Population Change, Resources, and the Environment

By Robert Livernash and Eric Rodenburg

Robert Livernash is a consultant on environment and development issues and is the principal author of the White House Council on Environmental Quality’s annual report, Environmental Quality. He is a senior adviser to the Global Environment Facility. Mr. Livernash has written extensively on population and development issues and was senior editor of World Resources, the biannual review of global environmental and resource issues.

Population Change, Resources, and the Environment

Eric Rodenburg is a senior associate at the World Resources Institute. He has written extensively on resource issues, and is coauthor of Resource Flows: The Material Basis of Industrial Economies, published in 1997.

The authors acknowledge the contributions of several reviewers, including David Blockstein, Allen Hammond, Jeffrey Jordan, Carrie Meyer, and Gayl Ness.

The Earth’s resources, natural systems, and human population are inherently connected. The fundamental relationships are fairly easy to grasp: People rely on food, air, and water for life. The Earth’s resources provide energy and raw materials for human activities, and those activities, in turn, have an impact on the Earth’s resources and systems.

The simple act of an individual lighting a campfire has environmental implications in terms of resource use (the wood used to build the fire), energy (the heat created by the fire), pollution (emissions of ash and carbon dioxide), and waste (carbon and ash left after the fire has burned out).

Assessing the impact of such an event requires several lines of inquiry: Was the fire lit in an area with abundant or scarce wood resources? How many other people light fires in the same area? Have some people figured out a way to burn wood more efficiently, thus reducing the need for the resource? Do some people have sufficient resources to burn a fire continuously, while others can only burn a fire at night? If wood is being consumed faster than it is being replaced, when will the resource be exhausted? Was the wood from a rare species of tree?

The impact of human activity on the environment was negligible 3,000 years ago when less than 100 million people inhabited the planet. But the collective impact of the 5.8 billion people living on the Earth today is tremendous.

Human interaction with the environment—resource use, consumption, pollution, and waste—involves the same processes today as it did at the dawn of human history, but the scale and complexity of these human activities are vastly greater. And the pace and magnitude of population growth over the past century, and the projected growth in the next century, are unprecedented in human history.

Now, as never before, government policies may increase (or reduce) resource use, consumption, and environmental change, and humans can devise new ways to accommodate their needs with less impact on the natural environment.

Assessing the connections among population, resources, and environment is a complex and frustrating exercise, marred by differences in approach, the biases of different methodologies, and the complexity of the linkages.

There is a basic philosophical division in the study of population and environment that is often characterized, or perhaps caricatured, as a debate between optimists and pessi-
The unprecedented population growth in the 20th century has intensified human impact on the environment and increased the demand for the Earth’s resources.

Optimists believe that people have the creative capacity to overcome potential environmental harm resulting from a growing population and intense economic activity. Pessimists foresee potential political, social, and environmental deterioration and collapse.

Optimists can point to the general improvements in human health and life expectancy, rising per capita incomes, remarkable advances in food production, and technical innovations that can reduce environmental pollution or improve the efficiency of economic activity. Some see population growth as a stimulant to human innovation and genius.

Pessimists make their case by pointing to rapid world population growth, the growing concentration of carbon dioxide in the atmosphere, the declining health of the oceans, reductions in biodiversity, and degradation of land.

A second major division in the debate involves the frame of reference for investigating population-environment linkages. Some investigators seek to manage Earth’s resources and ecosystems to benefit humans, while others strive to minimize human impact on the Earth.

Finally, these differences in philosophies and frames of reference influence the debate about how best to reduce the stress of human activity on the environment. Are better policies, different political or economic systems, new technologies, or changes in lifestyles the best way to protect the environment?

People and nations have an array of choices about the way they live and do business. They can choose to reduce their negative impact on the environment and move toward sustainable development. The apparent willingness of people to recycle solid waste and the willingness of governments to develop programs to protect the environment, for example, suggest that people and governments can make remarkable progress toward more sustainable development. But we need to understand more about the basic relationships to justify individual sacrifices in quality of life and to shore up the political will necessary to enact policies to protect the environment.

This Population Bulletin explores the debate about the contribution of
population and consumption to resource use and pressures on the natural environment. The report examines predictions about the consequences of population growth and the extent to which government policies might alter outcomes.

**The Population-Environment Debate**

The debate about the effect of population on the environment leads to many questions and analytical approaches. It involves concepts such as "carrying capacity" and "sustainable development," whose definitions often reflect the investigator’s frame of reference as well as our scientific knowledge.

Carrying capacity usually refers to the maximum number of animals of one or more species that can be supported by a particular habitat or area during the least favorable part of the year—for example, a cold winter or a dry season. The term is often used to define the number of people that can be supported by the Earth or a specific ecosystem. Human carrying capacity, however, depends on more than just the chemical and biological environment. It also depends on technology (for heating or water storage, for example); the social, political, and economic institutions that control the production and distribution of energy, water, and other resources; on living styles and levels of consumption; and on values, preferences, and moral judgments about how resources are used and by whom.1

The term sustainable development considers the level of human activity that can "meet the needs of the present without compromising the ability of future generations to meet their own needs." Sustainable development does not imply absolute limits on human activities or on the number of people, but, like carrying capacity, the limits are "imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities."2

**Limits to Population Size**

This anxiety about the Earth’s carrying capacity has a long history. Writing at the end of the 18th century, for example, English economist Thomas Malthus observed that population was growing faster than agricultural production. In his "Essay on the Principle of Population," Malthus noted that population grows geometrically (for example, from 2 to 4, 8, 16, 32), while the food supply can only increase arithmetically (from 1 to 2, 3, 4, 5).3 Population growth, he theorized, would ultimately be constrained by the amount of land available for food production. He described a feedback process in the population-environment relationship, in which overpopulation would produce widespread famine, illness, and death, and reduce population size.

Malthus’ concern about the limits to population size was shared by numerous philosophers and scientists throughout human history. The ancient Greeks and Egyptians voiced apprehension about overpopulation and the need to limit population growth as well as, in prosperous times, the need for couples to have more children.4 In modern times, the unprecedented population growth has heightened anxieties about the Earth’s carrying capacity. In his 1995 book, *How Many People Can the Earth Support?*, Professor Joel Cohen surveyed previous estimates of the Earth’s human carrying capacity, which ranged from fewer than 1 billion to more than 1,000 billion. The middle range of estimates extended from 7.7 billion to 12.0 billion.

Cohen concludes that "the possibility must be considered seriously that the number of people on the Earth has reached, or will reach within half a century, the maximum number the Earth can support in modes of life that we and our children and their children will choose to want."5

The real question, Cohen suggests, is not how many people can the Earth
support, but how many people can the Earth support with what quality of life? To answer this question we need to address a host of value-laden questions about human society as well as the natural environment. What levels of material well-being and technology do we expect to have, and for what share of the global population? What forms of governments and economic structures are acceptable? How much natural forest and range land do we expect to have? How clean do we expect the air and water to be? How many children do couples want to have? How long are we expected to live?

Cohen’s line of inquiry puts people first. A natural scientist might pose the question as: What combination of population size and consumption patterns can coexist with a healthy global environment? To answer this question we need to address other questions, such as: How much forest and other land area is needed to maintain reasonable stocks of biological diversity? What level of global carbon dioxide emissions would maintain a stable global climate? How many fish can we harvest from the oceans and still have healthy stocks of global fish species?

Using the Earth’s ecosystems rather than humans as a frame of reference might yield different, probably lower, estimates of optimum global population size. Several natural scientists writing in the 1970s and later suggested that we have already exceeded the population size that can be sustained over the long term.

Another perspective, characterized by the optimists, might focus on how we can best unleash human creative abilities, not on any inherent or implied limits to human population growth or resources.

There is overwhelming evidence, however, that we are already endangering the Earth’s life support systems. Human activities have altered more than one-third of the Earth’s ice-free surface and threatened the existence of many plant and animal species. The burning of gas, coal, and oil are increasing concentrations of carbon dioxide in the atmosphere, which could alter the global climate.

**Population-Environment Models**

Over the past few decades, scientists have developed a number of models to study the interactions among population, resources, and environmental systems. These models cannot predict whether or when population growth and human activities will be constrained by shortages in food, water, and other resources, but they have helped define the debate about the role of population in environmental degradation. The models also have contributed to the discussions of carrying capacity and sustainable development.

In 1972, Donella Meadows and her colleagues at the Massachusetts Institute of Technology published *The Limits to Growth*, which used a global systems model to describe how human populations interact with the environment and economy. The model used five variables: population, food, industrialization, nonrenewable resources, and pollution. In all the scenarios of future population and economic growth, population and industrialization surged upward and then fell sharply, a pattern the authors described as “overshoot and collapse.”

The Limits to Growth model provoked a storm of criticism. Some critics argued that human innovation and resourcefulness would improve the technology of food production, resource recycling, and pollution control enough to avoid “overshoot and collapse” and produce steady sustainable growth in population, food, and industrial output per person.

As information about population and the environment increases, models have become more complex and span more disciplines. The “overshoot and collapse” notion has largely given way, at least at the global level, to forecasts of more gradual environmental deterioration over a
longer period of time; the most severe degradation would be limited to specific regions. Some models include the effects of world trade or the age and education profile of a population. The interdisciplinary approach is illustrated in a series of models developed to study population trends, economic development, and environmental change based on a real-world model: the island nation of Mauritius (see Box 1).

Another innovative model of population-environment-resources interactions was developed for the UN Environment Programme in 1997. The model, developed by the National Institute of Public Health and the Environment (RIVM) in the Netherlands, forecasts a number of significant changes at global and regional levels.

The model shows that emissions of greenhouse gases from industrializing countries will heighten the likelihood of global climate change. RIVM’s conventional development scenario projects that the amount of land devoted to agriculture will increase from one-third to almost one-half of the Earth’s land mass by 2050. And, the Earth’s biodiversity will suffer as the amount of land left in natural areas shrinks. Further, water scarcity will afflict increasingly large areas, particularly in western Asia and Africa.

