complement of benefits.

Whatever we decide, our opportunities to improve our management of ecosystems are substantial. Our understanding of how ecosystems function, of the links between them and their biological limits, and of their total value has improved significantly in just a few short decades. Satellites and improved measurement techniques have heightened our ability to monitor ecosystems and measure the results of our management. Ecosystem restoration techniques have also advanced, giving the hope that some recovery of productivity is possible (Parrotta and Turnbull 1997). And, more and more, governments and communities have begun to understand the link between ecosystem health and their own economic prosperity and quality of life. Many have already started to define for themselves what sustainable ecosystem management might be–a regional approach to watershed management, perhaps, or land-use restrictions that seek to cluster suburban development rather than encourage sprawl.

The very process of global development, although it places greater pressures on ecosystems, can also be a positive force, changing the way we look at and manage ecosystems. As personal incomes rise and education and environmental awareness expand, the value we place on intact ecosystems will surely grow as well (Panayotou 1999). This is already in evidence in wealthier nations. The demand for nature-based tourism, for example, has started to increase sharply. Initiatives to preserve farmland and curb suburban sprawl have begun in many urban areas. Ambitious projects to restore threatened ecosystems such as the Rhine River or the Florida Everglades have garnered political and financial backing. These projects are evidence of a growing desire to experience and conserve ecosystems, and a willingness to pay for it.

Despite these positive signs, the challenge of defining equitable and sustainable ecosystem management at a global level should not be minimized. It includes asking ourselves such difficult questions as:

- How can we manage watersheds and water resources in the face of potential increases in demand of up to 50 percent for irrigation water and up to 100 percent for industrial water by 2025 (WMO 1997:19–20)?

- Even if irrigation water can be found, how can we intensify our agriculture enough to feed future populations without increasing the damage from nutrient and pesticide runoff or without continuing to convert forests and other ecosystems to croplands?

- How can we continue to supply the roughly 1 m^3 of wood products per year that the average person consumes without decimating existing forests? And what if wood demand doubles in the next 50 years, as some project (Watson et al. 1998:18)?

- How can we lessen the impact of climate change on ecosystems given that CO_2 emissions will likely increase as the global economy grows, at least in the short term?

- How can we reduce the impacts of urban areas–from sprawl to water use to air pollution and solid waste generation–on surrounding ecosystems as urban populations rise to an estimated 5 billion by 2025 (UNPD 1997)?

We have no option but to confront these and similar questions. Our dependence on ecosystems is growing, not diminishing. The productivity of ecosystems, once it is lost through poor management, is difficult and costly to replace.

Tackling these issues will require new strategies that reach across political boundaries without losing critical local support. These, in turn, will rely on an ever clearer understanding of the real state of global ecosystems–how much we have and how much we stand to lose without better management. As a first step, Chapter 2 presents the results of a comprehensive, albeit preliminary, assessment of the world's major ecosystems. The hope is that such background knowledge can help to reveal the trade-offs we have already made and crystallize the management choices that remain to us.