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Critical Links: Population, Health, and the Environment

by Roger-Mark De Souza, John S. Williams, and Frederick A.B. Meyerson

The scope, magnitude, and complexity of human impacts on the environment today are unprecedented.

Emerging knowledge helps us understand how environmental changes affect human well-being.

To protect human and environmental well-being, policy and perception need to match reality.

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Critical Links: Population, Health, and the Environment

About the Authors

Roger-Mark De Souza *is the technical director of the population, health, and environment program at the Population Reference Bureau. His responsibilities include designing, managing and implementing policy research, capacity building, technical assistance, and media projects in developing countries. De Souza holds graduate degrees from the George Washington University and the University of the West Indies.*

John S. Williams*, a demographer at the Population Reference Bureau, specializes in population, environment, and community programs. Williams, who holds a doctoral degree from Princeton University, is an active member of the World Conservation Union's Species Survival Commission and has supported integrated conservation and development research and projects in Asia and Africa.*

Frederick A.B. Meyerson *is an ecologist and demographer who specializes in population policy and the interactions between population and the environment, particularly climate change and biodiversity. He has a doctoral degree from Yale University and a law degree from Columbia University. Meyerson has taught at Yale and Brown universities, and was an American Association for the Advancement of Science Fellow at the National Science Foundation and the U.S. Environmental Protection Agency from 2001 to 2003. He is currently a public policy scholar at the Woodrow Wilson International Center for Scholars, writing a book on U.S. population policy.*

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Critical Links: Population, Health, and the Environment

by Roger-Mark De Souza, John S. Williams, and Frederick A.B. Meyerson

The impact of the world's 6.3 billion people on the environment is unprecedented. Humans had a negligible effect on the environment 3,000 years ago when fewer than 100 million people lived on Earth, but by the early 21st century, we have altered more than one-third of Earth's ice-free surface and threatened the existence of many plant and animal species. These changes also pose threats to our well-being. The burning of gas, coal, and oil, for example, is increasing concentrations of carbon dioxide in the atmosphere, altering the global climate and affecting human health.

The number of people is just one factor driving environmental change. Other demographic factors also cause change. Where people live and the rate of population growth increase the demand for natural resources such as water and fossil fuels, adding pressure on environmental systems such as watersheds and rainforests. The relative proportions of children, persons of working age, and elderly within a population have repercussions for future population growth, health risks, and use of services such as public transportation.

Other forces, such as public policies, technological developments, and culture, can ease or worsen the pressures that these demographic factors place on society and the environment. One example is the growth of cities throughout the world. This urban growth brings changes in lifestyles, consumption patterns, infrastructure development, and waste production.

Photo removed for copyright reasons.

The well-being of people and the natural environment are closely connected. Ensuring that well-being means meeting human needs without destroying the resources and natural services that sustain life on Earth.

This *Population Bulletin* highlights the results of research, community projects, and public policies to examine three critical questions about population, health, and environment relationships. First, what is the nature of these relationships? Second, how do these relationships affect human well-being and the environment? And finally, what can researchers, local communities, and policymakers do to address these impacts?

Addressing these questions means delving into the complexity of population, health, and environment relationships and reaching out to experts from diverse fields. Natural and social scientists who study demographic trends, political structure, land use, agriculture, climate change, biodiversity loss, and an array of other specialties can all contribute to a greater understanding of population, health, and environment relationships.

But the synthesis of these contributions has been stymied by the very diversity of the scientific disciplines involved. Each field has its own terminology, methodology, and priorities. Fortunately, there is a growing awareness that closer cooperation among scientists from different disciplines will help head off current and impending threats to human and environmental well-being.

Earth's natural resources and its human population are inherently connected.

Translating increased knowledge into policies and action that will protect the well-being of people and the environment may be the greatest challenge of all. Researchers need to educate policymakers and the public about why they need to take action and what they can do. Researchers also must be able to justify the social, political, and economic costs of laws and policies that sometimes conflict with culture and tradition, such as expanding women's rights, regulating land use, and requiring cleaner industrial technology. Efforts to address population, health, and environment issues extend from the global level, which requires international cooperation, to the household level, which involves individual choices and behavior.

These challenges are daunting, but there are a number of success stories to guide us. The policies that slow population growth by lowering fertility are well known, for example. Effective policies involve improving education, primary health care, and employment opportunities and raising the status of women. Laws to regulate pollution have been responsible for cleaner air and water in many countries. More efficient technology and new materials promise to reduce toxic wastes and ease the demand on natural resources.

At the community level, conservation and health organizations have cooperated on successful projects to integrate environmental protection and public health. And individuals have demonstrated a willingness to change behavior when they believe it is necessary, illustrated by a widespread compliance with recycling policies in some countries, for example. As the knowledge base, community experience, and political expertise expand, there will be many more lessons to guide the efforts to promote human and environmental well-being.

The Population-Environment Relationship

Earth's natural resources and systems and its human population are inherently connected. The fundamental relationships are fairly easy to grasp: People rely on food, air, and water for life. Earth provides energy and raw materials for human activities, and those activities, in turn, affect the resources and ecosystems. Pollution and damage to those environmental goods adversely affect people's health and well-being.

Assessing the interactions among population, health, and the environment is not that simple, however.[1] It encompasses the study of human population growth, consumption, and resource use as well as the study of the natural world, its climatology, genetics, biochemistry, and population biology. Cooperation between natural and social scientists has been complicated by major differences in paradigms, assumptions, and definitions (see Box 1). At the same time, many environmentalists and scientists concerned with protection of plant and animal species are acknowledging that protecting nature also involves improving the circumstances of people.

These challenges are evident in the study of effects of population growth on land use. First, much of the existing research focuses on case studies of specific areas or communities, and the results of such studies generally are not applicable to larger areas.[2] In addition, demographic and ecological data generally are not collected in comparable geographic areas. Demographic surveys are usually conducted within a political region, such as a district or country; land use data are more often collected for a particular ecosystem or landscape, which can cross political boundaries. Finally, much of the research conducted on population growth and environmental change has focused on documenting associations between environmental changes and demographic variables rather than identifying the specific causes of change.

It is difficult to evaluate such changes with regard to specific issues—such as land use—partly because of the poor quality of available data and problems determining what factors drive change. For example, does climate change or human activity have the greater effect on land use?[3] Careful research examining population and environment relationships has provided a better understanding of the importance of these connections to human and ecological well-being.

Box 1

What Do We Mean by Population, Health, and the Environment?

Increasing numbers of people and organizations are involved with issues related to population, health, and the environment. While many groups are working toward similar goals, communication among these groups is sometimes stymied by the lack of common definitions for basic terms. Population, health, and environment mean one thing to a conservation group, for example, and another thing to a family planning service coordinator or research demographer.

To demographers, the study of population involves the three variables that cause population change—births, deaths, and migration—and such population characteristics as age, sex, race, place of residence, income, and education.

When managers of family planning programs say they work in "population," they are likely to mean that their activities involve reproductive health and possibly gender issues, but they are not likely to consider migration or age structure to be part of the definition.[1]

People involved in community projects and studies may attribute yet another meaning to the term. Population work to them means encouraging public participation in meetings and involving communities in project design and management.

The term "health" may also carry different meanings to groups involved in the emerging field of population, health, and environment. Health may refer to public health or environmental health. Public health refers to the general well-being of a group of people and the factors that ensure that well-being. The term environmental health is used in a variety of ways, but it usually applies to the well-being of people and the natural environment. Groups that work in environmental health may limit that meaning to either people or the environment, or may include both.[2] Most groups working in this area tend to focus on the effects of environmental changes (such as air pollution) on human health (asthma, for example); the general quality of the air, water, forests, and other natural resources; and the health of global life-support systems.

When conservationists say they work on environmental issues, they often mean protecting natural areas and biodiversity, whereas a town planner may apply the term "the environment" in the context of land-use planning.

Research into population, health, and environment interactions may combine elements of all of these definitions. Once demographers, conservationists, and public health groups agree what the terms mean in a specific context, they might launch a study to examine, for example, how household transportation decisions affect urban air pollution and, subsequently, how that air pollution affects human health.

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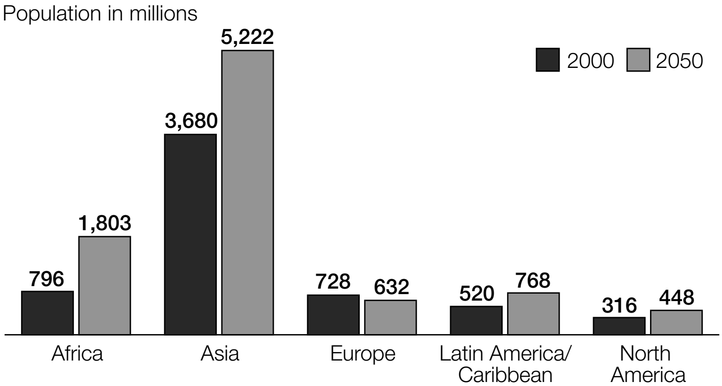
Figure 1
Population in Major World Regions, 2000 and Projections for 2050



Source: United Nations, *World Population Prospects: The 2002 Revision* (2003): medium projection series.

Demographic Outlook

Several demographic trends strongly affect the way humans change the natural world. The regional distribution of population is shifting as growth continues in some regions, especially in Africa and western and southern Asia, and declines in others, such as Europe. Within regions and countries, the population is shifting from rural to urban areas and concentrating in coastal regions. In addition, the number of households is increasing more rapidly than the population. Households are getting smaller as couples have fewer children and are less likely to share their homes with extended family members. Smaller households consume as much as or more than larger households.[4] Even those countries with stable or declining populations have increasing numbers of households and associated sprawl.

World population in 2050 is projected to range between 7.4 billion and 10.6 billion. The total will depend primarily on future fertility rates, but also on mortality rates, which have become less predictable in light of HIV/AIDS, agricultural and economic crises, and warfare around the world.[5] Ninety-nine percent of world population growth is occurring in less developed countries.

Among the larger developed countries, only the United States shows robust growth, because of its relatively high birth rate and steady immigration. In contrast, Europe's population is expected to decline from 728 million to 632 million between 2000 and 2050, because of low birth rates and an aging population (see Figure 1). Europe's fertility rates have been low for quite some time. As a result, Europe's population has been growing older; Europe's "youth dearth" is now taking on a more significant role because of impending population decline in much of the region.

Globally, there will be more than 1 billion people ages 60 and older by 2025, and nearly 2 billion by 2050. As world fertility rates decline and life expectancy rises, the population will age faster in the next 50 years. The age structure of the population also affects the environment. A rapid expansion of the working-age population, which many less developed countries are experiencing today, often drives economic expansion, migration to new areas, and construction of new homes and supporting infrastructure.[6] An older population is more vulnerable to health threats brought by environmental changes, including respiratory diseases associated with air pollution and the spread of infectious diseases associated with climate change, deforestation, and water pollution.

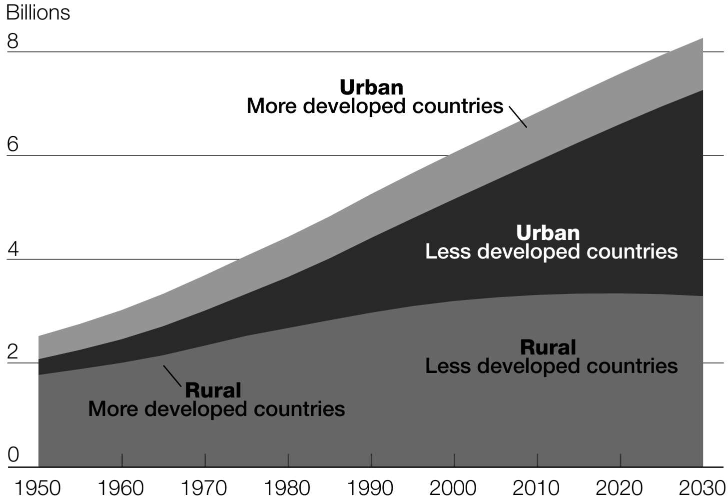
While life expectancy is rising in most countries, the rapid spread of HIV/AIDS in recent decades has depressed life expectancy in the most affected countries; the disease is now the fourth most-common cause of death worldwide. More than 60 million people have been infected with HIV since the 1970s, and 20 million have died. Of the 40 million people living with HIV/AIDS worldwide, 70 percent are in sub-Saharan Africa, where is it the leading cause of death.[7]

Even with fertility declines and increased mortality from HIV/AIDS, world population will probably continue to grow rapidly for several decades because of the momentum created by the large proportion of children. There have never been so many young people in the world. Today, children under age 15 make up one-third of the population in less developed countries and an even greater proportion in some regions. In contrast, less than one-sixth of the population in more developed countries is under age 15.[8]

Many of these young people are on the move. International migration is at an all-time high. At least 160 million people were living outside their country of birth or citizenship in 2000, up from an estimated 120 million in 1990.[9] Despite these high numbers of international migrants, most of the world's 6.3 billion people never cross a national border.