RIVM shows that these changes have a negative feedback effect on human health and development. Continued degradation of land and forests are likely to hinder economic activity and could worsen environment-related health problems, especially in sub-Saharan Africa and many urban areas.

A vital part of these models is the assumed relationship among population, consumption, and adverse environmental effects. Several attempts have been made to measure these relationships and to incorporate them into larger models. The most widely known measure was originally developed in the 1970s by Paul Ehrlich and J.P. Holdren. Ehrlich, a Stanford ecologist, was author of the controversial 1967 book, The Population Bomb. Ehrlich and Holdren defined the population-environment relationship in a formula: \( I = PAT \), where \( I \) is the environmental impact (such as pollution), \( P \) is population size, \( A \) is affluence (usually expressed as average gross domestic product (GDP) per capita), and \( T \) is technology (a measure of efficiency, for example, of energy use).

This formula has been criticized for a number of reasons. Some critics point out that the factors contributing to any particular impact can vary considerably depending on the environmental impact under study. For example, the factors contributing to the depletion of the ozone layer are quite different from the factors contributing to deforestation or biodiversity loss. Furthermore, the equation suggests that the three variables \( (P, A, \text{and} T) \) operate independently, yet these factors may interact with one another. Despite these drawbacks, the \( I=PA\text{T} \) formula created a useful way to study the relationships among the primary variables governing environmental factors. Researchers William Moomaw and Mark Tullis, for example, used the formula to evaluate the relative
Box 1
The Mauritius Model

One landmark study of population-environment-development interactions is based on the small island nation of Mauritius, in the Indian Ocean. In 1960, this nation was characterized by rapid population growth, extreme poverty, and poor economic prospects. Thirty years later, Mauritius had a booming economy with low unemployment. Fertility had dropped to around two children per woman, and life expectancy had increased to levels found in developed countries.

Using the Mauritius data, researchers developed a model that incorporated interactions and feedback effects among labor force, population, economic development, resources, and other factors. The model includes two types of feedback: balances—the relationship between the supply and demand of goods or resources; and influences, such as the effect of living standards on fertility or labor productivity.

The Mauritius model shows that changes in one or more elements can resolve conflicting trends in labor, budget, water, or land variables. For example, if water demand exceeds the supply, economic growth could be stunted, but the shortage could be eased and economic growth could resume if the government mandates water conservation or builds plants to treat or recycle water.

Researchers produced eight scenarios for Mauritius between 1990 and 2050. They compared the long-term effects of a large, traditional population (low educational levels and high fertility and mortality levels) with a small, modern population (high education and low fertility and mortality levels). They considered the effect of policies that emphasize food self-sufficiency; the effect of economic growth on wealth and the environment; the problems of a larger, less-educated labor force versus a smaller, more-educated labor force; and the effect of conscientious early versus ad hoc late pollution abatement.

In the scenario assuming a modern population and strong economy, land planted in sugar cane is converted to urban activities. This increases organic waste concentrations in Mauritius' extremely sensitive lagoon, which threatens aquatic life and kills the island's coral reefs. These developments, in turn, would probably end the tourism industry and seriously diminish Mauritians' quality of life.

Early treatment of the lagoon's water to avoid excessive organic waste concentrations required a substantial investment in water treatment technologies. This heavy economic burden slowed economic growth, but only in the short run.

The scenarios consistently show that water availability is the key environmental constraint to growth in Mauritius. Under laissez-faire, or "do-nothing" policies, usable water is quickly exhausted. With timely investment in water treatment and an emphasis on industry and services rather than irrigation-intensive sugar cane production, rapid economic growth is possible.

From a policy perspective, the study finds that investment in such human resources as education, health, and family planning, and stronger political empowerment and accountability are basic prerequisites for sustainable development. The flexibility and foresight of Mauritius political leaders translated into government policies that reflected their concern for long-term sustainable development.

Reference
Box 2
Greenhouse Gases and Climate Change

Human activities are fundamentally altering the global atmosphere and raising the prospect of potentially catastrophic changes in global climate. A warming of the global climate could cause a significant increase in sea level, major changes in the regional production of food, new stresses on ecological systems, and new threats to human health.

Carbon dioxide and other gases in the atmosphere trap heat as it is radiated from the Earth's surface back to space. This natural greenhouse effect keeps the Earth's temperature about 35 degrees Centigrade (nearly 60 degrees Fahrenheit) warmer than it would otherwise be.

The greenhouse effect is necessary to support life on Earth, but increasing levels of carbon dioxide, primarily from the burning of fossil fuels, are exaggerating the natural warming process. Since the preindustrial era, atmospheric concentrations of carbon dioxide (CO₂) have increased by nearly 30 percent. Other greenhouse gases such as methane and nitrous oxide have risen about 15 percent. Scientists estimate that atmospheric concentrations of CO₂—estimated at 360 parts per million by volume (ppmv) in 1995—are growing by about 1.5 percent annually and could reach 700 ppmv by the year 2100.

The United States generates about 4.8 billion metric tons of CO₂ from industrial activities, which is about 22 percent of total global industrial emissions. Emissions from the United States and the rest of the industrialized world are responsible for the bulk of excess CO₂ in the atmosphere today, but less developed nations such as China and India, with rapidly expanding economies and populations, are expected to produce much of the growth in CO₂ emissions over the next several decades. The per capita emission of CO₂ in China was less than one-sixth that of the United States in 1992, but because its population is so large (more than 1 billion), China was the second largest source of CO₂, just ahead of Russia. India (1992 population of nearly 900 million) ranked sixth in CO₂ emissions, after Russia, Japan, and Germany.

Emissions from the United States and the rest of the industrialized world are responsible for the bulk of excess carbon dioxide in the atmosphere.

contributions of population, affluence, and efficiency of carbon use (the technology factor) on carbon dioxide emissions in 12 countries between 1950 and 1990. They found that the relative importance of the three variables (P, A, and T) varied substantially among countries and over time. Population growth was the most important force increasing carbon dioxide (CO₂) emissions in Mexico, except for a brief period in the early 1980s, when Mexicans' rising affluence was the major factor. Population was also the primary factor increasing CO₂ emissions in Ghana, where affluence actually declined during the period. In the United States, where population and affluence increased, CO₂ emissions largely stabilized during the 1980s because of more efficient technology. Increasing affluence was the primary factor in Poland, and in China after 1981.16

Equity

The important role of relative affluence in consumption levels and, consequently, environmental impact, is complicated by the gross inequities both among and between regions. Natural resources, wealth, and political power are unequally distributed around the globe. The populations of western Asia, for example, face severe water shortages and rapid population growth, while Scandinavians have abundant water and little population growth.
There is a growing consensus that the stabilization of greenhouse gas emissions is essential to avoid further climate change. Yet controlling emissions is difficult. In the United States, about 85 percent of U.S. primary energy is produced from the combustion of fossil fuels. This combustion accounts for roughly 88 percent of all U.S. greenhouse gases (on a carbon-equivalent basis). Coal emits the most CO₂ because it has the most carbon per unit of energy, followed by petroleum (about 25 percent less) and natural gas (about 45 percent less).

Electrical utilities contribute 36 percent of annual CO₂ emissions, primarily from coal-burning power plants. The transportation sector is the second largest and fastest growing source of CO₂. Transportation, largely through gasoline consumption, contributes 32 percent of annual emissions. Industry contributes 21 percent of CO₂ emissions, also because of its reliance on fossil fuels.

At the UN Conference on Environment and Development in Rio de Janeiro in 1992, the United States joined 150 other nations in signing a convention on climate change that established a nonbinding goal for developed nations to return their greenhouse gas emissions to 1990 levels by the year 2000. In 1993, the U.S. government established a plan of largely voluntary measures—promoting the use of energy-efficient products, large-scale purchasing of energy-efficient and renewable technologies, and other measures—aimed at reducing net greenhouse gas emissions. But economic forces, in the form of stronger-than-expected economic growth and lower-than-expected energy prices, have more than offset these initiatives. In fact, between 1990 and 1994, CO₂ emissions from fossil fuels rose 4 percent, and total U.S. greenhouse gas emissions rose by about the same amount.

Reference

Unequal access to resources reflects political and social inequities as well. The world's farmers produce enough food for the 5.8 billion people living in the late 1990s, yet about 800 million people are malnourished, primarily in sub-Saharan Africa and South Asia. Poverty and lack of political power are the primary causes of their hunger, not insufficient food. The equity issue also involves the relative roles of population growth and consumption levels. It has become an especially sensitive issue between industrialized and industrializing countries, exemplified by the debate about who should be responsible for slowing global warming. The industrialized countries have emitted much more CO₂ than less developed countries, especially on a per capita basis. There is mounting evidence that CO₂ levels have so increased that they now endanger the global climate system (see Box 2). Rapid population growth and economic growth in less developed countries are expected to greatly increase emissions of CO₂ in the next few decades.

There is growing pressure for all countries to limit their emissions of CO₂, underscored by the discussions at the Kyoto Conference on Global Climate Change in 1997. But limiting CO₂ emissions may mean slowing economic growth in poorer countries because CO₂ is a byproduct of burning the fossil fuels that power industries and motor vehicles. From the perspec-
tive of less developed countries, the wealthy countries are responsible for the dangerously high buildup of CO₂ and other greenhouse gases in the atmosphere because they burned enormous volumes of fossil fuels for decades.

