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2 Trends and Transitions

This chapter explores some major historical trends and transitions that might significantly affect the prospects for sustainability over the next half-century. It addresses trends in human development and the earth's environment, and also the interactions between them. In the first part of this chapter, we look at directions in human development, especially the increasing connectedness of economies, peoples, and technologies; the persisting and even growing human diversity in modern cities; the changing patterns of consumption; the emergence of human development as a significant biogeochemical force; and the basic trends in population, economy, resource use, and pollution. In the second part, the chapter traces trends in the transformation of life support systems at local and regional scales, through trends in human-induced changes of atmosphere and climate, oceans, freshwater, land, species and ecosystems, and disease organisms and their vectors.

The trends discussed here are not always constant over time. Instead, long periods of relative constancy are sometimes interspersed with shorter episodes of rapid change. Early in these episodes, changes are often accelerating and may appear exponential. Later, as the episode runs its course or feedbacks cut in, these changes tend to decelerate and may even reverse direction. In between come periods of transition, marked by breaks or inflections in the long-term trends.[1] In its examination of critical trends in global change, the United Nations' Department for Policy Coordination and Sustainable Development defines transitions as gradual and continuous shifts in society from one state to another.[2]

We live in an era of such transitions, which are under way to varying degrees in specific places and regions around the globe. In the social realm, the transitions that seem most relevant to sustainability include the demographic transitions from high to low birth and death rates; the health transition from early death by infectious diseases to late death by cancer, heart attack, and stroke; the economic transition from state to market control; the civil society transition from single-party, military, or state-run institutions to multiparty politics and a rich mix of nongovernmental institutions. Environmentally, some of the more significant transitions or breaks in trends in specific regions include shifts from the dominance of particular biogeochemical cycles by natural forces to their dominance by human releases, from increasing to decreasing rates of emissions for specific pollutants, and from deforestation to reforestation.

How should societies think of the relationship between major trends or transitions and sustainability? A series of seven interlinked transitions to a more sustainable world has been identified.[3] These were later elaborated and amplified[4] as demographic, technological, economic, social, institutional, ideological, and informational transitions. For the most part, the researchers present these transitions as *requirements* for a more sustainable world: if each individual transition is completed successfully the result will constitute a transition to sustainability.

We take a different tack in this study. In Chapter 1 we argued that the path for a transition toward sustainability could not be charted in advance. Instead, we suggested that it would have to be navigated adaptively through trial-and-error experimentation. We remain unconvinced that any specific set of trends or transitions constitutes necessary or sufficient conditions for sustainability. Yet we think that the triad of goals set out in Chapter 1—meeting human needs, preserving life support systems, reducing hunger and poverty—would guide the successful navigation of a transition toward sustainability over the next two generations. Knowledge of trends and emerging transitions may well prove helpful in attaining these goals; societies must first know the directions of present trajectories in the environment and development. Thus, we begin with trends in human development, then turn to the environmental transformations that have been influenced by human actions, emphasizing the interconnectedness of human development and the environment and the needed shifts in trends for attaining a sustainable future. Specialized studies, named in the text that follows, have addressed trends and transitions for particular aspects of environmental change and particular regions of the world. National Research Council studies related to each developmental sector or environmental issue are provided in endnotes keyed to each section. Our purpose is not to duplicate these extensive treatments found throughout the environmental science literature. Rather, we cite recent studies that present authoritative findings on these topics.

HUMAN DEVELOPMENT

Population Growth, Urbanization, and Well-Being

Slowing Growth

The global human population at the end of the 20th century will reach about 6 billion people. With an annual growth rate of 1.33 percent between 1995 and 2000, about 80 million people were added to the planet each year. Current growth rates are falling and have been doing so since the peak global growth rate in the early 1960s of about 2.04 percent per year. Because this slowly declining growth rate is applied to an increasing population base, absolute population growth will remain high for the next few decades. Thus, population size is expected to increase by almost 2 billion between 2000 and 2025, the same amount as in the last quarter of this century.[5]

Changes in birth rates and death rates over time, a process referred to as the demographic transition, were first studied in Europe. Within two centuries, trends in Europe went from conditions of high birth and death rates to the current conditions of low birth and death rates. In such a transition, deaths first decline more rapidly than births. During that time, population grows rapidly, but eventually it stabilizes as the decline in birth rates matches or even exceeds the decline in death rates. While the general description of the demographic transition is widely accepted, there is much that is debated as to cause and details. Humanity is now in the midst of a global demographic transition that is more rapid than the European transition. Birth and death rates in developing countries have dropped unexpectedly rapidly. The transition in fertility rates in the developing world has declined to 3 births per woman compared to 6 births per woman at the post World War II peak of population growth and is more than halfway towards the level of 2.1 births per woman required to achieve eventual zero population growth. The average number of births for each woman of reproductive age has declined to 3 compared to 6 at the post World War II peak of population growth. The mortality transition in developing countries has also proceeded very rapidly, with life expectancy at birth having increased from 40 years in 1950 to about 64 years today—though this is still well below the 75 years of life expectancy in the industrialized countries.