Over the next 30 years, urban populations are expected to expand, while rural populations hold steady or decline worldwide (see Figure 2). The percentage of people living in urban areas is projected to increase from 47 percent to 60 percent worldwide between 2000 and 2030, according to the United Nations.[10] Rural populations are projected to decline in most more developed countries and some less developed countries (such as Brazil, China, and Mexico) between 2000 and 2030, although the world total is expected to rise from 2.9 billion to 3.1 billion, led by large increases in rural areas of India, Bangladesh, and Afghanistan, among other countries. Although the percentage of people living in rural areas has been declining throughout the world, the number of rural dwellers in less developed countries rose by almost 1 billion between 1960 and 2000.

Figure 2
Growth of Urban and Rural Populations, 1950–2030



Source: United Nations, *World Urbanization Prospects: The 2001 Revision* (2002): tables A.3 and A.4.

Environmental Impacts

Humans influence the natural environment in many ways. Some impacts are direct. Humans hunt and gather wild plant and animal species; clear forests for timber, agriculture, or infrastructure; and withdraw groundwater. Other impacts are indirect. Burning fossil fuel releases carbon into the atmosphere, increasing greenhouse gases that affect climate. Ships plying the oceans sometimes carry plant and animal species into new areas, crowding out or harming the native species. Insecticides used to protect harvests reduce insect populations, which are then unable to pollinate wild plants.

Population growth does not necessarily lead to a serious deterioration of the natural environment. Human inventiveness has resulted in technological advances that enable more food to be grown in smaller areas, wastewaters cleaned, and significant areas of biodiversity protected. In India, for example, a new concept—People's Protected Area (PPA)—aims to conserve biodiversity by facilitating poor people's access to the resources provided by protected natural areas. The network of PPAs focuses mainly on biodiversity-rich buffer zones, fringe areas, and corridors of natural parks and wildlife sanctuaries. It aims to convert open-access natural resources into community-controlled resources, thereby increasing the incomes earned by local people from forest products and protecting the area's biodiversity.[11]

Role of Migration

Because migration flows are so volatile, they are the most difficult demographic variable to forecast. Yet migration can play an important part in the future size and characteristics of local, country, and regional populations. In the early 1990s, environmental scientist Norman Myers estimated there were at least 25 million environmental refugees—people driven to migrate by environmental factors such as degraded agricultural land, deforestation, or drought. More than half were thought to be in sub-Saharan Africa.[12] Myers predicted that the number of environmental refugees was likely to double by 2010, and it could swell to 200 million by 2025 because of climate change and other sources of environmental degradation.

Most environmental migration occurs within national boundaries and does not affect national population size, but migration is important to population growth and characteristics at local levels (see Box 2). While the flow from rural to urban areas has been a dominant trend, especially in Latin America, people also move from one rural area to another, especially when drought, famine, or political events push agricultural workers off their land. Rural migrants sometimes move into forests or ecologically frag-

Box 2

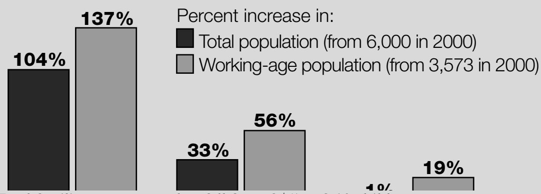
Local Area Perspective: Why Migration Matters

Population and conservation programs working in communities where population growth is pressuring natural resources frequently focus on providing reproductive health services. People living near remote protected areas or fragile coastlines often have the characteristics associated with high fertility: low education and incomes and limited access to family planning. They often have high fertility and a young population profile that drive future population growth. Expanding access to reproductive health services for these populations can help lower fertility and improve maternal and child health—which can benefit public and environmental health.

Community projects rarely consider the demographic effect of migration on population growth and composition and the additional stress it can bring to local ecosystems. A 2 percent annual net in-migration rate would cause a community of 6,000 persons in West Bengal, India, to more than double in 25 years, even if birth rates fell quickly to low levels (see figure). With no net migration, the same community would grow by about one-third through natural increase (births minus deaths). Net out-migration—which is common in many rural areas of less developed countries—would hold population steady, although the characteristics of the community would likely change.

Because people are most likely to move when they are in their young adult years, migration sometimes alters the age profile of the migrant-sending and

Effects of Migration on Population Growth, 2000 to 2025: Three Scenarios for a Community in West Bengal, India



Note: Total fertility rate assumed to fall from 3.75 to 2.10 children per woman between 2000 and 2010 and remain stable until 2025.

Source: Prepared by John S. Williams, Population Reference Bureau.

migrant-receiving communities. In the example above, the working-age population would increase by 137 percent over 25 years, assuming 2 percent annual net in-migration. With zero net migration, the working-age population would rise 56 percent. With net out-migration of 2 percent annually, the working-age population would still rise 19 percent in 25 years, although the number of children under age 15 would decline by 42 percent (not shown above).

If fertility declines rapidly, the size of households is likely to decline. But the number of households will increase much more rapidly than the community's total population because of the increase in the workile areas to farm or harvest wild species, which can cause considerable damage to local ecosystems if they lack the knowledge or resources to protect the natural environment.

Growing rural populations require additional land not only for food and income, but also for housing, roads, and other infrastructure. New rural residents will also require natural resources to meet food, fuel, water, and raw material needs. Most rural residents—including new immigrants—rely on agriculture for their livelihood.

Effects of Population Growth

Is population growth good or bad for the environment and human well-being? The answer to this question is neither straightforward nor simple. Consider the case of urbanization. A population shift toward urban areas means that a larger share of people will have access to health care, education, and other services; living standards are likely to improve. 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. And concentrating population within an urban area can preserve adjacent natural habitat, assuming that urban sprawl is contained.

At the same time, dense urban populations may produce more waste than the environment can absorb, leading to significant air and water pollution and a greater incidence of infectious and parasitic diseases. Cities often develop near fragile coastal areas or rivers or adjacent to fertile

ing-age population. An increase in households can have a greater impact on the environment than an increase in total population. Each new household requires electrical appliances, produces waste, and can involve constructing new buildings and infrastructure. Additional natural areas may be converted for human use.[1]

Most people move to improve their economic opportunities or escape from difficult political or environmental situations.[2] Government attempts to regulate migration have been largely unsuccessful. Policies can encourage or discourage migration—but sometimes as an unintended consequence. Efforts to conserve resources or spur economic growth in some communities adjacent to national parks have stimulated so much in-migration that the added population threatens the resources of the protected area.[3] Anecdotal evidence suggests that bringing electricity to an area can stimulate out-migration of young people because they are exposed to television and other influences from the outside world.[4]

Explicit policies to prevent or encourage migration are rarely successful. Migration from Bangladesh into India's West Bengal province is illegal, but Bengalis continue to flow into communities adjacent to the region's Jaldapara Sanctuary.[5] Similarly, large numbers of people are moving illegally from the hills to the lower valleys of Nepal.

Economic development in the migrant-sending areas can sometimes ease the push factors that stimulate migration, but these have not been very successful at controlling migration flows. Judicious land-use planning and zoning may encourage settlement patterns less disruptive to the natural environment and avoid development that stimulates further in-migration. In the Waza Logone community on the boundary of Waza National Park in northern Cameroon, the government has attempted to discourage in-migration by granting newcomers fewer rights than the original inhabitants.[6]

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agricultural land. Rapid urban growth often takes over farmland, destroys wildlife habitats, and threatens sensitive ecosystems and inshore fisheries. Urban populations generally use more water for domestic and industrial purposes than rural populations. In Jordan, for example, the rapid growth of Amman and Zarqa has led to the gradual depletion of a major underground water reserve, reducing water availability for farmers and desiccating an internationally important wetland.[13] This balance between the benefits and potential threats posed by current population trends harkens back to historic concerns about the limits to population size.

How many people can Earth support with what quality of life?

Limits to Population Size

Writing at the end of the 18th century, English economist Thomas Malthus observed that population was growing faster than agricultural production in England. In his famous *Essay on the Principle of Population,* Malthus stated that population grows geometrically (from 2 to 4 to 8, 16, and 32), while the food supply can only increase arithmetically (from 1 to 2, 3, 4, and 5).[14] 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 ultimately reduce population size.

Malthus' concern about the limits to population size has been 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 and, in prosperous times, the need for couples to have more children.[15]

The unprecedented population growth of the last century heightened anxieties about possible catastrophic collapse brought about by exceeding the population size Earth could support. In 1995, for example, demographer Joel Cohen noted 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."[16]

The idea of an ultimate limit to population size was rooted in the notion of carrying capacity, which refers to the maximum number of animals of one or more species that can be supported by a particular habitat during the least favorable time of year—for example, a cold winter or a dry season. Human carrying capacity is often used to define the number of people that can be supported by Earth or a specific ecosystem. Simple models of population growth that assume a limit to population size give rise to a growth pattern wherein population size increases quickly at first and then more slowly as it approaches its ultimate limit. Estimates of carrying capacity assume that a growing population will eventually trigger an increase in death rates as it pushes up against the limits of resources necessary to support life.

More recently, the concept of carrying capacity has given way to a related notion: sustainable development. Sustainable development has been used to describe 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."[17] 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."

The real question, however, as suggested by Cohen, is not how many people Earth can support, but how many people can Earth support with what quality of life? Answering this question involves addressing 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 rangeland 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?

Conceptual Approaches

Scientists have used a number of approaches to seek answers to these questions. Cohen's line of inquiry puts people first. A natural scientist might pose the question as: How many people, with what 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 maximum level of global carbon dioxide emissions would maintain a reasonably stable global climate? How many fish can we harvest from the oceans and still have healthy stocks of global fish species?

Using 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 after 1970 have suggested that we have already exceeded the population size that can be sustained over the long term.[18] Scientists with this generally pessimistic viewpoint often focus on rapid world population growth, the growing concentration of carbon dioxide in the atmosphere, the declining health of the oceans, reduced biodiversity, persistent diseases, and degraded land.

Scientists with a more optimistic perspective often examine how we can best unleash human creative abilities, not on limits to human population growth or resources. These optimists believe that people have the creative capacity to overcome potential environmental harm brought by a growing population and intense economic activity. They point to the general improvements in human health and life expectancy, rising per capita incomes, remarkable advances in food production, and technological innovations that can reduce environmental pollution and improve the efficiency of economic activity.[19]

Reconciling these different and sometimes contradictory conceptual approaches has been complicated by research, analytical, and statistical methodologies reflecting different disciplines and by the sometimes conflicting interests of individuals, communities, organizations, and governments.

Modeling Interactions

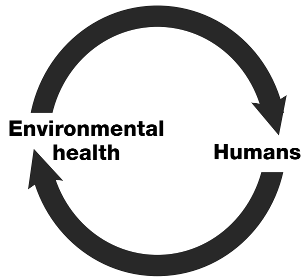
Over the past several decades, scientists have developed a number of models to study the interactions among population, health, and the environment. These models cannot fully predict whether or when population growth and human activities will be constrained by shortages in food, water, and other resources,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

Limits to Growth

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 might interact with the environment and economy.[20] 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.[21] Critics argued that human innovation and resourcefulness would improve the technology of food production, resource recycling, fertility reduc-

Figure 3
The Population, Health, and Environment Cycle



Source: Adapted from C.E. Orians and M. Skumanich, *The Population Environment Connection: What Does It Mean for Environmental Policy?* (1995): 45.

tion, and pollution control enough to avoid "overshoot and collapse" and produce steady sustainable growth in population, food, and industrial output per person.[22]

The "overshoot and collapse" notion has been largely replaced, at least at the global level, by forecasts of more gradual environmental deterioration over a longer period of time; the most severe degradation would be limited to specific regions.