Many leaders in less developed countries feel they are being asked to accept slower economic growth and, consequently, a lower quality of life to ensure that the industrialized countries can maintain their comfortable lifestyles.¹⁸

Many in the industrialized countries view the situation differently. They maintain that slowing population growth in less developed countries is essential and is more important than reducing CO₂ emissions in their own countries. They question why wealthy countries should limit fossil fuel consumption to reduce greenhouse gas emissions if all the savings will be wiped out by population growth in the less developed countries. The different perspectives of industrialized and less industrialized countries were highlighted at the 1992 UN Conference on Environment and Development in Rio de Janeiro, Brazil. Participants from the less industrialized nations chastised the industrialized countries for failing to help them relieve environmental pressures by, for example, forgiving debts and relaxing barriers to trade and technology transfers. They also decried the industrialized countries for emphasizing slower population growth as a solution to potential environmental problems. Family planning program support from the wealthy countries was viewed by some as an unwarranted and unwanted intrusion into private lives “to preserve the welfare of children in the rich countries.”¹⁹

**Population Trends and Development Pressures**

Population growth is a fundamental driver of the interactions between humans and the environment. More than 80 million people are added to the global population each year, which means that more food must be produced, more water must be available for agriculture and drinking, more materials must be processed to provide shelter, and so on.

It is not only the number of people, but also their lifestyles, political systems, and social structures that define the relationship between humans and environment. The geographic distribution of people throughout the globe, the concentration of people in urban areas, and the demographic characteristics of regional populations have an important influence on the effects of human activity on the environment.

**Population Growth and Change**

World population is projected to reach between 8 billion and 12 billion people by the middle of the 21st century. The most recent long-range population projections from the UN show world population size ranging between 6 billion and 18 billion in 2100, and between less than 4 billion and 27 billion by 2150 (see Figure 1).

The effects of population on the environment will be more moderate if future growth follows the lower
trajectory and levels off below its 1998 size, but this is unlikely to happen.
Future population growth will depend primarily on trends in fertility rates in major world regions. The total fertility rate (TFR)—or average number of children per woman given current birth rates—in less developed countries declined from 6.2 children in the 1950s to about 3.4 children in 1997. The UN projects the TFR to decline to 2.1 by 2050, but this will involve rapid declines in the world’s poorest regions. The TFR is still well above the 3.4 average in much of sub-Saharan Africa and in South Asia. In 1997, the average was 6.0 children per woman in sub-Saharan Africa, and 3.8 children per woman in South Central Asia.

Most demographic expect fertility to decline in less developed countries, but the pace of that decline may hinge on a number of social, political, and economic factors that influence the motivation and ability to limit family size. Fertility rates are substantially lower in the industrialized countries. In the mid-1990s, the average TFR was 1.4 children per woman in Europe, 1.9 in North America, and 1.5 in Japan. UN projections show the TFR in these countries rising to about two children per woman by 2050.

**Uneven Regional Distribution**
The size and growth rate of population in relation to agricultural lands, freshwater supply, forest preserves, and oceans affects the health and well-being of people and the environment. The unequal distribution of population also has important implications for the environmental impact of human activities. More than 90 percent of world population growth is occurring in less developed regions. The population size of Africa is projected to more than double between 1995 and 2050, from 720 million to 2 billion, while the population of Latin America is expected to grow from 477 million to 810 million, and the population of Asia from 3.4 billion to 5.4 billion. In contrast, Europe’s population is expected to decline over this period—from 728 million to 638 million—because of low birth rates and an aging population (see Figure 2). This regional disparity in population size and in future growth can have an enormous effect on population-resources-environment
interactions. As the residents of less developed countries embrace the living standards of the industrialized world, per capita consumption of energy and other goods will grow, resulting in a much greater impact on the environment. Moomaw and Tullis' analysis, for example, showed that rising affluence helped increase carbon emissions in China between 1950 and 1990 by a factor of seven.

Urbanization
Population density also plays a role in environmental degradation. Some analysts speculate that high levels of population density can trigger environmental degradation or socially disruptive events such as mass migration or civil violence.21

Most migrants move from rural to urban areas. As much as 90 percent of future population growth and a major share of future economic growth is expected to occur in cities. The percentage of people living in urban areas is projected to increase from 45 percent to 55 percent worldwide between 1995 and 2015.

The global urban population, just 750 million in 1950, is projected to rise from 2.6 billion to 5.1 billion between 1995 and 2030. Most of this increase will be in the less developed regions (see Figure 3). The populations of these regions have been transformed from overwhelmingly rural to about 40 percent urban in the past 50 years. The urban share is projected to rise to 57 percent in less developed countries and to 84 percent in developed countries by 2030.

More people will be living in large metropolises. Between 1995 and 2015, the number of people living in cities with populations of 1 million or more is projected to grow from about 927 million to 1.7 billion.

The population shift toward urban areas has many positive aspects. It means that a greater share of people will have access to health care, education, and other services. Living standards are likely to improve, on average. Greater population densities will enable more communities to capitalize on economies of scale, for example, by investing in more efficient and cost-effective water management.22

But the rapid population increase in urban areas in less developed countries also creates a host of social and environmental problems. Many cities are unable to expand their infrastructures and services fast enough to keep pace with population growth.

Urban growth often encroaches on farmland, destroys wildlife habitats, and threatens sensitive ecosystems and inshore fisheries. In Jordan, for example, the rapid growth of Amman and Zarqa has led to the gradual depletion of a major underground water reserve, which has reduced water availability for farmers and desiccated an internationally important wetland.23

Population Characteristics and Trends
Many demographic characteristics in addition to population size and distribution affect consumption levels
and natural resource use. Researchers are investigating, for example, the role of age structure, labor force profiles, educational levels, and family patterns on population-resource-environment interactions. The status of women is a particularly important variable in the population-environment relationship and is receiving increasing attention from researchers. In many societies, women’s status is closely associated with rates of fertility and infant and child mortality, health and nutrition, children’s education, and natural resource management. The importance of gender in the development and environment context was highlighted at the 1994 International Conference on Population and Development in Cairo, Egypt.

Poverty and Wealth
The impact of population growth on the natural environment varies tremendously according to a society’s lifestyle and economic activities. Poverty and depleted resources often encourage population movement from rural to urban areas, which increases the concentration of population and adds to the special problems those urban areas present. Poverty is also an important “push” factor in international migration.

Many parts of the world are getting wealthier, which usually means increases in consumption of food, fossil fuels, and other resources that can negatively affect the environment.

As societies grow wealthier, some environmental problems—such as lack of access to clean water and sanitation—are expected to ease, while others—such as the generation of solid waste—get worse. Wealthier societies also can more easily invest in equipment and infrastructure for environmental protection.

Poverty
In nearly all societies, poverty is a function of income and other factors such as health, education, access to goods and services, gender, and ethnicity. The percentage of people living in absolute poverty—defined as existing on less than one dollar per day—has fallen since the mid-1980s, led by the impressive economic growth in East Asia.

But because of disproportionate population growth among world regions, the total number of people living in absolute poverty has risen to about 1.3 billion—one-fifth of the world’s people. The poverty declines in East Asia were more than offset by population increases in sub-Saharan Africa and South Asia. Widespread poverty appears most persistent in countries experiencing continued, rapid population growth and economic stagnation.

Poverty induces a variety of behaviors that can promote environmental degradation. For example, a farmer living in poverty can easily let the immediate need to produce food outweigh the long-term benefits of conserving his land. Overplanting—planting too many crops within a growing season—is a serious problem in many areas. Farm families whose land becomes degraded through overplanting may move on in search of other land to cultivate or may

Although the percentage of people living in poverty has eased, the absolute number has grown, primarily because of population growth in the least developed countries.
migrate to urban areas. An estimated 200,000 square kilometers of land are degraded every year because of overplanting; some 70,000 square kilometers are abandoned annually as a result.27

In many parts of the less developed world, the poor rely heavily on forests and grasslands, which are often referred to as "common property resources." These areas provide animal fodder, organic manures, fuel supplies, edible fruits and nuts, and traditional medicines. Poor rural households may obtain up to one-fourth of their annual income from such resources. For centuries, such areas were managed in a sustainable manner by local communities, but in the last few decades population pressures and other factors have broken down old management systems and led to resource degradation in many areas.28 A survey of semiarid regions spanning eight states in India found that common property resources declined in area by 30 percent to 50 percent between 1950 and 1980.

Greater participation from local communities and nongovernmental organizations has helped restore common property resources in some areas. In most cases, such efforts depend on convincing all subgroups within a village of the benefits of cooperation and on actively seeking the involvement of women, who are usually responsible for collecting and processing fuelwood, fodder, food, and water. Such efforts also require a strong commitment by resource management officials.29

Poverty and Migration
In many less developed countries, particularly those where 50 percent or more of the population depends on agriculture for a living, cropland is increasingly scarce. During the 1980s, the amount of arable land per capita declined by an estimated 2 percent annually in less developed countries.30 These figures mask the disparity in the distribution of land within countries that helps perpetuate poverty.

Land scarcity and population growth seem to be the principal factors behind the emigration of 12 million to 17 million people from Bangladesh to the adjacent Indian states of Assam, Tripura, and West Bengal. This mass migration caused social disruption and even violence in some areas. In Assam, migrants from Bangladesh represented one-third of that state's 22 million residents in the 1990s. In Tripura, the shift in the ethnic balance caused by immigration fueled a violent insurgency that lasted throughout most of the 1980s.51

In the Philippines, population pressure on agricultural land, combined with government policies and high unemployment, sparked a series of migration flows that led to substantial degradation of forests as well as urban growth. The Philippines' arable lowlands were fully cultivated by the mid-1970s, and access to agricultural land was limited. From 1975 to 1980, the percentage of landless farm workers in the agricultural labor force grew from 40 percent to 56 percent. Over 60 percent of landless workers were employed on sugar and coconut farms at less than subsistence wages.32

Such situations traditionally augment the flow of migrants to urban areas to search for jobs. Manila, for example, absorbed more than 1 million migrants during the 1970s. But a severe economic crisis in the early 1980s drove urban unemployment up and wages down. With few urban job opportunities, increasing numbers of Filipinos migrated to forested upland areas.