Today's population growth has immense momentum because large new generations of young people are reaching reproductive age. How much population will grow depends on their choices of family size and their ability to implement these choices. Policies designed to encourage such implementation can slow growth considerably.[6] In fact, the recent rates of decline in fertility outpaced earlier projections of demographers, such that the United Nations reduced its mid-range forecast of global population for 2050 from almost 9.8 billion in the 1994 projection to 8.9 billion in the 1998 projection.[7] By the end of the 21st century, the world's human population is now projected to reach 9.5 billion.[8] Nearly all of this increase—about 97 percent—will occur in the less developed areas of the world.[9] (Figure 2.1).

Expanding Urbanization[10]

Changes in distribution of the world's population over the last 50 years have been relatively small at the global scale (that is, between continents), but relatively large at the intranational scale. Currently, more than half of the world's population lives in Asia, as was the case at the end of the Second World War. The percentage of the world's population residing in Europe and North America has steadily declined, from about

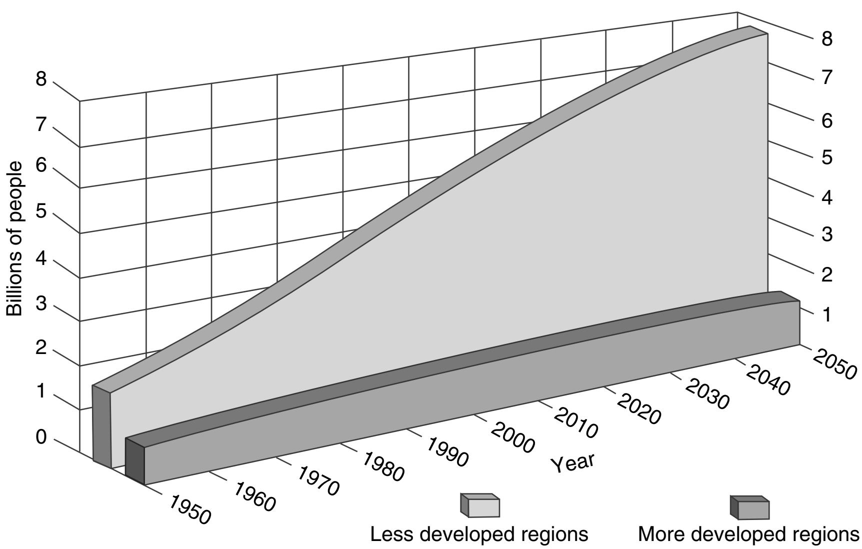

FIGURE 2.1 Historical and projected human population growth in billions for less developed and more developed regions, 1950-2050.
Source: UN (1999). Courtesy of the United Nations.

30 percent in 1950 to closer to 20 percent at the century's end. The largest proportional gains have been in Africa, which today has nearly 22 percent of the world's population, almost three times its share at mid-century.[11]

At the beginning of the 21st century, more people will live and work in the urban centers of the world than in rural areas for the first time in history. In 1999, the intranational changes in distribution are mostly related to past and current trends in urbanization. Urban populations are currently growing substantially faster than the population as a whole. The urban proportion of the world's population is thus projected to grow from 45 to about 60 percent in a generation.[12] It could well grow to upwards of the 80 percent that now characterizes Europe and Japan in two generations.[13] Combined with the rates of overall population growth cited earlier, this means accommodating on the order of 80 million new urban dwellers a year, every year, throughout the transition to sustainability, a feat equivalent to building almost 20 great cities or 10 megacities each year.*

Cities grow because people desire the infrastructure and opportunities that urban areas offer. Jobs, culture, schools, health care, and social services are generally more concentrated and accessible in cities than they are in rural areas. On average, people who live in urban areas receive more income, have fewer children, have better access to education, and live longer than their rural counterparts. But cities are also places of extreme contrast in wealth and opportunity. In some rapidly growing urban areas, it is harder to establish a sense of local community and shared responsibility for the well-being of the poor and hungry; thus in many cities, for the poor, urban life is more difficult, less healthy, and less safe than life in the countryside.[14]