Affluence and Technology

The most widely known model of the 1970s, developed by Paul Ehrlich and J.P. 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 per capita), and T is technology (a measure of efficiency, for example, of energy use).[23]

The $I = PAT$ formula created a useful way to study the relationships among the primary variables governing some environmental factors. Researchers William Moomaw and Mark Tullis, for example, used the formula to evaluate the relative 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 *P*, *A*, and *T* variables fluctuated substantially among countries and over time. Population growth was the most important force increasing carbon dioxide (CO_2) emissions in Mexico, except for a brief period in the early 1990s when Mexicans' rising affluence was the major factor. Population was also the primary factor increasing CO_2 emissions in Ghana, where affluence actually declined between 1950 and 1990. Increasing affluence was the primary factor in CO_2 emissions in Poland over the period and in China after 1981.[24]

The $I = PAT$ formula has been criticized for a number of reasons. Some critics point out that different factors contribute to different environmental impacts. Factors contributing to the depletion of the ozone layer, for example, are not the same as the factors contributing to deforestation or biodiversity loss. The $I = PAT$ equation suggests that the three variables (*P*, *A*, and *T*) operate independently, yet these factors may interact with one another.[25] And by reducing these relationships to a simple one-way negative relationship, the model ignores some important features such as the role of institutions, culture, or social systems in mediating human impact on the environment. In addition, the *P* in the framework typically stands for the number of persons in a population. But households are also significant units of consumption; the number, size, and composition of households are important considerations in looking at consumption levels.[26] Other critics suggest that the $I = PAT$ approach focuses on how human beings and their characteristics function as agents of environmental change but does not examine how humans are affected by those changes.

Health Impacts

In the 1990s, researchers at the Battelle Seattle Research Center presented a model that recognized the dual nature of population and environment interactions and, by extension, the health implications. This model recognized that human beings serve as a driving force of environmental change and that, in turn, people are also affected by the outcomes and consequences of these changes.[27]

While recognizing the dynamic interplay between population variables and the environment, the Battelle model broke the relationship into two parts, as shown in Figure 3. The first part focuses on how people are drivers of environmental change (the lower arrow) and the second part focuses on how people are affected by or are receptors of environmental change (the upper arrow). More recently, researchers have used this concept to refer to population and environment analysis as a "chair with four legs": population dynamics, environmental dynamics, and the influences of each on the other.[28] To date, the overwhelming majority of studies have focused primarily on the impact of changes in the human population on the environment, but that is slowly changing as the field evolves.

Population Dynamics

In the last decade, the International Institute for Applied Systems Analysis (IIASA), based in Austria, has developed two series of models that take into account a range of population dynamics beyond growth. These models incorporate other variables such as educational levels and policies that affect population and environment relationships.

The first series of models focused on population-development-environment interactions in Botswana, Cape Verde, Mauritius, Mozambique, Namibia, and the Yucatán Peninsula. These studies examined traditional population characteristics, including age, sex, and education levels, as well as other variables appropriate to the local context: Labor force participation in Mauritius, or HIV status in Botswana, Mozambique, and Namibia are examples.[29]

By including these ranges of variables and by producing various future scenarios, these studies helped policymakers understand that investment in human resources such as education, health, and voluntary family planning, combined with stronger political empowerment and accountability, were requirements for environmental management and sustainable development.

More recently, IIASA has collaborated with the UN Economic Commission for Africa to develop an interactive simulation model demonstrating the medium- to long-term impacts of alternative policies (including policies on HIV/AIDS) on the food security status of the population. This model, called population, environment, development, and agriculture (PEDA), focuses on the interactions between changes in population size and distribution, natural resource degradation, agricultural production, and food security.

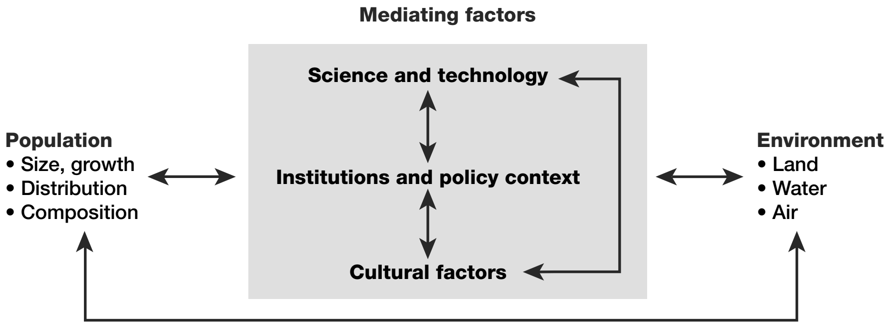
Ecosystem Approaches

Other models have focused on specific ecosystems. One such model, SAVANNA, was developed jointly by Colorado State University and the International Livestock Research Institute to help land-use planners create long-term plans for savannas, arid grassland ecosystems where wildlife, humans, and domestic livestock coexist. The model forecasts wildlife populations, the health of ecosystems, and human conditions five to 100 years after human and natural activity have changed the landscape. It takes into account the constant change of the natural world across large regions, at the same time forecasting the future of an area as small as a 50-meter-wide watering hole.[30] While many models are static, capturing a single point in time, SAVANNA shows the interaction of different processes over time.

The SAVANNA model is now being used by conservationists, development planners, and local people for land-use planning in the Maasai Mara National Reserve and Amboseli National Park in Kenya, and the Ngorongoro Conservation Area in Tanzania, which are part of the Greater Serengeti Ecosystem.[31]

Humans are a driving force of environmental change. People are also affected by the outcomes of these changes.

Figure 4
Factors Affecting the Population and Environment Relationship



Source: Adapted from F.L. MacKellar et al., "Population and Climate Change," in *Human Choices and Climate Change: The Societal Framework*, vol. 1, ed. S. Rayner and E.L. Malone (1998): 89-133, with permission from Battelle Press.

Species Extinction

Another series of models have been examining threats to species linked to human activity. Population viability analysis (PVA) models have been developed to look at extinction risks of threatened species. The Species Survival Commission of the World Conservation Union (IUCN) has used the VORTEX model to predict the extinction of species, including the black panther and orangutan. VORTEX attempted to integrate wildlife population models with models of human demographics, economics, and land use.[32] The model can simulate the effects of threats associated with human population change, such as hunting practices, road construction, deforestation, and pollution. Such PVA models help determine processes to identify and manage threats to wildlife populations and habitats, and are useful for conservation planning.

Questions of Scale

All these models operate on different scales, particularly regarding time and space. Generally there are three levels of spatial scale: the global level, the national or regional level, and the local level.[33]

Individual and community-level behaviors can have national and even global impacts; correspondingly, a change such as global warming affects communities and individuals. At the national level, policies and actions also play a key role in how population, health, and environmental issues are managed because this is the level at which many of the institutional, economic, and political mechanisms operate.

The problem of scale for population-environment interactions is illustrated by the case of coral reefs. Human activity and the fragmentation of coral reef habitat on a local scale have made many of the world's coral reefs much more susceptible to global trends, including threats from climate change.[34]

Recent research points to direct links between increased greenhouse gases, climate change, and bleaching of corals. (Bleaching, or loss of color and essential nutrients, occurs when the coral's algae die from excessive water temperature or disease.) Episodes of coral bleaching and diseases linked to global conditions and warming have been more frequent and widespread over the past 30 years. Most coral reefs can recover from bleaching if the temperature anomalies persist for less than a month, but sustained high temperatures can cause irreversible damage. There have been six major bleaching events worldwide since 1979. The most severe bleaching episode, in 1998, destroyed an estimated 16 percent of the world's coral reefs, with heaviest damage to reefs in the Indian Ocean, Southeast Asia, and the far western Pacific.[35]

The intensity and effects of population, health, and environment interactions are greatly affected by time. The evidence of change often cannot be discerned for years or decades. Global climate change may affect health, for example, through complex disturbances of natural systems over several decades. Toxic environmental pollutants in a local area might produce more immediate health effects. Generally, epidemiologists find it harder to quantify the adverse health effects of global environmental changes.[36] Researchers have found it difficult to reconcile varying time and spatial scales within the same study or to analyze studies conducted at different scales. Policies, institutions, and culture related to population and environment dynamics create additional challenges for scientists seeking ways to protect human and environmental health.

Mediating Factors

In addition to the role of science and technology recognized in the *I = PAT* framework, public policies, political institutions, and cultural factors are important mediating factors in population, health, and environment interactions (see Figure 4).

Policies

In many cases, public policies, guided by cultural norms and attitudes about the environment and civic responsibility, can lessen environmental problems. Emissions standards for chlorofluorocarbons (CFCs) enacted through the 1987 Montreal Protocol, for example, slowed the deterioration of the ozone layer. The ozone layer shields humans from potential eye damage and skin cancers caused by the sun's high-energy ultraviolet radiation. The primary cause of ozone depletion is most likely human activity—especially the production of synthetic organic compounds like CFCs, which are used in refrigeration, solvents, and propellants. Changes prompted by the Montreal Protocol dramatically reduced the emissions of manufactured ozone-depleting substances.[37]

Population, health, and environment relationships were also a consideration in advancing national population policies. After the 1950s, policies in many countries focused on restraining population growth because of concern that the unprecedented pace and volume of growth was a serious threat to economic development, public health, and the environment.

A turning point in international discussions on population was the 1994 International Conference on Population and Development held in Cairo. The Cairo conference widened the scope of earlier population policies. Governments agreed that population policies should address social development beyond family planning, especially the advancement of women, and that family planning should be provided in the context of reproductive health care. By focusing on individual rights, the Cairo consensus enhanced individual health and rights, which was expected to eventually lower fertility and slow population

Photo removed for copyright reasons.

In Bangkok, public policies and local community action are helping convince industries and individuals to adopt technologies and lifestyles that reduce air pollution, and the city's air is getting cleaner.

growth by increasing women's status and education.[38]

But policies can also worsen environmental conditions. Irrigation policies of the former Soviet Union, instituted to boost agricultural production, resulted in a 40 percent reduction in the size of the Aral Sea in Central Asia.[39] In the Philippines, timber policies encouraged the surge in upland migration in the 1980s, resulting in a heavy loss of forest cover and substantial increases in soil erosion.[40]

Subsidies are example of a policy intervention that can have positive or negative effects on human and environmental well-being. Subsidies can help farmers support their families, grow their businesses, minimize environmental degradation, and help achieve equity. In Bangladesh, general food price subsidies were replaced with a program to provide food to poor rural families who send their children to school. The new subsidies increased school enrollments, particularly for girls, and improved food security for poor rural households.[41]

Subsidies may also have unintended negative consequences, including wasteful resource use, excessive environmental damage, and growing financial strains on governments. Subsidies interfere with market forces by artificially lowering the prices of agricultural inputs such as fertilizer, water, and machinery.

Institutions

During the past 60 years, much of the world has relied on the institutions of the state, or groups of states, as mechanisms for common action. In recent decades, civil society has gained importance, as evidenced in spectacular events such as the fall of the Berlin wall, and more modest phenomena such as a heightened concern with environmental health within some corporations, stronger policies to protect forests in Latin America, and greater impact of nongovernmental organizations (NGOs) in international conventions. Around the world there is an increasing trend of devolution from centralized power to more local management.

The international environmental conference in Rio de Janeiro in 1992 helped establish the role of NGOs in the international arena, with 17,000 NGO representatives participating in a parallel forum outside the official conference and 1,400 directly involved in the intergovernmental negotiations. NGOs helped make the conference a success, claimed an important place in the conference declaration, and played a key role in developing post-conference institutions such as the Commission on Sustainable Development. Three years later, in September 1995, the Fourth World Conference on Women attracted an astonishing 35,000 NGO representatives to Beijing to a parallel forum and 2,600 to the official conference.[42]

Although NGOs have few formal powers in international decisionmaking, they have successfully promoted new environmental agreements and greatly strengthened women's rights, among other accomplishments. NGO work on the environment led to the adoption of the 1987 Montreal Protocol on Substances That Deplete the Ozone Layer.

Culture

Together with policies and institutions, cultural factors—beliefs, values, norms, and traditions—influence public support for public policies and the ways that human interact with their environment. Women's social status, especially in less developed countries, limits their access to land. In many countries, a woman's property rights are linked to her marital status; she may lose these rights if she is divorced or widowed. Even in countries where the law guarantees women and men equal access to land, customs may exclude women from exercising their rights.