The Philippine government's timber policies also encouraged the surge in upland migration. Twenty-five-year timber licenses gave timber operators an incentive to build access roads to the forests over a period of years and then abandon the sites once the prime timber was gone. The result was a network of roads and logged land that was relatively easy for migrants to clear for cultivation. Thousands of migrants moved in, some of whom had worked for the logging companies. By 1985, more
than 62 percent of the total upland population resided in timber concession areas. The result was a heavy loss of forest cover and substantial increases in soil erosion in upland areas. Other factors, such as rising demand for fuelwood, added to the loss of forest cover in the uplands.53

The Philippines example shows how a combination of factors—limited access to arable land, high population density and growth, reduced employment opportunities in urban areas, and government policies—can contribute to substantial migration to rural areas and considerable environmental impacts.

Poverty and Resource Subsidies
Many governments in both developed and less developed countries enact subsidies to promote development in rural areas and lessen rural poverty. Subsidies typically reduce the cost of fertilizer, farm equipment, or other agricultural inputs so more farmers can afford to buy them. According to World Bank estimates, subsidies to energy, roads, water, and agriculture in less developed and transition economies totaled over $240 billion annually in the 1990s.

Subsidies often have unintended negative consequences. They lead to wasteful resource use, environmental damage, and growing financial strains on government budgets. They also interfere with market forces by artificially lowering the prices of inputs. In India, for example, fertilizers, electricity, irrigation, credit, and farm machinery costs have all been heavily subsidized. By 1990, tariffs for electric tubewell pumps covered only about one-tenth the energy costs, while user charges for canal irrigation recovered only about 20 percent of construction and operating costs.54

Electricity subsidies in the Ludhiana district in northwestern India encouraged excessive use of groundwater for irrigation. Water tables dropped significantly in recent decades, by about 0.8 meters per year.55 Agricultural subsidies can reduce the number of job opportuni-

ties by giving farmers an incentive to substitute subsidized pesticides or other inputs for labor. And, subsidies sometimes favor farmers in one region over those in another region.56

Resource subsidies are difficult to dislodge once they become established, but there are cases in which they were reduced or removed without disrupting rural economic development. In Bangladesh, for example, fertilizer subsidies cost the government about $93 million (in 1995 dollars) in 1978. Between 1978 and 1983, subsidies were phased out on the sale of urea, an important fertilizer, eventually saving more than 2 percent of government revenue per year. Despite the abolition of price controls and the reduction in subsidies, real prices of urea declined because of improved efficiency in distribution, increased domestic production, and decreases in world urea prices. Fertilizer use increased after subsidies were removed.57

Wealth
Wealth can provide the resources for substantial investments in environmental protection, while at the same time it can exacerbate some environmental problems. In the United States, for example, population growth, economic activity, and rising per capita income all put pressures on the environment. From 1970 to 1995, U.S. population rose from 205 million to 263 million people; gross domestic product (in 1992 dollars) grew from $3.4 trillion to $6.7 trillion; and per capita disposable income rose from $12,022 to $18,800 (also in 1992 dollars).58 Yet by many measures, environmental quality improved: Between 1970 and 1994, total emissions of six common air pollutants decreased by 24 percent; emissions of particulates (fine particles suspended in the air) decreased by 78 percent; and emissions of lead declined by 98 percent, primarily by eliminating lead from gasoline and controlling specific industrial sources of lead. Water quality improved...
because of massive investment in wastewater treatment. Direct discharges of toxic pollutants declined dramatically after 1988; water pollution controls on industry prevent about 1 billion pounds of toxic pollutants from entering U.S. waters every year.

The cost of environmental progress has been high. From 1972 to 1990, the federal government invested nearly $60 billion in the construction of wastewater treatment plants, while state and local governments contributed more than $20 billion. Amendments to the Clean Water Act of 1972 have substantially increased the share of wastewater treatment to be borne by local governments. According to the U.S. Department of Commerce, the nation spent an estimated $102 billion on environmental protection in 1992.

It is difficult to quantify the benefits of pollution reduction for human health and welfare and the environment. A study by the U.S. Environmental Protection Agency concluded that health-related and other benefits from Clean Air Act programs between 1970 and 1990 far outweighed the costs. A large proportion of the benefits were linked to the dramatic reduction in two pollutants: lead and particulates.

**Wealth and Waste**

The disposal of increasing volumes of waste is one of the most intractable problems wealthy countries face. Between 1960 and 1994, the amount of municipal solid waste generated in the United States increased from 88 million to 209 million tons. It is projected to rise to 262 million tons by 2010. On average, each American produced 4.4 pounds of garbage each day in 1994, up from 2.7 pounds per person daily in 1960. Per capita waste is projected to increase to 4.7 pounds daily by 2010. Most of this waste is either deposited in landfills or burned, emitting pollutants into the air.

Most future increases in U.S. waste generation will probably be recovered through recycling or composting programs. The share of waste disposed...
of by traditional methods—landfilling or combustion—will gradually diminish. For example, landfill tonnage is expected to decrease from 127 million tons (61 percent of generated waste) in 1994 to 122 million tons (55 percent of generation) in 2000, primarily because yard trimmings (grass, leaves, and brush) will be diverted to municipal and residential compost areas.

Recovery programs are growing steadily. In the United States, they accounted for almost one-quarter of all solid waste generated in 1994: 49.3 million tons. As state and local governments continue to emphasize recovery programs—the purchase of recycled products, investment by industries, and expansion of programs to keep yard trimmings out of landfills—35 percent of total solid waste generation could be recovered by the year 2010.

The United States is the largest generator of municipal solid waste among the 25 industrialized nations in the Organisation for Economic Co-operation and Development (OECD) in 1995, both in absolute and per capita terms. Average per capita waste generation in Europe is only about half that of the United States.

Evidence from the United States and other wealthy countries suggests that government policies and local support for recycling and recovery programs can influence waste generation. Waste recycling rates are also substantially higher in some European countries, and they have been increasing. In 1995, for example, Germany recycled 75 percent of its glass waste and 67 percent of its cardboard and paper waste, a substantial increase over 1980 numbers. Recycling has increased more slowly in the United States. Americans recycled about 23 percent of glass and 35 percent of paper and cardboard in 1995, similar to recycling levels in the United Kingdom (see Figure 4).

**Wealth and Motor Vehicles**

Motor vehicle ownership is concentrated in wealthier nations. About 70 percent of the world’s automobiles were in OECD nations in 1993.

The United States has the greatest per capita car ownership of any nation. In 1993, there were 561 cars per 1,000 Americans, compared with 366 cars per 1,000 people for all OECD nations combined. Between 1970 and 1995, the number of registered motor vehicles in the United States rose from 111 million to 205 million, and the number of highway passenger miles traveled per capita nearly doubled.

Relatively few people in less developed countries own cars. In 1993, there were only 14 automobiles per 1,000 Africans, three per 1,000 South Asians, and 68 per 1,000 Latin Americans. China had less than two cars per 1,000 people.

As these countries industrialize, per capita ownership is expected to increase, which, combined with population growth, will expand their share of motor vehicles. The percentage of motor vehicles in less developed countries rose from about 12 percent to about 18 percent between 1970 and 1990. A recent World Bank report projects that about 26 percent—282 million of the world’s
estimated 1 billion motor vehicles—will be in less developed countries in 2010 (see Figure 5). While automobiles are out of financial reach of many less developed country residents, increasing numbers of people are buying the less expensive two- and three-wheel motor vehicles. In India, for example, motorcycle ownership is increasing by 17 percent annually.

The growing reliance on motor vehicles is associated with a number of environmental problems aside from urban air pollution, including urban and suburban encroachment on agricultural land and natural areas. The most serious problem is probably the emission of gases that contribute to global warming.

The transportation sector, which is dominated by motor vehicles, contributes 30 percent of all greenhouse gas emissions. It is the second largest source of greenhouse gas emissions in the United States. Despite diligent and successful efforts to reduce motor vehicle exhaust, motor vehicles still account for more than two-thirds of all carbon monoxide emissions, 45 percent of nitrogen oxides emissions, 56 percent of volatile organic compounds, and 22 percent of particulates in the United States.

### Other Stresses From Wealth

Affluence is related to a number of consumption patterns that exert pressure on resources and environment. Wealthy nations have higher per capita consumption of petroleum, cement, metals, wood, and other commodities that deplete world resources, emit pollutants, and generate large volumes of waste.

As incomes increase, people tend to add more animal fats to their diets. Unlike energy consumption, there appears to be a limit to the amount of animal fat that people consume. Many developed countries may have reached that limit, but worldwide food requirements will expand as population increases and as more countries adopt the high-fat diets popular in most developed countries.

### Renewable Resources

The shift of population from rural to urban areas, population growth, and the concentration of population growth in less developed regions will amplify many of the effects of human activity on renewable resources: land, water, and air. Forests, which are protectors of Earth’s biodiversity and serve vital functions in many global systems, are receiving increasing attention.

### Agricultural Land

Based on his observations of late 18th-century England, Thomas Malthus concluded that the amount of agricultural land was the ultimate constraint on population growth. He did not
foresee the remarkable improvements in agricultural technology and genetic engineering of plants that would expand the world food supply. Despite the unprecedented population growth in the second half of the 20th century, the world’s farmers produce enough food to feed the current population and will probably be able to feed several billion more people in the next century.

Over the past few decades, yield increases—that is, higher productivity on existing cropland—have accounted for most of the increase in food production. Relatively little came from expanding the amount of land planted in crops. Total cropland, which is estimated at 1.45 billion hectares (one hectare is equivalent to 2.47 acres), increased by about 1 percent between the early 1980s and the mid-1990s. The largest increase in cropland area since the early 1980s was a 6 percent expansion in Africa. Europe’s total declined by about 3 percent over the same period.

Most of the best agricultural land is already in production. Some prime land has been lost through conversion to urban uses or degraded through improper agricultural methods, overgrazing, or other human activities.