The global transition to urban life is reflected in increases in both the proportion of urban dwellers and the size of cities. Within these constraints, the growth in the proportion of the population that is urban seems to follow an "s" shaped logistic, leveling off at 80 to 90 percent in industrialized countries.[15] The overall percentage of people worldwide living in urban areas increased from 37 percent in 1970 to 45 percent in 1994, and is projected to reach 60 percent in 2025.[16] The number of large cities has also grown significantly. In 1950, there were 81 "million cities" (cities with populations between 1 and 10 million); by 1990 there were 270 cities of this size. The number of megacities is increasing rapidly; while in 1950 there were only two megacities, New York and London, by 1990 there were 21 cities of this size, 15 in less developed regions. By 2015,

*A "megacity" is defined as an urban aggregation of 8 million or more inhabitants. A "great city" is a city of 5 million inhabitants.

these numbers are projected to increase to 516 "million cities" and 33 megacities. But while the number of megacities has increased, their growth has slowed, suggesting that there may be some ceilings for city size. Twenty-three of these megacities will be located in less developed countries, a dramatic increase over the complete absence of cities of this size in these regions in the 1950s. By 2015, 378 million persons, or 12 percent of the urban population of these areas, will live in megacities.[17]

Improved Well-Being

As population has doubled and urbanized over the past two generations, the overall well-being of people has substantially improved. Life expectancy has been rapidly extended; lifestyle has been enriched by literacy and education and made more secure economically. The Human Development Index (HDI), reported by the UN Development Program in its annual *Human Development Report*, provides a convenient and graphic indicator of these changes in the human condition, combining four indicators of well-being in the population of a nation: life expectancy at birth, adult literacy, school enrollment ratio, and real gross domestic product (GDP) per capita. The measures of lifespan, education, and economic welfare are transformed into index values, and the HDI is the simple average of the three index values.[18] Figure 2.2 compares the distribution of the world's population on the HDI scale in 1960 and 1992.

The evolving distribution of the human population on the HDI scale reflects the dramatic improvement in the material conditions of human life since the Second World War, particularly in developing countries. Since 1960 life expectancy in the developing world has increased by 17 years, and infant mortality has been cut in half. Access to safe drinking water has roughly doubled to more than two-thirds of all people. Primary school enrollment has increased by nearly two-thirds, reaching 77 percent by 1991. Per capita income has more than tripled. In sum, the developing world has covered as much ground in a generation, in a material sense, as the developed economies did in a century.[19] Yet despite these gains, over one-sixth of the population still lives in poverty; and while the percentage of people living below the absolute poverty line of US$1/day in developing countries declined slightly from 30.1 percent in 1987 to 29.4 percent in 1993, the actual number of people living in poverty rose from 1.2 billion in 1987 to 1.3 billion in 1993.[20] *

Progress has been social as well as material. Women have made im-

*The absolute poverty line of US$1/day is measured as purchasing power parity (PPP) dollars in 1985. World Bank (1999).

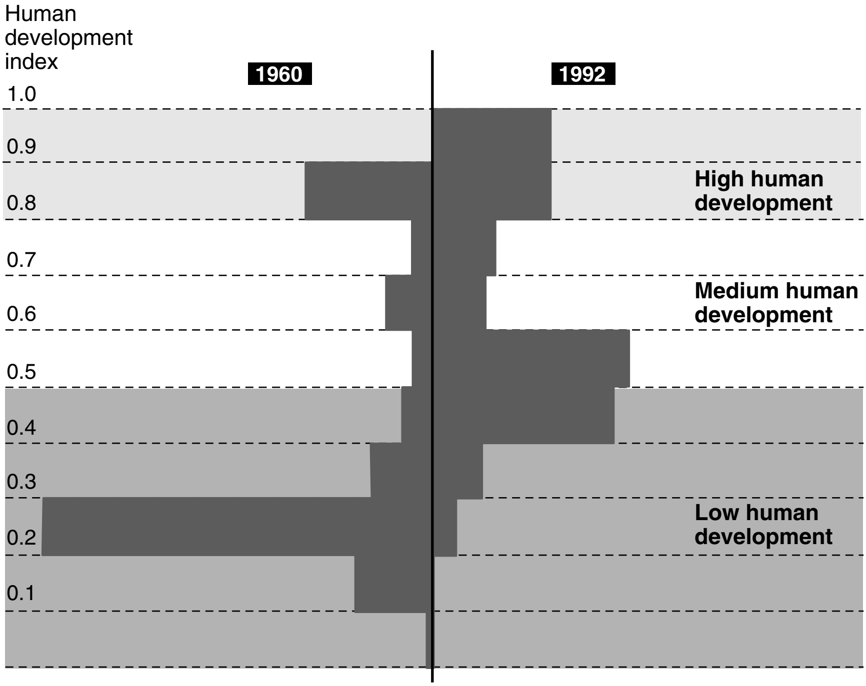

FIGURE 2.2 Distribution of the world's population by decile of the Human Development Index (HDI), 1960 versus 1992. The HDI provides a convenient and graphic indicator of changes in the human condition by combining four indicators of well-being in the population of a nation: life expectancy at birth, adult literacy, school enrollment ratio, and real GDP per capita. Source: UNDP (1995). Courtesy of Oxford University Press.

portant gains over the past generation in ways that go beyond economic measures, including through narrowing gender gaps in education, increased literacy, and decreased female child labor rates.[21] The available measures, however, show clearly that no society treats its women as well as its men. In addition, the relative well-being of different groups in societies remains contentious, as demonstrated by the persistence of underclasses of race, ethnicity, and poverty, and increasing disparities among groups in most societies.