Many demographers draw a link between fertility, women's status, education, and access to family planning methods. Women in many countries have little power over their reproductive lives, just as they have little say about how household resources are used. Women with little or no education and women in rural areas tend to have less say in their marriages and households, and they tend to have more children than other women. Alternatively, increasing educational levels encourages girls to wait longer before marrying and starting a family and to have fewer children.[43]

Culture also supports changes that may be beneficial for the environment. In the United States, for example, public support helped spur technology and innovation to curb environmental degradation. Between 1970 and 2001, the U.S. population rose more than one-third, from 203 million to 281 million people, while gross domestic product more than doubled, from $3.6 trillion to $9.3 trillion (in 1996 dollars), and per capita disposable income nearly doubled, from $12,823 to $23,687 (also in 1996 dollars).

These population and economic pressures have degraded environmental quality. Carbon dioxide emissions, for example, increased about as fast as population. Yet, by some measures, U.S. environmental quality improved: Between 1970 and 1998, total emissions of sulfur dioxide decreased by 37 percent; emissions of particulates decreased by 71 percent; and emissions of lead declined by 98 percent.[44]

Culture can also inhibit efforts to improve the environment. In many countries, policies to promote environmental conservation are perceived as detrimental to business interests and individual advancement. In Bangkok, for example, a growing culture of individualism and consumerism in the 1990s inhibited community action to address problems caused by the city's congestion and air pollution.[45]

Far-Reaching Consequences

Population, health, and environment interactions have far-reaching consequences for human and environmental well-being. Some of the most important interactions and trends are associated with poverty and wealth; demand and supply of food, water, and energy; and emerging health risks.

Poverty

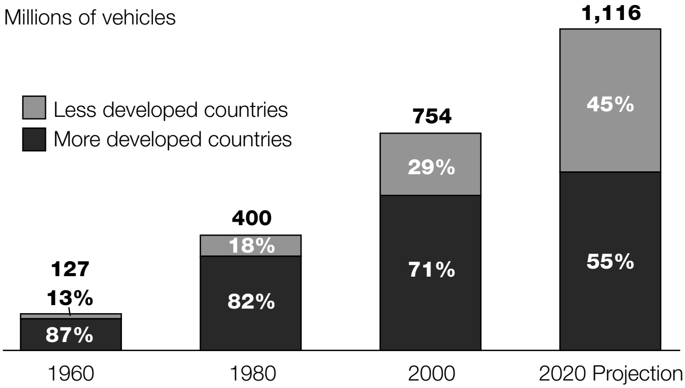
Poverty may promote environmental degradation in a variety of ways. Poor rural families are more likely to support themselves with subsistence slash-and-burn agriculture; use forest products as fuel, fodder, and building materials; and live in ecologically fragile zones. In poor rural communities, the continuing need for family labor supports high fertility and rapid population growth, which some analysts believe places additional strain on forests.

An estimated 70 percent of the world's poor rely on the land for income and subsistence, although many do not own or control these resources.[46] In Burkina Faso, Côte d'Ivoire, and Senegal, extremely high rates of deforestation are associated with the expansion of cash crops (groundnuts, cotton, coffee, and cocoa) by large companies for export. This expansion directly displaces forests and reduces the availability of arable land for subsistence farmers, driving them to encroach on forested land. Abject poverty can also push many of these rural residents to destroy the very resources they rely on for their livelihoods.

The World Bank estimates that the number of people living in absolute poverty (less than US$1 a day) has fallen since the mid-1980s, from 1.3 billion in 1990 to 1.2 billion in 1999. Today, however, poverty is conceptualized in much broader terms than just income. It includes access to opportunity, security, and empowerment.[47] With this broader definition, ethnic minorities, rural residents, and women are much more likely than their counterparts to be poor. These same groups often are disproportionately affected by environmental degradation. The relative situation of ethnic or religious minorities varies tremendously around the world, but even in more developed countries like the United States, disadvantaged minorities are more likely to

Seventy percent of the world's poor rely on the land for income and subsistence.

Figure 5
Increase in Motor Vehicles, 1960 to 2020



Source: M. Pemberton, *Managing the Future—World Vehicle Forecasts and Strategies to 2020*, Vol. 1: *Changing Patterns of Demand* (2000).

live in areas that are heavily polluted and that have substandard sanitation and health services.[48]

These disadvantaged groups also face challenges in meeting basic human needs when the prices of environmental goods such as water, land, or marine life increase. According to U.S. and Malaysian agricultural economists, prices for salmon and other high-value fish could rise by 15 percent by 2020, while prices for less valuable fish such as milkfish and carp could increase by 6 percent.[49]

The lifestyles of these vulnerable population groups may also be at risk. Indigenous communities with lives intimately adapted to local climate, vegetation, and wildlife may be particularly threatened by environmental change. The native peoples of the Mackenzie Basin in Northwest Canada hunt, fish, and trap wildlife for their food, income, and traditional clothing. Changes in the ecosystem and resource base—melted permafrost, increasing numbers of landslides and forest fires, and declining groundwater levels—jeopardize their traditional lifestyles.[50]

Wealth

At the other end of the spectrum, wealth brings greater environmental management opportunities and challenges. As societies grow wealthier, some human-induced environmental problems—such as access to water and sanitation—are expected to improve, while others—such as the generation of solid waste and greenhouse gases—get worse.

Wealthy nations have higher per capita consumption of petroleum, cement, metals, wood, and other commodities that deplete world resources, generate a large volume of waste, and emit higher levels of pollutants. Between 1960 and 2000, the municipal solid waste generated in the United States increased from 88 million to 232 million tons. On average, each American produced 4.5 pounds of garbage each day in 2000, up from 2.7 pounds per day in 1960.[51] Most of this waste is either burned, emitting pollutants into the air, or deposited in landfills, taking up increasing land near urban areas and introducing toxic substances to groundwater and soil.

Wealth and economic development also bring a greater reliance on motor vehicles, with major environmental effects. In 2000, about 70 percent of the world's automobiles were in more developed countries (see Figure 5). The United States and a handful of other wealthy countries have more than 400 cars per 1,000 people, according to the World Bank. In contrast, less developed countries like Bangladesh, India, and Sierra Leone had fewer than 5 cars per 1,000 people in 2000.[52]

The increase in motor vehicles is associated with pollution and land-use problems. A recent assessment of the health impact of air pollution in Austria, France, and Switzerland revealed that car-related pollution kills more people than car accidents in these three countries.[53] Pollution from motor vehicle emissions is increasing as the numbers of vehicles increases throughout the world.

More affordable two- and three-wheeled motor vehicles are gaining popularity in the less developed world. The World Bank reports that ownership of two-wheeled motor vehicles in Cambodia, for example, rose from 9 per 1,000 people to 134 per 1,000 people between 1990 and 2000. In India, the ratio rose from 15 to 29 during the 1990s. Production and use of hybrid (gas-electric) vehicles is also increasing in many countries.

Increasing wealth is also associated with greater environmental demands from food production. As their incomes increase, people tend to add more animal fats to their diets. Raising livestock requires more land, produces more waste, and consumes more grain per food calorie than growing grains such as wheat or rice for direct consumption. While energy use appears to have no natural maximum, there is a limit to the amount of animal fat per capita that people consume, and many countries appear to have reached that limit already. The demand for food is expected to slow between 2000 and 2030, but continued population growth and a shift to high-fat diets in less developed countries mean that agricultural production will need to grow at least 2 percent annually in less developed countries until 2030.[54]

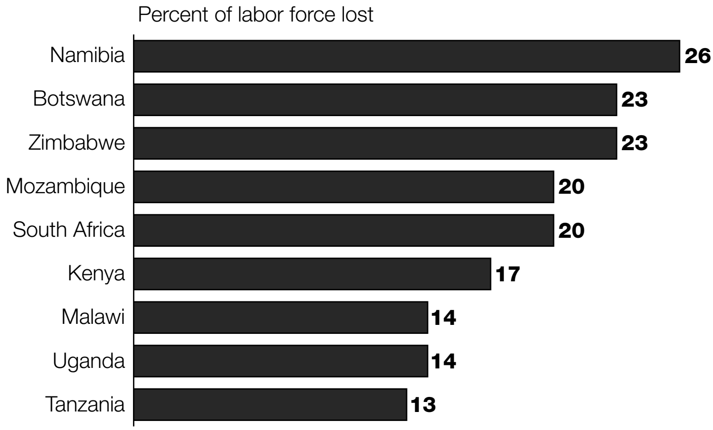
Land, Food, and Agriculture

From 1985 to 1995, population growth outdistanced food production in many parts of the world, particularly in Africa. In 64 of 105 developing countries studied in this period, food production lagged behind population growth.[55] And there were 2.2 billion more people to feed in 2002 than there were in 1972.

Traditionally, the major means for increasing the food supply for a growing population has been converting more land to agricultural production. Most of the best agricultural land, however, is already in production. Each year, prime agricultural land is lost through conversion to urban uses or degraded through imprudent agricultural methods, overgrazing, or other activities. Erosion, salinization, leaching of nutrients, and increased toxicity from use of chemical fertilizers and pesticides may all contribute to degradation.

Figure 6

Projected Loss of Agricultural Labor Force Because of HIV/AIDS, Selected African Countries, 1985–2020



Source: Food and Agriculture Organization (FAO), "AIDS—A Threat to Rural Africa: Fact Sheet" (www.fao.org/Focus/E/aids6-e.htm, accessed July 12, 2002).

The imbalance between food supply and demand often reflects political and social inequities. Famines generally occur because food is not available where people need it, rather than from an overall shortage in supply. These localized imbalances could become more extreme because population is growing fastest in the regions with the least-efficient food production and distribution systems.

Agricultural production and food security is also threatened by AIDS-related deaths among farm workers, most notably in southern and eastern Africa. In 25 African countries with high rates of HIV prevalence, the Food and Agriculture Organization (FAO) estimates that 7 million agricultural workers have died of AIDS since 1985. FAO projects that 16 million more agricultural workers in these countries will die because of AIDS between 2000 and 2020. Population losses in the agricultural labor force between 1985 and 2020 in the worst-affected countries will range from 13 percent in Tanzania to 26 percent in Namibia (see Figure 6).

In eastern Africa, AIDS-related labor shortages have led to lower crop yields, smaller amounts of land being cultivated, and a move from cash crops

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Crop yields have increased through the use of fertilizers and pesticides, but these chemicals can contaminate soil and water, harm animals, and produce pesticide-resistant insects.

to subsistence crops.[56] In Zimbabwe, the Farmers Union found that the loss of a breadwinner to AIDS decreased crop output by as much as 61 percent in small-scale farming areas.[57]

Many less developed countries have the potential to increase their food production substantially, yet only a small fraction of the increase is likely to come from expanding the amount of land under production. There are ways to increase yield and maintain the soil quality. One is to alternate planting legumes such as mung beans or soybeans with rice crops to help replenish nitrogen in the soil. Current plant-breeding programs could provide additional yield increases by improving plant stocks. Biotechnology may become a principal source of further productivity gains as scientists bioengineer genes for insect and disease resistance.

Genetic improvements through crop and livestock breeding have played a major role in increasing production. A newly developed set of tools, generally referred to as genetic engineering, now enables specific traits to be directly inserted into the genetic material of a crop or animal. A plant may be genetically altered by inserting a single gene from the same species or an entirely different organism that contains desired characteristics, such as herbicide resistance or an antibacterial compound. Frost resistance in tomatoes has been enhanced using fish genes. Bioengineering may increase the yield of some crops by re-engineering the photosynthesis process, reducing the need for pesticides or water, or increasing the tolerance of saline soils.