The best estimate of land degradation done to date—the 1990 Global Assessment of Soil Degradation, or GLASOD—estimated that 17 percent of the Earth’s vegetated land area was degraded; 10 percent was classified as moderately or severely degraded. Land is considered degraded if the chemical, physiological, or biological characteristics of the land have been altered and fertility compromised. GLASOD found the causes of land degradation almost equally divided among overgrazing of livestock, agricultural activities, and forestry practices. Population’s contribution to land degradation in less developed countries is the source of an intriguing debate.

Human activity has degraded land, sometimes beyond recovery, but some scientists are optimistic that innovation can overcome the short-sighted, destructive practices of some farmers and ranchers. Danish economist Ester Boserup wrote in the 1970s that the pressures of population growth had forced farmers to develop such innovations as irrigation, using manure as fertilizer, composting, and rotating legumes with crops to enrich the soil. Some studies seem to confirm this assertion; the best-known example is Machakos District, Kenya. But most researchers have concluded that agricultural innovation did not result from population growth but from government policies intended to encourage innovation and increase crop yields.

Many other studies have found that increasing population and population density have negative impacts on soil quality. A study of 38 sub-Saharan African countries found that population growth tended to increase cropping frequency, land degradation, and breakdowns in communal land management controls. The study found little association between population growth and agricultural innovation.

Other studies have found that population pressures in rural areas appear to encourage farmers to plant crops or graze their livestock in...
forests, on steep hillsides, and on semiarid lands of marginal quality.

Demographer Richard Bilsborrow found that population pressures in Latin America contributed to an expansion of cropland area or a reduction in the time fields are allowed to lie fallow. Bilsborrow also saw evidence that populations may respond to the shortage of agricultural land by reducing their fertility, changing technology, or migrating to another area.48

Water Quality and Scarcity
Water, like land, is a renewable resource on which human life depends. Water is one of the most plentiful of the Earth's resources, yet it is unevenly distributed throughout the globe. Vast supplies are frozen in glaciers or stored underground in aquifers that may be tapped only through deep wells. Water supplies are altered seasonally by cyclical droughts or floods, so that the population "carrying capacity" may be influenced more by periodic droughts than by average annual rainfall.

Waterways often cover wide areas that encompass more than one nation. Upstream uses can have a significant impact on downstream conditions in another country. In the Ganges River basin, for example, deforestation and water use in Nepal and India have reduced river flows and caused dry-season water shortages, salinization, and depletion of fishery resources in Bangladesh.49

Much of the increase in agricultural production in recent decades has depended upon large and constant quantities of water. Many less developed countries have made substantial investments in irrigated agriculture, which have boosted yields at a cost to the environment. In some parts of the Indus plains in Pakistan, for example, irrigation led to waterlogging and salinization of the soil.50 Irrigation also tends to reduce wetland areas and mangrove forests, which serve as habitats for many birds, fish, and other wildlife.

Expanding the supply of safe drinking water to cities, towns, and villages has been hampered by poverty, poor infrastructure, and increasing pollution of waterways and groundwater. Nearly $100 billion was invested worldwide from 1981 to 1990 to accelerate the introduction of water services in poor regions, but gains in the number of people served were offset by population growth, especially in urban areas. By 1994, about 1.2 billion people in less developed countries still lacked safe water supplies and about 3 billion—more than half the world's population—lacked access to sanitation services.51

In many less developed countries, rising volumes of industrial and household effluent often overwhelm municipal treatment capacity and contaminate surface water and groundwater. Untreated waste from paper, textile, and food industries in Alexandria, Egypt, for example, flows into nearby Lake Mariut, which has suffered an 80 percent decline in fish production since the 1980s. And, the Tieté River picks up several hundred tons of industrial effluent per day as it flows through Greater São Paulo, Brazil.

More than 1 billion people in Asia depend on groundwater for household use, yet in many areas reserves are increasingly threatened by contamination, especially from intensive agriculture.

New irrigation schemes are causing significant increases in water-related diseases. Dam construction has increased infection rates for schistosomiasis to nearly 100 percent in North and West Africa, up from 5 percent to 10 percent before the dams were constructed. The World Health Organization estimates that waterborne or water-related diseases affect almost one-half the world's population and account for about 5 million deaths each year.52

Although the links between population and freshwater resources are not clearly understood, a number of key characteristics are reasonably well established. Population growth

Much of the increase in agricultural production in recent decades has depended upon large and constant quantities of water.
clearly has increased demands for water, expanded well drilling, and in some areas (and with some crops such as rice) contributed to the depletion of groundwater resources. The effects vary according to local climate, vegetation, geology, institutional arrangements, and government policies.

Oceans
The impact of human activities on the oceans is a subject of mounting concern among natural scientists. In January 1998, 1,600 scientists and conservation biologists from 65 countries issued a warning that the world’s oceans are seriously threatened by ecosystem destruction and pollution. The United Nations has declared 1998 the International Year of the Ocean.

The dwindling supply of marine fish offers a good example of what can happen when a renewable resource is overused. After nearly a five-fold increase in the marine fish catch between 1950 and 1989, the marine harvest (excluding shrimp or other fish raised domestically via aquaculture) leveled off at 84 million to 88 million metric tons annually between 1987 and 1993, and then jumped to 93 million metric tons in both 1994 and 1995 (see Figure 6).

The UN Food and Agriculture Organization (FAO) has estimated that more than two-thirds of the world’s marine fish stocks were being fished at or beyond their maximum sustainable level by 1993. In the northern Atlantic, the catch of Atlantic cod has plunged to about one-fourth the size it was in the late 1960s. Off the Asian coast in the Pacific, every fish stock that experts examined was being exploited at or beyond sustainable limits in the 1990s.

The prime cause of the dwindling fish population is overfishing—by huge industrial fishing fleets as well as by small fleets and subsistence fishers. The limits of the marine fish catch are a particularly troubling aspect of the global food production outlook. According to many assessments, the current volume of marine harvest is close to the global maximum. The FAO projects that a further increase of perhaps 10 million tons is possible, including 4 million tons from improved management of overfished stocks in each of the Atlantic and Pacific Oceans, and 2 million tons from fisheries development in the Indian Ocean.

Mounting Health Problems
The global supply of fish and the viability of the oceans are being threatened by viruses and bacteria that attack marine life. Harmful blooms of algae often referred to as “red tides” are increasing in incidence, duration, and geographic extent. In red tides, a powerful toxin accumulates in the shellfish that feed on the algae and can produce serious illness in humans. In the Pacific Northwest, the *dinoflagellate* produced by blooms has led to “amnesiac shellfish poisoning”—loss of memory and even death.

Red tides are just one example of the diseases sweeping through marine species from corals to dolphins. The Marine Conservation Biology Institute claims that dozens of diseases—including yellow blotch, white pox,
Population, Forests, and Biodiversity

By increasing demands for food, fuel, shelter, and other amenities, population growth and urbanization contribute to the loss of forests around the world. Nearly one-half of the forests that covered the Earth 8,000 years ago are gone, primarily because of human activities, according to a recent study by the World Resources Institute and the World Conservation Monitoring Centre. Logging threatens 70 percent, and agriculture threatens 20 percent, of the world’s remaining frontier forests.

The world’s forests are essential for a number of reasons. Forests provide wood pulp and timber and offer areas of natural beauty and recreation for people. They provide a habitat for millions of species of plants and animals, most of which have not yet been catalogued. Forests are integral to global weather systems and the world’s oxygen supply, and they serve as watersheds that absorb water and prevent soil erosion. Forests act as storehouses of the global carbon supply, and thus are crucial to the international negotiations on global warming, as explained below.

Tropical forests, which make up just over one-half of the world’s forest cover, totaled about 1.8 billion hectares in 1990 (one hectare is equivalent to 2.47 acres). This represents a decline of about 450 million hectares since 1960. Between 1960 and 1990, about one-fifth of all natural tropical forest cover in less developed countries was lost. Asia lost one-third of its tropical forest cover in that period, while Africa and Latin America each lost more than one-sixth.

The total area of forests in temperate climates, such as in North America and the former Soviet Union, remained fairly stable in the 1980s. Forest cover actually increased slightly in the sparsely populated northern forests of Canada and Russia; the area planted (or replanted) with trees expanded in these countries. The
forested area in temperate climates is, however, just a fraction of what it was before human settlement. The countries of the former Soviet Union have lost an estimated 35 percent of their dense forests and a larger share of woodlands.\textsuperscript{54}

Natural forest cover (both tropical and temperate) is estimated to have declined by about 8 percent (163 million hectares) in less developed countries during the 1980s. This loss was partially offset by new plantation cover totaling about 31.9 million hectares and by a 32.1-million-hectare increase in other wooded areas (mostly former natural forest).

The substitution of planted forests for natural forests is a significant loss for the Earth’s biodiversity, however. Replanted forests often consist of few tree species, which makes them vulnerable to disease, drought, and other natural stresses. And, these less diverse tree plantations cannot support as many species of other plants and animals.\textsuperscript{55}

The Earth has perhaps 14 million different species, of which only about 1.7 million have been identified and described. Between 50 percent and 90 percent of all land species inhabit the world’s forests. Many are threatened with extinction, primarily because of habitat loss. An estimated 1 percent to 11 percent of the world’s species have become or will become extinct per decade between 1975 and 2015.\textsuperscript{56}

**Population Pressure**

Population and economic growth exert considerable pressure on global forest resources. Between 1961 and 1994, per capita consumption of paper increased by 86 percent globally and by 350 percent in less developed countries. Between 1993 and 2010, global consumption of industrial wood products is expected to grow another 50 percent.\textsuperscript{57} Forests are also being cleared to build roads, feed livestock, and grow crops.