But scientists and the public have economic, social, health, and ethical concerns about genetically modified (GM) crops, and some governments refuse to allow GM foods into their countries even when they face food shortages. In 2002, a number of sub-Saharan countries suffered massive agricultural losses primarily because of a severe drought; the international community responded by offering tons of grain and other food. But the government of Zambia rejected thousands of tons of corn donated by the United States because it was likely to contain GM kernels. Swaziland accepted unprocessed U.S. corn, whereas Lesotho, Malawi, Mozambique, and Zimbabwe accepted it on the condition that the kernels first be milled into flour to prevent farmers from using them to grow GM crops.[58]

Public and scientific concerns about GM foods fall into two main categories: risks to human health and risks to ecological integrity. Risks to human health appear to be minimal. Furthermore, chemical techniques used in food testing screen out possibly toxic or allergenic foods. Less is known about environmental risks and the benefits. One concern has been the potential for genes to migrate from domesticated GM crops into wild plants, just as genes already migrate from conventionally bred crops to wild relatives.[59]

More effective agricultural policies offer 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. Reducing waste in the system could also increase potential food supply. In high-income countries, for example, the amount of lost or wasted food is equivalent to anywhere from 30 percent to 70 percent of the food actually consumed.

Future increases in food production are likely to come from more intensive use of current farms rather than from expanding farmland and from such technological innovations as improved seeds and the use of chemical fertilizers, insecticides, and herbicides.

But chemicals used to boost yield also carry health risks. People can become ill if they come into contact with the pesticides applied to crops or consume food with pesticide residues. Pesticides can also seep into the ground and contaminate drinking water. Although pesticides are used worldwide, some regions are particularly affected. Central America, for example, uses 1.5 kilograms of pesticides per person each year, more than any other world region.[60]

Chemicals and heavy metals found in industrial effluents and pesticide runoff also damage human and marine health. The most serious concerns worldwide involve persistent organic pollutants (POPs)—particularly dichlorodiphenyltrichloroethane (DDT) and polychlorinated biphenyls (PCBs)—that can be transported in the atmosphere and have become common in the oceans. POPs tend to linger in living tissue and become more concentrated as they move up the food chain, so they are sometimes found even in people who live in remote, undeveloped regions.

Evidence links long-term, low-level exposure to certain POPs with reproductive, immunological, neurological, and other problems in marine organisms and humans. These toxins can kill or contaminate marine life; people who eat seafood from polluted areas or who swim in contaminated waters are vulnerable to gastric and other infections. In order to manage such threats, the Stockholm Convention on Persistent Organic Pollutants, adopted in May 2001, sets out control measures covering pesticides, industrial chemicals, and unintended byproducts.[61]

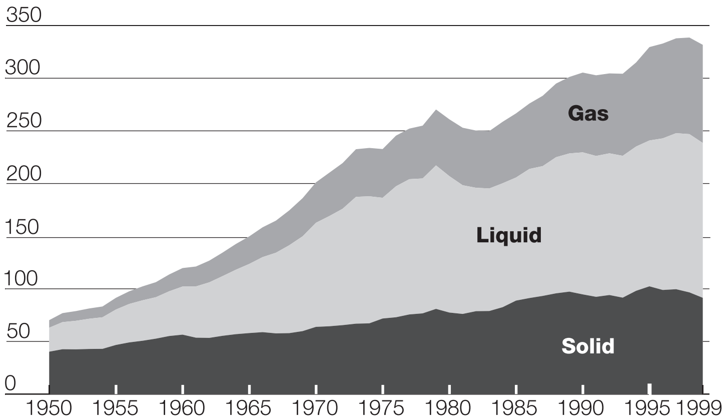
Deforestation

The environment performs two basic functions. “Source” or production functions support the livelihood of millions who depend upon environmental resources. “Sink” or pollution absorption and cleansing functions help support human health and well-being by naturally purifying air and water. Forests provide a number of these functions, including buffering soil erosion and land degradation, protecting the biological diversity in delicate and fragile ecosystems, and regulating climatic variability. These functions are disrupted when forests are destroyed or fragmented.

During the 1990s, human activities resulted in the deforestation of 146 million hectares (563,709 square miles)—roughly the combined areas of Colombia and Ecuador. During that same time period, 52 million hectares were regained due to reforestation efforts and natural regrowth. South America and Africa experienced the greatest total deforestation; the substantial deforestation in Asia was offset by reforestation. In general, the 1990s saw forest cover expand in temperate less developed countries, decline in tropical less developed countries, and remain relatively stable in more developed countries.

The direct causes of deforestation are themselves symptoms of underlying demographic, social, and economic connections. More developed countries such as Japan and the United States can drive deforestation in less developed countries by importing tropical hardwoods. Rising paper consumption has also encouraged overcutting of forests.

Figure 7
World Production of Fossil-Fuel Energy by Type, 1950–1999



Note: One exajoule of energy is equivalent to about 363 million barrels of oil.

Source: United Nations, *Energy Statistics Yearbook* (1997 and 1999 editions): table 3.

Some less developed countries also exploit their own forest resources to pay down debts or import goods for economic development. Less developed countries can also drive deforestation beyond their own borders. China declared a moratorium on national deforestation, which caused Chinese loggers to cross into Myanmar and Russia and cause widespread deforestation.[62]

Deforestation can have a range of consequences for both people and the environment, including degradation of surrounding ecosystems, reduced crop yields, and the loss of aesthetic value and natural beauty. Two consequences are particularly troubling: the loss of biodiversity and the exacerbation of climatic irregularities.

As forests are destroyed, degraded, or fragmented, many plant and animal species are threatened or eliminated. The loss of forests in recent decades had been partially offset by new plantations. But the substitution of planted forests for natural forests is a net loss for Earth's biodiversity. Replanted forests often consist of few tree species, making forests more vulnerable to disease, drought, and other natural stresses. And less-diverse tree plantations cannot support as many species of other plants and animals.

A large number of species are now threatened with extinction. Nearly one-quarter of all mammals and one-eighth of all birds are threatened, under criteria established by the World Conservation Union (IUCN).[63] Less is known about the extinction rate of plants or marine life. Only about 2,000 of an estimated 25,000 fish species have been assessed of which 30 percent were considered threatened. Only about 11,000 plants have been assessed, although the total number of plant species may range from 265,000 to 422,000. About 40 percent of the assessed plant species may be in danger of extinction.[64]

Many geographic areas rich in biodiversity also have a high population density. More than 1.1 billion people live within the 25 global biodiversity hotspots that ecologists describe as the most threatened species-rich regions on Earth. About 75 million live in the three major tropical wilderness areas—the Upper Amazonia and Guyana Shield, the Congo River Basin, and the New Guinea-Melanesia complex of islands—which together cover about 6 percent of Earth's surface.[65]

The overlap of protected areas with agricultural lands (defined as more than 30 percent of land cover under crops or planted pastures) is also notable. Nearly 29 percent of globally protected areas are in agricultural areas. In Central America, for example, many protected areas are interspersed with agricultural lands, and increasing population density is closely associated with deforestation.[66] Yet Java—one of the most densely populated areas of the world—has more than 20 national parks and nature reserves covering nearly 650,000 hectares and demonstrating that people can conserve wild habitats even in densely populated areas.[67]

Energy Use

Global energy production and consumption have risen steadily for several decades, and this has the greatest potential impact on climate. In 2001, commercial global energy production totaled 9.3 billion metric tons of oil-equivalent. More than 1 billion metric tons of oil-equivalent energy were produced by burning traditional fuels such as wood, charcoal, and biomass (animal and vegetal wastes).[68]

The vast majority of the world's energy comes from the burning of fossil fuels, in liquid (petroleum), solid (coal or lignite), or gas (natural gas) form (see Figure 7). The extraction and processing of these fuels also constitutes one of the major flows of natural materials in industrial economies.

Petroleum accounts for about 39 percent of global commercial energy production. Solid fuels—primarily coal and lignite—are relatively abundant and account for about 24 percent of global commercial energy production. Natural gas, the least environmentally damaging greenhouse gas, provided about 23 percent of global commercial energy in 2000. However, natural gas production in the United States, by far the largest fossil fuel consumer, is very unlikely to meet future demand.

Traditional fuels such as firewood and biomass fill the energy needs of millions of people in less developed countries. These fuels often are collected from common or publicly shared resources such as open land and woodlands. The collection and burning of these fuels create their own environmental problems, including soil erosion, loss of watershed areas, and emission of particulates and other pollutants. But as countries industrialize, they tend to replace traditional fuels with fossil fuels and other commercially produced energy sources.[69]

Average energy use per person is still more than nine times greater in developed than in less developed regions. North Americans consume far more energy than any other region. In 1999, per capita energy use among Americans was nearly twice that of Europeans, nearly eight times that of Asians, and 15 times that of Africans (see Figure 8).

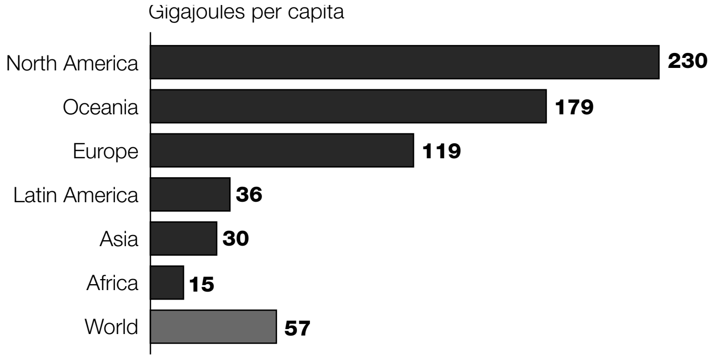
Per capita energy consumption has increased modestly in less developed countries in the last two decades. Yet total consumption increased by 274 percent in Africa and by 187 percent in Asia between 1977 and 1997.[70] Total emissions in the United States have increased every decade since the 1950s; they rose from 1.2 billion metric tons of carbon in 1970 to 1.5 billion metric tons in 1999, the most recent year for which data are available.[71]

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

The *International Energy Outlook* from the U.S. Energy Information Administration projects global energy use will grow by 1.7 percent annually between 2001 and 2025, slightly faster than the rate of population growth. Energy consumption in less developed countries is expected to increase by 2.8 percent per year. Total consumption would increase by 58 percent in these scenarios. The projected increase in energy use in Asia accounts for approximately 40 percent of the total increase in world consumption and for 69 percent of the increase in consumption among developing coun-

Figure 8

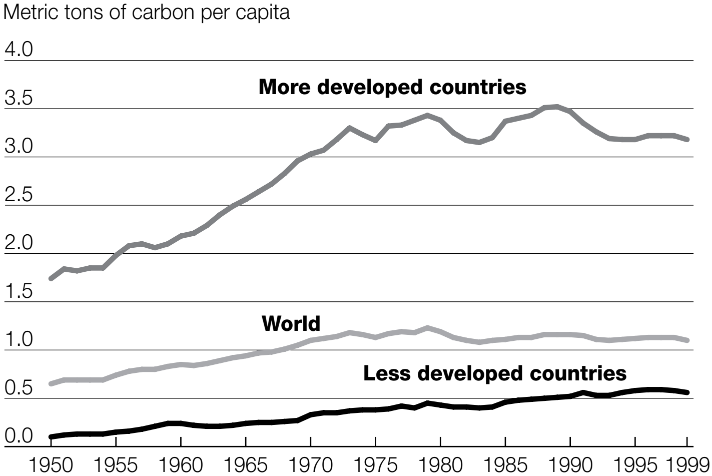
Energy Consumption per Capita, World Regions, 1999



Note: Excludes traditional fuels such as firewood and biomass. One gigajoule is equivalent to about 0.4 barrels of oil.

Source: United Nations, *Energy Statistics Yearbook 1999* (2002): table 3.

Figure 9
Per Capita Carbon Dioxide (CO_2) Emissions, 1950–1999



Source: Updated and adapted from F.A.B. Meyerson, "Population, Carbon Emissions, and Global Warming: The Forgotten Relationships at Kyoto," *Population and Development Review* 24, no. 1 (1998): 115-30.

tries. Almost all of this growth will involve fossil fuels.

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.

Climate Change

Carbon dioxide and other gases naturally trap heat as it is radiated from Earth's surface back to the atmosphere. This "natural" greenhouse effect keeps Earth's temperature about 33 degrees Centigrade (nearly 60 degrees Fahrenheit) warmer than it would otherwise be. Carbon dioxide, primarily from the burning of fossil fuels, adds to the natural greenhouse effect.