Many research studies associate population growth with forest loss around the world. In an analysis of 41 countries in the humid tropics, geographer Alan Grainger found that average annual deforestation rates fluctuated according to average annual population growth rates in the 1970s. Grainger also found an association between declining forest cover and increasing population density in 43 countries in the humid tropics.\textsuperscript{58}

Population growth and density were the most important factors contributing to deforestation in northeast Thailand, according to another study, mainly because of increasing demand for agricultural land.\textsuperscript{59} Richard Bilsborrow found that forest loss in Indonesia could be traced to both population growth and government policies to encourage migration to Indonesia’s outer islands.\textsuperscript{60}

**Forest Management**

The management of logging in forested areas could protect more of the area needed to support the Earth’s species. Forest management is hampered by a lack of knowledge about how much logging a forest can sustain without endangering the area’s ecosystems. Fragmented forests are often too small to support a full complement of species, for example. Cleared forests that are replanted with single plant or tree species (monocultures) often are not suitable habitats for the same species that lived in the original forests.

Determining how best to manage the world’s forests is also affected by philosophical questions. Should forests be managed for the maximum benefit of people, for example, or should forests be protected because of their intrinsic value as part of the natural environment?

Overriding these philosophical differences, however, is an increasing international consensus about the importance of forests in storing the world’s carbon supply. Trees, like all growing plants, remove carbon (C) from the CO\textsubscript{2} in the atmosphere, and release the leftover oxygen (O\textsubscript{2}) back into the air. When trees are burned, carbon is released back into the atmosphere, where it recombines with...
1997 meeting on climate change in Kyoto, Japan, industrialized nations formally agreed to such a joint implementation under the clean development mechanisms (CDM), with details to be worked out later.

**Nonrenewable Resources**

Two decades ago, media reports reflected a widespread anxiety that population growth and rapidly rising per capita consumption would soon exhaust the Earth’s nonrenewable resources, such as fossil fuels and subsoil minerals. These concerns were reflected in Paul Ehrlich’s *The Population Bomb*, Donella Meadows’ *The Limits to Growth*, and several other publications from the 1960s and 1970s. Detractors, such as economists Herman Kahn and Julian Simon, argued that human ingenuity and technology would prevent any catastrophic loss of resources, and further, that population growth stimulated such innovation.

In 1980, Paul Ehrlich made a public bet with Julian Simon about future trends in mineral resources. Ehrlich bet that increasing shortages would push up the prices of five metals—copper, chrome, nickel, tin, and tungsten—between 1980 and 1990. Simon bet that the prices would go down because of technological improvements in mining and resource use. Simon won the bet handily and gained considerable media attention. In the 1990s, known reserves of many natural resources are generally more abundant and prices generally lower than they were 20 years ago, despite rising consumption.

One reason for this apparent contradiction is that improved technologies drove down the cost of exploration and extraction of minerals and other resources, which increased the potential supply. Furthermore, new substances and products have been developed that can substitute for the natural resource-based materials, relieving some of the demand.
Between 1980 and 1994, worldwide consumption of most metals generally rose, with the most spectacular growth occurring in East Asia. In the case of copper, for example, global consumption rose from 9.4 million to 11.1 million metric tons. Consumption in China roughly doubled, rising from 386,000 to 745,000 metric tons. Copper consumption in South Korea grew even faster, from 84,000 to 476,000 metric tons. There was modest consumption growth in advanced industrial countries such as Japan and Germany. In the countries of the former Soviet Union—in transition to market economies—copper consumption dropped precipitously, from 1.3 million to 560,000 metric tons, between 1980 and 1994. Over the same period, world copper reserves increased from 494 million to 590 million metric tons (see Figure 7).

Iron consumption also rose, from 890 million to 970 million metric tons between 1980 and 1994. In China, iron consumption rose from 120 million to 222 million metric tons, making China the world's largest consumer of iron. Other less developed nations, such as Brazil and South Korea, also experienced rapid consumption gains.

In the wealthier industrialized countries, however, iron consumption was stable or declining. In the United States, for example, consumption dropped from 91 million to 63 million metric tons between 1980 and 1994. In the former Soviet Union, iron consumption fell from 198 million to 169 million metric tons and iron reserves decreased from 93 billion to 65 billion metric tons of iron content.65

Less developed countries' consumption of other metals and minerals is also growing rapidly, although per capita consumption of most resources remains much higher in the industrialized countries. Per capita consumption of copper, for example, was about 17 times greater in industrialized countries than in less developed countries in the late 1980s.

Wind-generated electricity, along with geothermal plants, solar panels, and other alternative energy sources, account for less than 5 percent of commercial energy production worldwide.

**Energy Production/Consumption**

Global energy production and consumption has risen steadily for several decades. In 1995, commercial global energy production totaled 365 exajoules (equivalent to 59.5 trillion barrels of oil). An estimated 20 additional exajoules of energy were produced by burning traditional fuels, such as wood, charcoal, and biomass (animal and vegetal wastes).

The vast majority of the world's energy comes from the burning of fossil fuels—in liquid (petroleum), solid (coal or lignite), or gas form (natural gas). The extraction and processing of these fuels also constitutes one of the major flows of natural resource materials in industrial economies (see Box 3, page 26). In addition to emitting greenhouse gases, the burning of fossil fuels releases particulates that have been associated with increased cancer risk, respiratory disease, and other health problems.

Petroleum plays a central role in world energy supplies and markets. Oil accounts for about 40 percent of global commercial energy production (see Figure 8, page 27). Estimates of petroleum reserves rose about 43 percent between 1984 and 1994.
Box 3
Tracking Natural Resource Material Flows

The study of material flows—the process by which materials flow from nature to the economy and back—provides new insights into the connections among population, resources, and the environment.

When primary materials are extracted from the environment, they are transformed into products and services, sold to consumers, and ultimately disposed as waste, recycled or reused, or dispersed into the environment.

Modern industrial economies use a vast volume of resources to support their flow of goods and services. According to a recent study, wealthy economies require 45 to 85 metric tons of natural resources per person annually.¹ These resources include the commodities that enter into commerce, the flows associated with making a commodity available for human use, direct and indirect uses of natural resources in construction, deliberate alterations of the landscape, and other effects of human activity such as soil erosion from cultivated fields.

Many material flows are integral to a country’s economic activity but never enter the monetary economy. In industrial economies, such “hidden” flows include removal of rock and soil to extract coal and other materials, erosion of soil from agriculture, generation of waste from dredging operations, and the shifting of earth and stone in the building of highways. These flows account for 55 percent to 75 percent of total material requirements.²

Fossil fuel use is a major component of material flows in most countries. It is the largest contributor to material requirements in the United States and Germany, for example, and the second largest contributor in Japan and the Netherlands. Japan’s relatively small per capita energy use is the primary reason that its material requirements are significantly lower than many European countries.

Countries may become less material-intensive as their economies shift away from producing goods to producing services. A recent study of four industrialized countries (the United States, Germany, Japan, and the Netherlands) found that the ratio of national income to natural materials used in economic activity declined between the 1970s and 1990, and has since stabilized.³

With rising population, economic activity, and consumption, industrial nations are beginning to formulate policies that help reduce their dependence on natural resources. The international Factor 10 Club, which consists of 16 distinguished scientists from 10 countries, argues that over the next 30 to 50 years the industrialized countries “must work toward cutting in half present global nonrenewable material flows, including minerals, freshwater, and nonrenewable energy carriers. To achieve this, it is our view that a political commitment to a tenfold increase in the average resource productivity of the presently industrialized countries is a prerequisite for meeting the goal of long-term sustainability.”⁴

References
2. Ibid.
4. This conclusion was noted in the February 1996 communiqué of the OECD ministerial-level environmental policy committee.

Wealthy economies require 45 to 85 metric tons of natural resources per person annually.
mainly because of revised estimates of
reserves in the Middle East, but
petroleum reserves have been declining in the former Soviet Union and
the United States.

Solid fuels—primarily coal and
lignite—are relatively abundant and
account for about 27 percent of global
commercial energy production. They
provide about three-fourths of
commercial energy production in
China and India. The burning of coal
produces more particulates and
greenhouse gases than the other
forms of fossil fuels. Air pollution
from coal fires blanketed London in
the 19th century and currently
plagues many urban areas in China
and India.

Natural gas, the least environmen-
tally damaging greenhouse gas,
provides about 23 percent of global
commercial energy. Production and
consumption has risen about 70
percent over the past two decades.
Estimates of gas reserves also have
increased; the largest reserves are in
Russia, which holds about one-third of
the world total, and in the Middle East.

Primary electricity—produced by
hydroelectric, geothermal, nuclear,
wind, or solar power—accounts for
about 10 percent of commercial
energy production in the 1990s. About
70 percent of primary electricity is
from nuclear power plants and 25
percent is from large-scale hydroelec-
tric plants. All other sources—
geothermal, wind, and solar energy—
account for about 5 percent of
primary electricity.

Traditional fuels—such as firewood
and biomass—fill the energy needs of
millions of people in less developed
countries, but they are not easily
measured in international statistics.
The UN estimates that traditional
fuels supplied about 6 percent of
energy consumed worldwide in 1993,
but they accounted for 35 percent of
fuel consumption in Africa, 21
percent in South America, and 9
percent in Asia. Many of the least
developed countries rely almost
exclusively on traditional fuels. The
UN estimates, for example, that such
fuels provided at least 85 percent of
the energy used in Burkina Faso, Laos,

These fuels often are collected
from common resources such as open
land and woodlands. The collection
and burning of these fuels create their
own environmental problems, includ-
ing soil erosion, loss of watershed
areas, and emission of particulates and
other pollutants. As countries industril-
ize, they tend to replace traditional
fuels with fossil fuels and other
commercially produced energy
sources.