Since the preindustrial era, atmospheric concentrations of carbon dioxide have increased by nearly 30 percent. Other greenhouse gases such as methane and nitrous oxide have risen about 15 percent. Now estimated at 373 parts per million by volume (ppmv), scientists estimate that atmospheric concentrations of carbon dioxide are growing by about 1.5 percent annually and could reach 700 ppmv by the year 2100.[72]

Global emissions of carbon dioxide from fossil-fuel combustion grew from 8 million to 6,518 million metric tons between 1800 and 1999. Over the same period, global per capita fossil-fuel emissions surged from less than 0.01 metric tons (mt) in 1800 to 1.13 mt in 1999. Carbon dioxide emissions can vary greatly from year to year, in part because climate variations and weather cycles such as El Niño affect the frequency of natural and human-induced fires. In recent decades, per capita consumption has stabilized (see Figure 9), suggesting that slowing population growth would hold down the increases in the total emissions of greenhouse gases.[73]

The extraction, processing, transport, and use of fossil fuels affects habitat, landscapes, ecosystem health, water and air quality, and the global climate system. Human activity adds 3 million tons of oil per year to the oceans through extraction, processing, and transport, and 50 million tons of sulfur dioxide per year to the atmosphere from burning fossil fuels. These numbers could increase as economies industrialize.[74]

While the mechanisms by which atmospheric changes affect climate are not clearly understood, agreement is emerging among scientists that Earth's surface temperature is warming significantly, that the warming is likely due to human activity, and that it will harm humans and other species.

In 1997, the nations of the world met in Kyoto, Japan, to frame a response to the problem and develop a protocol for reducing emissions. However, the United States, the largest producer of greenhouse gases, rejected the agreement in 2001, and no global consensus of action has emerged. Only a handful of the countries still committed to the Kyoto Protocol are on track to meet the obligations to reduce global warming emissions developed at the conference.[75] Even if fully enacted, the Kyoto Protocol would not significantly alter the upward trend in global emissions and atmospheric greenhouse gas concentrations, and the agreement will expire in 2012. There is no global consensus on how to proceed after Kyoto. At the most recent round of global climate talks in New Delhi in October 2002, the emphasis shifted from preventing climate change to ways to adapt to it.

Climate change from the buildup of gases is thought to lead to more frequent extreme weather events such as droughts, violent storms, and flooding. Heat waves can be deadly. In summer 2003, several thousand people died in France because of record high temperatures. Global warming could melt polar ice caps, raising sea levels by several feet and threatening low-lying countries. If the sea level were to rise by 150 centimeters, Bangladesh could lose up to 16 percent of its land area, displacing 34 million people.

Extreme weather also affects human health, particularly in less developed countries. Intense precipitation and flooding can spawn outbreaks of cholera, malaria, dengue fever, and other diseases. Severe drought often triggers migration of people and animals, which can facilitate the spread of infectious diseases.

While there is no certainty about the health effects of climate change from global warming, research suggests that it can increase the location, spread, and intensity of insect- and water-borne diseases. Epidemics can develop when disease-carrying insects or animals reproduce rapidly or move to new locations where people have not developed immunities. Higher rainfall, for example, could trigger mosquito-borne disease outbreaks, increase flooding (spreading parasitic diseases), increase contamination of water supplies with human or animal wastes, and increase exposure to runoff of pesticides and other chemicals. Increased ultraviolet radiation exposure and acid rain are two increasingly prevalent factors that can harm human health. Many other health effects of environmental change may not become evident for decades.[76]

Water Availability

About one-third of the world's population lives in countries suffering from moderate to high water stress—where water consumption is more than 10 percent of renewable freshwater resources. Lack of access to safe water supply and sanitation also results in hundreds of millions of cases of water-related diseases and more than 5 million deaths every year.[77]

Water is one of the most plentiful natural resources, yet it is a finite resource that is unevenly distributed throughout the globe. Only 3 percent of all water is salt-free. Moreover, 70 percent of fresh water is locked in glaciers or icebergs. Water supplies are altered seasonally by cyclical droughts or floods, so that the amount reliably available for human use may be influenced more by periodic droughts than by average annual rainfall.

Humans alter freshwater systems by building dams and flood control systems, draining wetlands, clearing forests, and modifying land within watersheds. Since 1950, large dams have increased sevenfold in number and now impound 14 percent of the world's runoff. Sixty percent of the world's major watersheds are fragmented by dams. Dams create reservoirs that provide drinking water, support agriculture, and generate electricity needed for human health and activity, but dams and reservoirs can limit biodiversity within major river watersheds by altering migratory routes and causing habitat changes.

Irrigation of crops has been key to the rapid increase in food production over the last half-century and may account for about 80 percent of human consumption of water. But population growth is increasing demand for water for industrial and household use; water allocated to irrigation in most regions is expected to

Agreement is emerging that Earth's surface temperature is warming significantly.

Photo removed for copyright reasons.

Overfishing has diminished the wild stock of many fish and shellfish, and the current fish catch is probably close to the sustainable limit.

decline. As more water is diverted to human activities, it is becoming more difficult to maintain water levels in the rivers and wetlands that are important habitats for many species.

Groundwater provides a backup to rivers, lakes, and reservoirs for local water needs. Groundwater is replenished from the surface at a very slow rate, and it is often pumped out faster than the rate of natural recharge. Overuse of groundwater lowers water tables, decreases water quality, and allows salt water into aquifers in coastal areas. More than 1 billion people in Asia depend on groundwater for household use, yet in many areas water reserves are threatened by depletion and contamination, especially from intensive agriculture.

Contaminated water and inadequate sanitation cause a range of diseases, many of which are life-threatening. The most deadly are diarrheal diseases, 80 percent to 90 percent of which result from environmental factors. In 2001, diarrheal infections caused nearly 2 million deaths in children under age 5, primarily from dehydration; many more children suffer from nonfatal diarrhea that leaves them underweight, physically stunted, vulnerable to disease, and drained of energy. Poor sanitation conditions and inadequate personal, household, and community hygiene are responsible for most diarrheal infections.[78]

Despite significant investments in improving water supplies and sanitation over the last 20 years, about 18 percent of the world's population still lacks access to safe drinking water, and nearly 40 percent has no access to sanitation. At present, people in rural areas are the most affected, although continual urbanization means that increasing numbers of people live in densely populated cities, where they face shortages of potable water supplies and sanitation systems, as well as growing pollution. More than 1 billion people, mostly in Africa, Asia, and Latin America, currently live in slums or as squatters.

In general, those areas with the greatest water scarcity are those that are most rapidly depleting their aquifers. This is particularly true in the Middle East and North Africa, where rapid population growth has exacerbated water scarcity. Twelve of the world's 15 water-scarce countries are in the Middle East and North Africa. The region's population more than doubled between 1970 and 2001, rising from 173 million people to 385 million people, thereby reducing the amount of fresh water available per capita by more than half.[79] By 2030, about half the world's population is projected to live in water-stressed areas.

Coastal and Marine Life

Today, more than 3 billion people—over half of the world's population—live along a coastline or within 200 kilometers (125 miles) of one. By 2025, the coastal population may double to 6 billion. This concentration of people in coastal regions has many economic benefits: more transportation links, industrial and urban development, revenue from tourism, and food products. The combined effects of booming population growth and economic and technological developments, however, are threatening the ecosystems that provide these economic benefits.

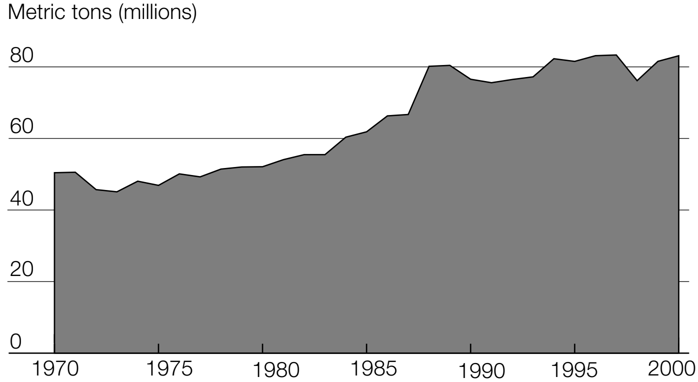
Many of the world's coasts are increasingly urban. Fourteen of the world's 17 largest cities—so-called megacities, with populations of at least 10 million people—are located on coasts. Eleven of these megacities (including Bangkok, Jakarta, and Shanghai) are in Asia. In addition, two-fifths of smaller cities—those with populations of 1 million to 10 million—are located near coasts.[80]

The urbanization of coasts has increased coastal pollution. Worldwide, sewage remains the largest source of contamination, with discharges increasing dramatically in the past three decades. Eighty percent of marine pollution results from land-based sources.

Population growth and the activities associated with it can contribute to degradation of coastal and marine ecosystems. Some trends include a heavy exploitation of fisheries where coastal fish stocks in some geographic regions are down to 30 percent or less of the supply that existed 30 years ago; growing damage to coral reefs worldwide; destruction of 50 percent of the world's mangrove forests; and growing degradation of the quality of fresh water from industrial, agricultural, urban, and environmental contamination.[81]

Marine fisheries and aquaculture (raising fish and marine organisms in a controlled environment) produce nearly 100 million tons of fish each year, and provide livelihood to about 35 million people.[82] Overexploitation of fish, shellfish, seaweeds, and other marine organisms diminishes the production of harvested species and can alter species composition and the biological structure of coastal ecosystems. Maintaining a healthy coastal habitat for marine organisms is critical because the majority of the world's fish catch produces its young inshore and feeds on organisms in coastal waters.

Figure 10
World Marine Catch, 1970–2000



Source: World Resources Institute, *Earth Trends: Coastal and Marine Ecosystems* (http://earthtrends.wri.org, accessed July 2, 2003).

The global fish catch has remained near historically high levels over the last decade (see Figure 10), but that figure masks divergent underlying trends. Total catches in the northwestern and southeastern Atlantic Ocean have stabilized over the last decade to levels approximately half the maximum reached three decades ago. A number of fish species (10 percent) have become so seriously depleted that they are no longer commercially harvested. Another 18 percent are overexploited and, in the absence of effective regulation, will likely decline. About 47 percent of fish species are essentially fully exploited, meaning that the current catch is at or very close to the maximum sustainable limits.[83]

The global fish supply is being threatened by viruses and bacteria. Harmful blooms of algae, often referred to as "red tides," are increasing in incidence, duration, and geographic reach. These red tides cost the industry millions of dollars (see Table 1, page 28). In red tides, a powerful toxin accumulates in the shellfish that feed on the algae, and can produce serious illness in humans and kill dolphins and other wildlife.

Mangrove forests, which grow along the water's edge on about 8 percent of the world's coastlines and

Table 1
Economic Losses From Red Tides, 1970s to 1990s

Date	Location	Species	Estimated loss (US$ million)
1972	Japan	yellowtail	$47
1977	Japan	yellowtail	20
1978	Republic of Korea	oyster	5
1979	United States (Maine)	(many)	3
1980	United States (New England)	(many)	7
1981	Republic of Korea	oyster	>60
1985	United States (Long Island)	scallops	2
1986	Chile	red salmon	21
1987	Japan	yellowtail	15
1988	Norway and Sweden	salmon	5
1989	Norway	salmon, rainbow trout	5
1989–90	United States (Puget Sound)	salmon	5
1991	United States (Washington)	oyster	15–20
1991–92	Republic of Korea	farmed fish	133
1996	United States (Texas)	oyster	24
1998	Hong Kong	farmed fish	32

Source: Worldwatch Institute, *State of the World 1999* (1999): chap. 5.

25 percent of the world's tropical coastlines, absorb the impact of storms and offer nutrients for most of the world's marine life.[84] Mangrove forests have been cleared for commercial and development purposes, including fish and shrimp ponds, logging activities, human settlements, and agricultural and industrial developments. Kenya, Liberia, the Philippines, and Puerto Rico have lost over 70 percent of their mangroves. Aquaculture, which grew about 10 percent annually in the 1990s, can destroy mangrove forests and cause irreversible damage to estuarine and offshore fisheries.

By 2020, marine harvests are projected to be at or below current levels, which means less seafood available per capita because the population is continuing to grow. Although experts expect some gains in harvests from better handling of the marine catch by some industries and exploitation of the few underused fishing areas, these gains will be offset by losses from poorly managed fishing areas, increased protection of areas and species from fishing, and continued degradation of marine environments.

Consequences for Health

Environmental conditions affect the spread of communicable diseases, which account for about one-fifth of annual deaths worldwide. An estimated 60 percent of the global burden of disease from acute respiratory infections, 90 percent from diarrheal disease, 50 percent from chronic respiratory conditions, and 90 percent from malaria could be avoided by simple environmental interventions.[85]

More than 60 percent of the diseases associated with respiratory infections are linked to air pollution. Air pollution is defined as abnormally high concentrations of suspended particulate matter, gases, and vapors in the atmosphere. Outdoor pollutants such as sulfur dioxide, ozone, nitrogen oxide, carbon monoxide, and volatile organic compounds come mainly from motor vehicle exhaust, power plant emissions, open burning of solid waste, and construction and related activities.

Most air pollution comes from burning fossil fuels, but the distribution and concentration of pollutants depends on which fuels are used, the chemical composition of those fuels, the available technologies, local atmospheric conditions, and other factors. Increases in efficiency and energy conservation, regulations such as those used to prevent the sale of leaded gasoline, and technological advances that limit emissions may, in combination, serve to improve air quality.

Outdoor air pollution has stabilized or declined in Western Europe and North America since 1970, according to the World Health Organization's (WHO) air quality standards, while it has continued to increase in the less developed countries.[86] Despite improvements, urban areas in industrialized countries continue to suffer from poor air quality. A recent assessment by the European Environment Agency found about half of the European urban population was exposed to elevated particulate concentrations, and more than 95 percent to excess concentrations of ozone. However, levels of lead, nitrogen oxides, and sulfur dioxide have declined to acceptable levels in Europe.[87]

Air pollution is most severe in the large cities in less developed countries, including Delhi, Jakarta, and Mexico City. In some of China's cities, particulate levels are as much as six times higher than WHO guidelines.[88]

The health consequences of high levels of pollution are considerable. An assessment for the Air Management Information System of the WHO recently projected that the total annual excess mortality due to suspended particulate matter is currently about 460,000, with an additional 370,000 deaths attributable to sulfur dioxide, which, along with nitrogen oxides, is the major source of acid rain. The illness and disability caused by air pollution is far greater than the mortality. A WHO study concluded that air pollution in cities in less developed countries is responsible for some 50 million cases per year of chronic coughing in children under age 14.[89] Mental retardation, respiratory disorders, cardiovascular problems, and cancer have also been linked to air pollution.

Overall, children are at greater risk from environmental health problems than adults. Children under age 5 breathe more air, drink more water, and eat more food per unit of body weight than adults do, so they may experience higher rates of exposure to pathogens and pollutants. Typical childhood behaviors, such as crawling and putting objects in the mouth, can increase exposure to environmental pollution. Exposure to lead remains a principal environmental problem for young children in less developed countries. Lead exposure can also cause anemia, kidney disease, hearing damage, and impaired fertility; at high levels, it can result in coma or death. Leaded gasoline accounts for most airborne lead pollution in many cities.

Indoor air pollution also poses serious health risks. Half of the world's households use biomass fuels, such as wood, animal dung, or crop residues that produce particulates, carbon monoxide, and other indoor pollutants. The WHO has determined that as many as 1 billion people, mostly women and children, are regularly exposed to levels of indoor air pollution up to 100 times above acceptable maximums.

Studies in less developed countries have linked indoor air pollution to lung cancer, stillbirths, low birth weight, heart ailments, and chronic respiratory diseases, including asthma. Asthma affects between 100 million and 150 million people worldwide, and asthma rates have risen by 50 percent every 10 years since 1980. The disease causes the deaths of more than 180,000 people every year, including 25,000 children.

In addition to well-known threats from outdoor and indoor air pollution, new threats have been posed by industrialization. Since 1900, modern industry has introduced almost 100,000 previously unknown chemicals into the environment. Many have found their way into the air, water, soil, food—and people. Many of these chemicals cause cancer, reproductive disorders, and a growing list of other ailments.[90] Heavy metals released into the environment by metal smelters and other industrial activities, the unsafe disposal of industrial wastes, and the use of lead in water pipes and gasoline have contributed to health problems.

The most dangerous metals, when concentrated above naturally occurring levels, include lead, mercury, cadmium, arsenic, copper, zinc, and chromium. These metals have diverse effects relating to cancers (arsenic and cadmium), genetic damage (mercury), and brain and bone damage (copper, lead, and mercury). People exposed to radiation from the 1986 accident at the Chernobyl nuclear facility in Ukraine have elevated rates of thyroid and other cancers. The nuclear wastes from Chernobyl's reactor polluted water, contaminated soil, and killed trees in the surrounding area.[91]

Emerging Infectious Diseases

Human population growth and migration has also facilitated the emergence of a number of infectious diseases by increasing population density, especially in urban areas (where dengue and cholera are becoming more common) and by encroaching into wildlife habitats (leading to, for example, Ross River virus—an infection spread by mosquitoes that can cause long-term joint pain and fatigue). Increased contact with wildlife and associated diseases, combined with international trade in livestock, has led to outbreaks of diseases such as rinderpest in Africa and foot-and-mouth disease in Europe.

Clearing forests for agricultural or pasture use can also spread disease to humans. Farmers in Venezuela's Portuguesa state converted millions of acres of forest into cropland, inadvertently attracting rodents as well as many additional workers. In the 1980s, more than 100 people in the region contracted the deadly guanarito virus spread by rodents. In 1999, Malaysian farmers contracted a virus spread to their pigs by fruit bats displaced by deforestation.[92]

Disease transmission also occurs in the other direction, as livestock diseases can devastate wildlife. Bovine tuberculosis originating from domestic cattle has spread rapidly in recent decades among buffalo and lions and among smaller numbers of cheetah and baboons in parts of East Africa. This disease is also seriously compromising the rapidly expanding deer-farming industry of China and Southeast Asia. Many infectious diseases such as rabies, hog cholera, African swine fever, and screwworm are potentially dangerous to humans as well as to wild and domestic animals.[93]

Looking to the Future

Efforts to understand and manage the relationships between population, health, and the environment and to enact appropriate public policies are underway through field studies; university programs to educate policymakers about population, health, and environment relationships; international projects to document, evaluate, and disseminate information; and international conferences and working groups (see Box 3). These efforts contribute to a knowledge base on population, health, and environment interactions; test methods for appropriate field interventions; engage policymakers in concrete action; and capitalize on human ingenuity to balance human needs with environmental protection.

Building a Knowledge Base

The relationships among environmental and demographic variables have spurred hundreds of studies over the three decades since Paul Ehrlich, Donella Meadows, and others have revived the hypotheses and apocalyptic warning of Thomas Malthus. According to demographers Wolfgang Lutz, Alexia Prskawetz, and Warren Sanderson, this body of research constitutes an emerging field of investigation.[94]

Three criteria justify calling a body of research studies a distinct field: a critical mass of people who work on the issues, joint research questions, and common methodologies. Lutz and his colleagues suggest that population and environment analysis easily meets the first two criteria, but not necessarily the third.

Despite the lack of common methodologies, there is an increasing body of empirical data about the population and health impacts of climate change, land degradation, forest loss, and species threats. Accordingly, there is greater agreement among scientists about global changes and the factors that contribute to those changes. Satellite and other types of images are providing clearer evidence of what is happening over time.

The ability to track information from different sources with geographic information systems and remote sensing is opening new areas

Box 3

Enhancing Expertise in Population, Health, and the Environment

The University of Michigan School of Public Health offers two programs to advance population, health, and environment expertise among professionals. The Population-Environment Fellows Program offers two-year fellowships to U.S. graduates to work on projects that combine assistance for threatened environments with attention to the population dynamics and reproductive health needs of the communities living within those areas.

Another initiative, the Professional Exchange for Applied Knowledge (PEAK) initiative, aims to develop the leadership capacity of professionals and organizations in less developed countries who work in family planning, reproductive health, and population-environment fields. The centerpiece of this initiative is a two- to six-month fellowship for early-career professionals from Mexico, Central America, and sub-Saharan Africa. It also supports activities for the fellows' home organizations.

These programs provide a way for conservation, health, and development organizations to create projects that are more people-centered than the traditional conservation projects and policies that rely on "fences and fines" to protect natural areas and resources.

Participants in these programs generally have advanced degrees in population, health, and environment-related areas and several years of experience in the field. They engage in a variety of projects, including conducting cost-benefit analyses of adding family planning services to an organization's environmental and economic development activities; developing partnerships among conservation and reproductive-health NGOs in protected areas; and identifying the forces driving migration into protected areas. The common goals of many of the projects are to ease the environmental and human costs of rapid population growth, unsustainable resource use, rural-to-rural migration, and unmanaged urban growth.

For more information, see the Population Fellows Programs website: www.sph.umich.edu/pfps/.

of study. Patterns and trends in human distribution and land and resource use may be analyzed in relation to economic and market activity and changes in geographic and biological measurements.

In 1999, scientists used satellite images to determine threats to aquatic plants and animals in Lake Victoria in East Africa. Blooms of blue-green algae caused by the runoff of agricultural chemicals starved fish and plankton of oxygen and sunlight and reduced diversity of aquatic plants. Increased turbidity interfered with mate choice, causing some fish species to die out. An invasive species, the water hyacinth, had multiplied, causing the lake water to stagnate and creating a breeding ground for mosquitoes that spread malaria and snails that host bilharzia, a human parasite. Scientists used remote sensing technology to identify sources of the nitrogen- and phosphorus-rich sediments that were polluting the lake. Using this information, researchers, government extension agents, and local NGOs are working with communities to rehabilitate key microwatersheds.[95]

Reliable information on population, health, and environment relationships is now available on the Internet. IUCN—an international group of government agencies, nongovernmental organizations, and scientists—has created a database that documents long-term threats to animal and plant species. The IUCN data suggest that an increasing proportion of global land, fresh water, and biological production systems are dominated by people.

A similar effort to spur scientific debate and to share information has been launched by the Population-Environment Research Network (PERN), a joint project of the International Union for the Scientific Study of Population and the International Human Dimensions Program. PERN conducts a series of electronic discussion forums, or cyberseminars, on population, health, and environment topics that focus on analyses of relevant scientific and policy issues.[96]

Refining Programs

Around the world, a number of organizations are addressing population, health, and environmental concerns by incorporating reproductive health information and services into environmental protection efforts or adding environmental issues to reproductive health or population education programs.

Rural development programs in the 1970s and 1980s, as well as more recent integrated conservation and development projects (ICDPs), were the first to attempt integration on a large scale. ICDPs represent an approach that aims to meet social development priorities and conservation goals and therefore is based on the links between the social setting and natural environments.[97]

ICDPs were popular in the conservation community in the mid-1980s, following the creation of a large number of parks and protected areas in the 1970s. Initially, they were well-supported by conservation organizations and development agencies. But highly publicized evaluations and critiques of ICDPs and their outcomes surfaced in the 1990s, calling into question the effectiveness of the approach in meeting conservation goals. Some groups have been concerned that integration of population and conservation activities leads to "mission drift"—that the groups were straying too far from their key objectives and capabilities.[98]

Today, conservation organizations are exploring other ways to develop integrated programs. Newer projects tend to be smaller than ICDPs, and they build on partnerships between sectors instead of incorporating all functions into a single project.[99]

A new generation of integrated population, health, and environment programs is being implemented in a variety of countries, including Ecuador, Guatemala, Belize, Madagascar, Tanzania, and the Philippines. The synergy produced by integrating family planning and conservation activities into community-based projects can create more effective and sustainable programs.

In these smaller projects, ecologists, health specialists, and community development experts connect a number of factors, including environmental stress, fertility, migration, women's health, women's educational status, and economic decisions. Close to 50 of these projects have been documented, and many are being carried out in the world's biodiversity hotspots and tropical wildernesses by local conservation groups, national governments, and international organizations.[100]

These projects use various strategies to incorporate activities within the population, health, and environment sectors in their programs. The "staggered approach" involves establishing a single-sector program and later incorporating activities from a second sector. Conservation International (CI), an international NGO, used a staggered approach strategy in the remote forests of the Petén region of Guatemala. CI's project staff assessed an immediate need for reproductive health services as well as conservation activities among the small population living in the region. Because of a lack of immediate political and community support for conservation work, CI—a conservation, not health services, organization—started delivering reproductive health services. While CI would ordinarily have partnered with established local experts in reproductive health, its direct involvement in the community's health services provided an entry point for its conservation work. Once CI established the services, its staff was able to integrate conservation activities.[101]

Other approaches include "simultaneous introduction," which introduces a number of programs dealing with various issues at the same time, and the "bridge" approach, in which activities in one sector, for example, health or conservation, support activities in another.