Consumption of commercial
energy has been growing rapidly in
Asia, particularly in China, India,
South Korea, Thailand, Taiwan, and
Indonesia. Energy use also has
increased rapidly in Latin America
and Africa, though these regions still
account for a relatively small propor-
tion of the less developed world’s total
energy consumption. Asia (excluding
Japan) consumes 60 percent of all
energy in the less developed world.
Africa has nearly tripled its consump-

---

Note: 1 exajoule of energy is equivalent to about 365 million barrels of oil.
Population growth has helped keep per capita energy consumption low in less developed countries, yet the volume of energy consumed is expanding rapidly. Consumption increased by 144 percent in Africa, and by 185 percent in Asia, between 1973 and 1993.

Demand far outweighs the supply throughout much of the less developed world; energy brownouts and blackouts are commonplace in many countries. The demand for energy will continue to grow, propelled primarily by population and economic growth and tempered by technological advances in energy efficiency.

The International Energy Outlook from the U.S. Energy Information Administration projects global energy use to grow by between 1.4 percent and 2.6 percent per year between 1990 and 2010, depending primarily on the rate of economic growth. Energy consumption in less developed countries is expected to increase by 3.0 percent to 4.9 percent annually over the 20-year period (see Table 1). Total energy consumption would increase by one-third to two-thirds in these scenarios. Almost all of this growth will involve fossil fuels.

The OECD’s International Energy Agency (IEA) provides an alternative set of projections of world energy consumption, which reflects possible changes in consumption patterns and energy efficiency. The IEA’s “capacity constraints” model assumes that recent trends in energy efficiency and consumption will continue; Energy demand slows, primarily because prices rise as production is unable to keep pace with demand. World population increases to 6.9 billion by 2010, following the UN medium-range projections. Under this scenario, world energy demand increases by an annual rate of 2.2 percent—which means a 46 percent increase over the period. The scenario suggests that CO₂ emissions will increase 47 percent between 1993 and 2010.

The IEA’s “energy savings” model assumes somewhat faster gains in energy efficiency and no change in
real prices. Energy demand still rises by about one-third under this model, suggesting that conservation and efficiency gains alone will not completely offset rising demand.

The World Energy Council (WEC) also has developed a number of future scenarios of energy consumption (not shown in Table 1). WEC’s reference case—which assumes moderate economic growth, increased supplies of fossil fuels, a slow expansion of nuclear and renewable sources, and improvements in energy efficiency—projects a 54 percent increase in world energy demand between 1990 and 2020.

WEC’s “ecologically driven” model assumes rapid improvements in energy efficiency, a massive transfer of energy-efficient technologies to less developed nations, and an accelerated switch to natural gas and renewable energy sources. This scenario shows much slower growth in consumption, but it still yields a 30 percent increase in world energy demand between 1990 and 2020. Annual CO₂ emissions would increase by 5 percent over 1990 levels.

While supplies of these fuels are finite, reserve estimates continue to grow. In the 1940s, for example, recoverable crude oil resources were estimated at about 600 billion barrels. In the 1990s, the U.S. Geological Survey estimates that untapped resources, including allowances for undiscovered oil, total between 2,094 billion and 2,807 billion barrels. No new major fields have been located in recent years, however, and some experts believe that most large oil fields have been discovered.

Worldwide production of petroleum is projected to rise from 653 billion barrels in 1993 to as high as 1,700 billion barrels by 2020. Many experts believe that global petroleum production will peak in the early part of the next century and then begin a slow decline. By 2020, one-half of the conventional oil resources that once existed in the ground will have been extracted.

The timing of this peak production will depend on how fast, or whether, production facilities are expanded to extract oil from ever more difficult sources such as oil shales. Nevertheless, energy analysts predict that when this peak occurs, it will have significant consequences on prices for consumer goods, economic development, and efforts to curtail global warming.

This global pattern may mirror what occurred on a smaller scale in the United States in recent decades. U.S. petroleum production peaked in the early 1970s and then declined. By 1995, 85 percent of the estimated total U.S. resources had been extracted and production was down to 1950 levels. In the case of the United States, the shortfall in production was made up by imports. In the global context, the shortfall in production can be ex-

Table 1
Projections of Energy Consumption Growth Under Various Scenarios, 1990-2010

<table>
<thead>
<tr>
<th>Region</th>
<th>International Energy Outlook</th>
<th>International Energy Agency*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Slower economic growth</td>
<td>Rapid economic growth</td>
</tr>
<tr>
<td>World</td>
<td>1.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Industrialized countries</td>
<td>1.3</td>
<td>1.7</td>
</tr>
<tr>
<td>Eastern Europe and former Soviet States</td>
<td>-0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>Less developed countries</td>
<td>3.0</td>
<td>4.9</td>
</tr>
</tbody>
</table>

* 1993-2010
pected to be made up in part by substituting coal and natural gas along with increasing use of unconventional oil supplies.

The decline in oil production could be countered by developing alternative energy sources. But demand for liquid fuels, coupled with the cost of producing them from alternative sources (such as heavy oils, bitumen, oil sands, oil shales, and coal), will almost certainly drive up their prices. These high-priced replacements will limit economic growth in industrialized countries, and, more critically, in the less developed countries where most of the world’s population lives.

Some liquid fuel demand is likely to be converted either to gas or coal. For each unit of energy extracted, coal emits more carbon dioxide than either petroleum or natural gas. Coal extraction releases significant amounts of methane (a greenhouse gas that is 21 times more powerful than carbon dioxide as a contributor to global warming) into the atmosphere. Meeting a shortfall in petroleum supplies with an increase in coal production could slow efforts to deal with climate change.

Increasing production and consumption of fossil fuels will increase humankind’s impact on the environment. The extraction, processing, transport, and use of these fuels will affect habitat, landscapes, ecosystems health, water and air quality, and the global climate system. Human activity adds 3 million tons of oil to the oceans through extraction, processing, and transport, and 60 million tons of sulfur dioxide to the atmosphere from burning fossil fuels. These numbers could increase as economies industrialize.

The extraction and processing of fossil fuels on land disrupts ecosystems and hydrological systems. In principle, some of these disruptions could be mitigated by adopting the best technology or by developing more efficient technology.

It is far more difficult to imagine mitigation for the increased emissions of carbon dioxide. Most of this growth will occur in the less developed countries, with the highest growth occurring in China and India.

Meeting Future Needs

As world population continues to grow, and more people expand their diets and buy cars, the pressures of human activities on the Earth’s resources will intensify. Some of this pressure may be released through technological innovation or substitution, as described below. And, government policies, especially when they reflect public attitudes and tastes, can have a tremendous influence on the management of the Earth’s resources.

The Promise of Substitution

When supply or environmental constraint drives up the cost of one resource, another material can often be substituted to accomplish the same function. Common silicon can replace copper wire in communication devices, for example, not because silicon conducts electricity like copper but because fiber optics made of silicon can also transmit information using light instead of electricity. The fabrication of optical cable and the ancillary equipment required to make it work requires technologically advanced production capabilities. Optical cable, furthermore, is more efficient than copper in transmitting information and requires less environmental disruption and lower costs.

Even without new energy technology, one energy form can be transformed into another for the purpose of substitution. Liquid fuels can be derived from coal, for example. Solar electricity can create hydrogen that can be burned in internal combustion engines. Biomass from landfills can fuel electrical generating plants.

New technological developments can also lead to substitution. Energy efficiency is a form of substitution. Electric motors with computerized controls can run more efficiently than the traditional models, thus saving
energy. Generating electricity through gas turbines rather than large thermal plants is another illustration of substituting a more efficient technology for a less efficient one.

Substitutions can require high economic and social costs. Construction of a large dam to generate electricity will disrupt human settlements, river and terrestrial ecosystems, and even local seismic stability. But the costs of that disruption might be less than the capital, operating, and environmental costs of a coal-fired thermal plant or thousands of internal combustion engines that might otherwise pollute urban areas.

Substitutions are inherent in technological progress—regardless of supply constraints or environmental problems with the materials being substituted. Copper replaced stone, bronze replaced copper, iron and later steel replaced bronze, aluminum replaced steel, and engineered composites of carbon and of glass and designer ceramics are substituting for all of these. Concrete and asphalt roads have replaced iron tracks in transport networks. Silicon-based chips replaced bulky vacuum tubes in communication and computing technology.

Technology, including advances in metallurgy and in the creation of composite materials, promises continued change in the materials upon which economies depend. The new materials sometimes perform better than those replaced. Carbon-fiber-based composites, which are used in the construction of aircraft and many other applications, are lighter, stronger, and less chemically reactive than the metals they replace, with potentially fewer environmental costs.

Better engineering is another form of substitution. A car made of lighter materials, buildings with more efficient heating systems, and computer disks that store more information in less space are all forms of substitution.

Recycling of materials—the use of previously processed materials rather than virgin raw materials—is also substitution. Recycling avoids the economic and environmental costs of extracting raw materials and the economic and environmental costs of its processing and disposal. One-fourth of America’s aluminum demand is met by recycled materials. More than one-half (56 percent) of the material that would otherwise be extracted and smelted is avoided by the recycling of iron. The existing stock of products and infrastructure is, in fact, a new source of materials. It is even possible, for example, to imagine a future in which the amount of iron recycled satisfies an economy’s new demand.

**Future Food Supply and Demand**

Future demand for food will be determined by population growth, per capita income, and changes in diet. For example, residents of less developed countries are expected to add more meat and animal products to their diets as their incomes increase. This will increase the per capita demand for grain because grain produces many fewer food calories per kilogram when used to produce
The imbalance between food supply and demand often reflects political and social inequities.
of Bangladesh, India, and the Philippines, the rate of increase in yields is slowing. In Central Luzon and Laguna in the Philippines, for example, average wet-season rice yields rose from 2.5 tons per hectare in 1966 to 4.2 to 4.7 tons per hectare by the early 1980s, but then leveled off or declined slightly. In the 1980s, much of the growth in yields was in countries and regions that were just beginning to adopt the technologies—including fertilizer use, irrigation, and machinery—that were introduced in many other less developed countries during the 1970s.