A project managed by Save the Children-U.S. in the Philippines used a "symbiotic" approach to balance activities linked to population growth and environmental management in coastal areas. In this approach, activities depend on one another and are conducted by the same staff. Building on participatory research, community mobilization, and pilot projects, the Save the Children project used various approaches to understand how population dynamics were affecting fishing practices. An environmental site assessment investigated coastal environmental conditions, resource management practices, population dynamics, and community attitudes toward both population and environmental issues. Geographic information system maps compared population and land-use data from 50 years ago with recent trends. Local communities constructed three-dimensional maps highlighting current land-use patterns relative to environmental resources.[102]

These approaches allowed the project to develop baseline data and conduct focus-group discussions with communities and local decisionmakers on the relationship between population and land-use changes, the direction of these changes, and possible steps to address these trends. Once community members realized that population pressures, together with other factors, were increasing sedimentation along the coast and threatening corals and fish catch, they started planting family and community forests and voluntarily began to use family planning services offered at the local clinic.

As a result, the use of modern family planning methods among couples of reproductive age increased by 7 percent in less than two years, and communities decided to increase the size of protected marine areas from 12 to 203 hectares. While this is a small-scale and recent project, its initial success provides insight into how local communities and government units can design and implement integrated population, health, and environment programs for the protection and rehabilitation of the coastal environment.

Ecosystem models such as the SAVANNA model (see page 13), are also project management tools. These models allow the visual display of different scenarios, enabling local policymakers and scientists to evaluate various land-use strategies. In addition to being used in the Greater Serengeti Ecosystem, SAVANNA has been adapted for use for areas in the United States, including Wyoming's Yellowstone National Park, Colorado's Rocky Mountain National Park, and Montana's Pryor Mountain Wild Horse Range.[103]

Other efforts have focused on community empowerment and mobilization. In South Africa, a community-based environmental and reproductive health program in two rural districts was initiated in 1998 by the government, the UN Population Fund, the Planned Parenthood Association of South Africa, and the Working for Water Programme. The project was undertaken to restore original water flows to rivers and streams; created many jobs, especially for women; and was linked to the provision of reproductive health services.[104]

Photo removed for copyright reasons.

In the Philippines, local communities are mapping environmental and population changes in their landscapes to develop strategies to ensure the livelihood and well-being of upcoming generations.

Engaging Policymakers

Institutional structures, such as high-level government committees charged with integrating population, health, and environment concerns into national development strategies, can promote sustainable development. Nepal, for example, established a separate Ministry for Population and Environment in 1995 that was responsible for formulating environmental and population policies, developing suitable programs, conducting research, and coordinating population, reproductive health, and environment activities with various governmental bodies and NGOs.[105]

These approaches are important because they emphasize the need for collaboration across ministries and government departments. Policies to solve broad problems such as food shortages may address migration, intensified industrialization, and higher food imports. Short-term solutions in only one sector are unlikely to be sustainable over the long term.[106]

Another strategy for giving policymakers a deeper understanding of population, health, and environment interactions is to present the results of scientific research in formats accessible to a nontechnical audience. The Millennium Ecosystem Assessment, launched on World Environment Day 2001, is working to synthesize for policymakers what is known about the

Integrating population science into environmental negotiations is an unexploited opportunity.

Box 4

Missed Connections: International Environmental and Population Conferences

From the 1972 United Nations (UN) Conference on the Human Environment in Stockholm through the 1992 UN Conference on Environment and Development in Rio de Janeiro, there was hope that environmental and demographic challenges facing the planet could be addressed in an integrated fashion in international forums. Unfortunately, the political resolve and capacity for multifaceted international conferences may be fading. Before the 2002 Johannesburg World Summit on Sustainable Development (which was also a 10-year review of the Rio conference), its chairman, Emil Salim, remarked that the event would likely be the last of its kind. In 2003, the UN General Assembly voted to end the automatic five-year reviews of conferences; the format and timing of future conferences will be decided on a case-by-case basis.[1] The UN action reflects concerns that such conferences were expensive and time- and energy-consuming, and had become routine exercises rather than valuable opportunities for international cooperation.

Population has not been a major component of international environmental conferences. Climate models necessarily use demographic projections to create future scenarios of greenhouse gas emissions, atmospheric concentrations, and climate change and impact. While these models are considered in the ongoing Kyoto Protocol negotiations, no real effort has been made to link population and climate policy. Similarly, the Convention on Biological Diversity, signed in Rio in 1992, has spawned more than 15 major international negotiations and technical meetings. Although conference proceedings usually include population growth as an underlying cause of the loss of biodiversity and habitat, the possibility of involving demographers and reproductive health experts has not been actively considered. Integration of population science and policy into environmental negotiations remains a significant unexploited opportunity.[2]

Parallel circumstances have affected international population conferences. At the 1992 Rio environmental conference, also known as the "Earth Summit," governments often deferred population-environment discussions in the belief that these topics would be addressed at the International Conference on Population and Development (ICPD) scheduled for 1994 in Cairo. But the ICPD negotiations focused almost entirely on reproductive rights rather than on global population policy; environmental concerns were mostly limited to unofficial events hosted by nongovernmental organizations. There has been a reticence to mix environworld's ecosystems. The US$21 million, four-year effort is bringing together 1,500 of the world's leading ecologists and social scientists to analyze data on the state of the world's ecosystems, assess nature's ability to provide essential functions such as food and clean water, and project environmental trends such as deforestation, loss of species, and pollution. The Global International Waters Assessment is also examining international water conditions and problems, as well as their social causes. New studies on the nitrogen cycle and persistent organic pollutants are also complementing the ongoing investigation of climate change by the Intergovernmental Panel on Climate Change.[107]

A few years ago, about 1,800 scientists participated in the Global Biodiversity Assessment to document the magnitude and distribution of biodiversity and to inventory and monitor species' economic value. This assessment had little impact on policy because it failed to find a receptive audience. The report is respected among the scientific community, but it has not been used by policymakers.

mental and population policy issues, perhaps because both present difficult political challenges by themselves, and they often appeal to different and sometimes clashing constituencies.

One challenge to including population in international environmental discussions is the growing public perception that population growth is near its end in both the more and less developed countries. This view has been reinforced by UN projections based on assumptions that fertility rates will fall below the two-child, or replacement, level in most countries within the next few decades. Even if these projections are realized, almost 3 billion more people are likely to be added to the world's population by 2050. Much of the fastest growth will occur in countries with the greatest biodiversity in tropical forests and other unique habitats. The limited funds spent on family planning and other reproductive health services usually flow first to urban areas, where greater economies of scale are possible. Populations living in forest and frontier areas are often left with few or no services, leading to more rapid population growth and loss of species and habitat.[3] Integration of population and conservation policy at the international and local levels could protect biodiversity by recognizing that even relatively small populations can lead to environmental damage when they live in fragile ecosystems and by giving a higher priority to reproductive health services for frontier populations.

Ideally, policies on population, energy, environment, and climate should be closely coordinated because these arenas greatly affect each other. The new, less-formulaic configuration of UN environmental conferences may present an opportunity not only to integrate the goals and agreements hammered out in Cairo, Rio, and Johannesburg, but also to facilitate a synthesis of population and environment research and action.

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Researchers and policymakers need to communicate better.

According to analysts, the assessment had three main problems for policymakers: The researchers failed to determine policymakers' needs before launching the project; governments feared being blamed for the loss of biodiversity documented in the report; and the researchers did not present the results in a format policymakers could understand and use.[108]

One of the lessons of the Global Assessment Report was that researchers and policymakers need to communicate better, and greater communication is occurring at the national and regional levels. In Bangladesh, the Centre for Policy Dialogue, and in the Philippines, the Philippine Legislators' Committee on Population and Development, have been working to sensitize policymakers and planners on issues related to population, health, and the environment. These groups work with other local groups, such as municipal governing bodies and community NGOs, to mobilize policymakers' support for policy decisions through regular dialogue at the national and regional levels, research studies on population and sustainable development, and policy papers based on research findings and policy consultations.[109]

The Philippine group has taken this dialogue to both regional and international levels. At a meeting held in Bangkok in December 2002, 89 parliamentarians from 30 countries signed a declaration for the World Summit on Sustainable Development that recognized the importance of the population, health, and environment interactions.

Scientists have also been working to communicate with policymakers at the international level. In 2002, the Global Science Panel, a group of more than 30 international scientists from various disciplines, prepared a comprehensive scientific assessment of the role of population in sustainable development strategies. The panel's report was released at the 2002 Johannesburg World Summit on Sustainable Development.

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, but so far the actions have not successfully integrated population, health, and environment concerns (see Box 4, page 34).

Finding Creative Solutions

Humans have always sought more efficient ways to use resources and to substitute a more abundant resource for a rare or costly one. 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, and aluminum replaced steel; carbon and glass composites and designer ceramics are substituting for all of these. Concrete and asphalt roads have replaced iron tracks in transportation networks, and 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 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.

Even without new energy technology, energy forms can be transformed into other material forms for the purpose of substitution. Liquid fuels can be derived from coal. Solar electricity can create hydrogen that can be burned in internal combustion engines. Biomass (biological waste from industry or from municipal landfills) can fuel electrical generating plants.

Energy efficiency is a form of substitution. Electric motors with computerized controls can run more efficiently than traditional motors. Generating electricity through gas turbines rather than large thermal plants is another way to substitute a more-efficient technology for a less-efficient one.

But substitutions can be costly. Constructing 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, health, and environmental costs of a coal-fired thermal plant or thousands of internal combustion engines that might otherwise pollute urban areas.

Recycling of manufacturing materials is also substitution. Recycling avoids the economic and environmental costs of extracting raw materials and the economic and environmental costs of processing and disposal. One-fourth of America's aluminum demand is met by recycled materials. More than one-half of the natural material that would otherwise be extracted and smelted is avoided by recycling iron.

Better engineering is another form of substitution. Cars made of lighter materials, buildings with more efficient heating systems, and computers that store more information in less space are all forms of substitution. The high-tech solutions to energy needs offer exciting possibilities that energy demands need not signify environmental degradation and threaten catastrophic climate change.

Conclusion

The field of population, health, and environment studies has encountered a number of barriers, most notably a limited theoretical framework and incompatible methodologies. Researchers also face problems of working outside their academic disciplines and dealing with the complexities of topics that cross many disciplines. Topics like food security, environmental health, water availability, energy production and consumption, and economic opportunities are at the heart of human and environmental well-being.

Policymakers need to better understand research results to guide policy decisions. But population and environmental changes are often slow, and projections of future scenarios are based on assumptions of conditions that are difficult to predict with a high degree of certainty.

Investing in family planning and reproductive health services benefits people and the environment. The most rapid fertility declines have occurred in developing countries that have improved child survival rates and educational levels and have implemented family planning programs. The relatively small investment necessary to implement such programs can yield immense long-term benefits.

Politicians often are stereotyped as short-term crisis managers, but the international political community has demonstrated a willingness and ability to address complex long-term issues, as evidenced in recent international agreements on population, biodiversity, and ozone depletion. Additional evidence that reducing pollution benefits vulnerable groups such as the young, the elderly, and women can help buttress the political case for investing in environmental protection and reproductive health. Solid documentation can also support the argument that such investments can complement economic growth and human well-being.

Sub-Saharan Africa and South Asia stand out as the regions most likely to be adversely affected by rapidly rising population, given their young age structures. Especially in Africa, many governments and communities lack the resources or institutional capacity to build sound environmental policies, strengthen investment in education and primary health care, and quickly adopt new technological innovations that further economic growth with less environmental impact.

Of the many connections among population, health, and environment, a few stand out as particularly troubling: the dependence on fossil fuels for economic growth; the challenge of mobilizing support for resource conservation and biodiversity protection; freshwater scarcity; and environmental health threats.

Because these issues have population, health, and environment dimensions, we need to address them in an integrated fashion, and improve the way we study, document, and communicate the relationships. We need to test approaches to manage these problems at different geographic levels and for different time periods. And we need to find ways to engage policymakers on these issues. Ultimately, the real issue is whether perception and policy can keep pace with a rapidly changing world.

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