Yields have stopped increasing, and even declined in some areas, which may mean that we are approaching the upper limits for yield expansion. Agronomists suspect that the perennial flooding of rice paddies and planting of single plant varieties in many parts of Asia reduced the nitrogen carrying-capacity of the soil; depleted essential micronutrients such as phosphorus, potassium, and zinc; and built up toxic substances in the soil. In South and Southeast Asia, agronomists estimate that phosphorus, zinc, and other deficiencies account for about 11 million tons of lost rice production annually, while soil salinity accounts for about 2 million tons, and iron toxicity for about 1.6 million tons. The total loss amounts to 10 percent of the region’s rice harvest.

There are ways to avoid some of these problems and to increase yields. One is to alternate planting legumes such as mungbeans or soybeans with rice crops, which would help replenish nitrogen in the soil. Current plant-breeding programs could provide additional yield increases by improving existing plant stocks. Within two decades, however, biotechnology may become a principal source of further productivity gains. By 2010, scientists expect to field test bioengineered genes for insect resistance and disease resistance. But only about 2 percent of the world’s agricultural biotechnology research is taking place in less developed countries. It is not clear that biotechnology will benefit them in the near term.

Crafting more effective agricultural policies offers great potential for boosting food production in less developed countries over the next few decades. Giving farmers better access to credit, improving extension and training programs, improving rural infrastructure, and encouraging more competitive private markets are among the many reforms that could strengthen incentives for food production. Other reforms, such as reducing input subsidies and establishing market prices for water, could improve the efficiency of resource use and reduce environmental damage.

Improving the efficiency of the global food system is another way to increase potential food supply. In countries with the highest incomes, for example, the amount of lost or wasted food is equivalent to anywhere from 30 percent to 70 percent of the food actually consumed. If every middle- to high-income country reduced its level of waste to 30 percent, global food requirements would fall 7.4 percent. Reducing the amount of animal fat in the diet in industrial countries and slowing the addition of meat to diets in less developed countries could also ease the demands on the world food supply.

**Marine Resources**

By the year 2020, marine harvests are projected to be at or below current levels, which means there will be less seafood available per capita. Although experts expect some gains in harvests from better handling of catch, more use of by-catch (low-value or undersized fish that are usually discarded), and exploitation of the few underused fishing areas, these gains will be offset by losses from poor management of fishing areas, increased protection of areas and species from fishing, and continued degradation of marine environments.

Some of the gap between supply and demand will be made up by aquaculture. Domestic cultivation of
shrimp and other seafood is likely to rise from the 1990s level of about 17 million tons to between 30 million and 40 million tons by 2020.\(^5\) But aquaculture can disrupt and harm coastal ecosystems. It destroys vital mangrove swamps and coastal estuaries, and it requires large amounts of water and energy. Furthermore, in the case of prawn aquaculture in Asia, intensively farmed shrimp ponds are only viable for five to 10 years and then must be abandoned. In 1994 alone, an estimated 20,000 hectares were abandoned, and another 100,000 hectares of shrimp farms may be abandoned by 2000.\(^6\) Aquaculture, as currently practiced, may not be a viable long-term solution to future supply shortages.

**Water Supply**
The water available for human use is shrinking because pollution from agriculture, industry, and other human activities is degrading water quality in many rivers, lakes, and groundwater sources. Underground deposits of water are being pumped out faster than they are being replenished by surface water. And population is growing rapidly in areas already experiencing water scarcity.

Yet there are a number of ways that water can be used much more efficiently. Farmers and communities can build irrigation systems that lose less water to evaporation. For example, and farmers in dry areas can adopt agricultural methods that preserve soil moisture. Agroforestry—which incorporates trees and woody plants into cropland—and specific plowing techniques, for example, allow farmers to use existing water more efficiently.

**Policies and Outcomes**
The environmental strains that population growth and resource use will exert over the next century and the health effects likely to result from environmental degradation can be mitigated through government policies. Indeed, policies can make a vast difference in the efficiency of resource use and in reducing the most adverse environmental impacts.

Even in rapidly growing less developed countries such as China, pollution can be substantially reduced under some policy scenarios. These efforts are expensive, but they usually prove to be cost-effective. A World Bank study shows that each Chinese yuan invested in a medium-cost scenario of pollution abatement would yield 3 yuan in reduced pollution damages.\(^5\)

The direction of China’s policy regarding environmental and health issues is particularly important because it is the world’s most populous country and because it is growing rapidly economically. The Chinese government’s and people’s choices about lifestyle and economic patterns—automobile use, diet changes, and agricultural and fishing methods, to name a few—will have enormous implications for global resources in the future.

The interdependence of the Earth’s systems, as well as the Earth’s nations, suggests that policymakers in every country must consider the international implications of their actions. Several international conferences and agreements in recent years offer encouraging signs that the world community is ready to act to reduce negative environmental impacts from human activities.

In December 1997, delegates from more than 160 nations met in Kyoto, Japan, to produce a protocol on climate change. Under the protocol, industrialized nations agreed to reduce their aggregate emissions of greenhouse gases by at least 5 percent below 1990 levels between 2008 and 2012. Commitments vary from an 8 percent decrease to a 10 percent increase according to the circumstances of individual nations. The European Union nations are treated as one unit and must collectively reduce their emissions to meet the protocol’s goals.
Industrial nations may trade credit for emissions reductions with one another. The protocol also calls for creation of a clean development mechanism (CDM) to oversee emission reduction projects in less developed nations. The many unresolved details of the Kyoto protocol will be addressed at a conference scheduled for November 1998 in Buenos Aires, Argentina.

Of the many trends that will characterize human development over the next several decades, none is more important than the demographic transition taking hold in less developed countries. The population growth rate is leveling or slowing in all major regions, primarily because couples are having fewer children.

There is evidence that fertility is likely to continue to fall. Some two-thirds of less developed countries now regard their fertility rates as too high, and more than half have policies in place aimed at reducing their population growth rates.

Policies can help improve the education, health, and job opportunities for women, especially when spurred on by economic growth. The most rapid fertility declines have occurred in less developed countries that have increased child survival rates and educational levels and have implemented family planning programs.\(^4\) The relatively small investment necessary to implement such changes will provide less developed countries with immense long-term benefits.

Sub-Saharan Africa and South Asia stand out as the regions most likely to be adversely affected by rapidly rising population. Many governments lack the resources or institutional capacity to build sound environmental policies, strengthen investment in education and primary health care, or to quickly adapt new technical innovations that further economic growth with less environmental impact.

Even in the best possible scenario—that global population follows the “low-variant” trajectory and reaches 8 billion people by 2050—the addition of 2 billion people will put great pressure on the Earth’s resources. This growth will bring additional pressures on open-access...
resources such as coastal fisheries; further development of marginal lands and deforestation; further habitat fragmentation and loss of species; further pressure on global food production, with possibly increased environmental impacts; and some local or even regional crises in freshwater availability.

Under most "business-as-usual" scenarios, there will be massive increases in conventional air and water pollution and in the emission of greenhouse gases, primarily because of increasing economic activity but abetted by population growth.

In regions with rapid growth, the severity of these impacts on resources and the environment really depends on politics and the perception among policymakers of the seriousness of these issues. Though politicians often are stereotyped as short-term crisis managers, the ability of the international political community to address complex, incremental issues is already evident in international agreements on ozone depletion and climate change.

Our ability to document the benefits of pollution reduction also can help buttress the political case for investing in environmental protection and strengthen the view that investing in environmental protection can complement economic growth.

The world community is just beginning to turn its attention to the current size and direction of energy and materials consumption and to think about policies that encourage economic growth with less resource use. The resource material flows analysis shows that economies can grow without increasing consumption.

Of the many connections among population, resources, and environment, three stand out as particularly troubling: the continuing dependence of the world on fossil fuels to support economic growth, which throws more carbon dioxide into the atmosphere and worsens the outlook for climate change; the challenge of mobilizing support for conservation of resources and biodiversity; and the Earth's ability to absorb the growing quantities of waste generated by rising economic activity.

Even in these most dire cases, however, we should not underestimate our ability to find new ways to manage such problems. In the end, the real issue is whether perception and politics can keep pace with a rapidly changing world.
References

6. Ibid.
12. Biodiversity is usually defined as the range of differences in ecosystems, species, and genetic composition in a given geographic area. An ecosystem can be defined as the system in which the interaction between different organisms and their environment generates a cyclic interchange of materials and energy. See UN, *Glossary of Environmental Statistics* (New York: United Nations, 1997): 8, 26.

Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.
30. UN Economic and Social Council, "Recommendations of the Expert Group Meeting."
33. Ibid.
34. Repetto, The "Second India" Revisited.
35. Paul Faeth, Agricultural Policy and Sustainability: Case Studies from India, Chile, the Philippines, and the United States (Washington, DC: World Resources Institute, 1993).
39. Ibid.
41. As cited in Executive Office of the President, Council on Environmental Quality, Environmental Quality.
42. Ibid.
43. Bender and Smith, "Population, Food, and Nutrition."
50. IUCN and PRB, Water and Population Dynamics.
51. UN Department for Policy Coordination and Sustainable Development, Critical Trends: 49.
52. Ibid.
55. Ibid.


79. Bender, "How Much Food Will We Need in the 21st Century?: 27.

80. Ibid.


Suggested Readings


Discussion Questions

1. The authors state that as societies grow wealthier, some environmental problems are expected to lessen, while others will get worse. Explain this statement using concrete examples.

2. Which world regions are most likely to face water scarcity in the future? What new or different policies could alleviate water scarcity?

3. Discuss the impact of the continued increase in motor vehicles on resource use, habitat, and local and global ecosystems.

4. If you were advising the president of the United States on environmental issues, which two issues would you recommend he or she give top priority? Defend your selections and outline your policy recommendations.

5. Outline the major factors contributing to global warming in industrialized and less industrialized countries. Suggest several steps each can take to slow the accumulation of carbon dioxide in the atmosphere.

Discussion questions prepared by Kimberly A. Crews