Transitions are also taking place in many other aspects of human development. They include the health transition underlying increasing longevity, with movement away from the infectious diseases characteristic of developing countries to the chronic diseases of industrialized countries. Yet despite these trends, there has been a surprising reemergence of infectious disease even in industrialized countries, with human immunodeficiency virus (HIV) being the most prominent example. A number of diseases have been connected to technological and environmental changes, such as Legionnaire's disease (air conditioning), toxic shock syndrome (super-absorbent tampons), Lyme disease (changing suburban ecology), and Hanta virus (desert ecology). There may be a transition in education as well—from predominantly informal to formal learning and now to lifelong learning. Educational institutions, especially in the developed countries, are now addressing the needs for lifelong learning. And with the continued development and use of the Internet, especially in the developing countries, education and access to information are both expected to increase rapidly. Development itself was once thought to be a progression of stages.[22] But if this is true, it is highly irregular and punctuated by regional differences and periods of economic stagnation and decline (Figure 2.3), by reversals of longevity, such as that of young people in AIDS-affected countries and of men in Russia, and by educational requirements outpacing of educational offerings.

For a Sustainable Future

The persistent trends of growing population numbers but slowing rates of population increase have two major implications. There will be an enormous challenge in meeting the needs of almost twice as many people as there are today in the space of a few decades. But if met successfully, this challenge is not likely to be repeated within the next century or two. Housing and employing the additional people of the equivalent of a thousand additional cities over the next two generations is one part of today's challenge. The 600 million homeless and overcrowded in today's cities suggest the magnitude of the future task. At the same time, building these equivalent cities provides a needed opportunity to replace the current infrastructure and to build anew in an energy- and water-efficient manner.[23]

The rapid improvements in human well-being over the last two generations make more realistic the prospects of attaining the social goals of a sustainability transition. But the absolute numbers to be fed, nurtured, and educated will be almost twice those of the past two generations. Recent reversals in longevity and sustained periods of economic stagnation in Africa, Latin America, and perhaps Asia argue for caution in the simple projection of trends of improvement into the future. Thus, meeting human needs in ways that provide for future generations is at the heart of the transition to sustainability.

Wealth and Consumption[24]

Growing Wealth—Growing Disparities

Dramatic changes in human well-being are reflected substantially in changes in economic output (Figure 2.3). Trends in GDP—a measure of the total economic activity in a nation's markets—reflect a nation's production and income per capita, and hence give an indication of a country's poverty levels. GDP has been tracked back to 1820 (shown in Figure 2.3 on a logarithmic scale), a date at which the modern era of economic growth began in the view of an economic historian.[25]

There has been an average worldwide gain in GDP per person by a factor of 7.9 between 1820 and 1992; in the four "Western offshoots," Australia, Canada, New Zealand, and the United States, economic growth has brought about a gain of more than 17-fold over this span of roughly six generations—doubling economic output within each human lifespan. Even in Africa, the region with the weakest record, economic output per capita almost tripled between 1820 and 1980.

Despite recent gains in GDP per capita, however, economic statistics do not provide a complete measure of societal production. A society that measures its economic attainments only by market transactions misses important activities. For example, family work in households, which is usually done by women, is not counted unless it generates market transactions; and home appliance use is not accounted for in GDP, while appliance repair is incorporated into this measure of economic activity. Pollution, which diminishes the value of ecosystem services and other valued activities and assets, is excluded from conventional GDP accounts as a liability, but appears as a valued economic good as effort, money, and materials are used to respond to it (such as for the repair of a pollution-damaged building façade or the restoration of habitat).

Favorable trends in GDP also fail to account for disparities in the distribution of income. These disparities are widening and are likely to continue to do so in the absence of strong remedial actions.[26] The gap is growing between rich and poor countries as a whole and between the rich and poor within many countries. On a global basis, the ratio of the income share of the richest 20 percent to the poorest 20 percent doubled over the past 30 years from 30:1 to 60:1.[27] Among the rich countries (OECD countries), there has been a tendency over the last half-century toward convergence of productivity and income levels and a narrowing of disparities in wealth. Between the OECD and the poor or less developed countries, however, there has not been a general trend toward convergence, with the exception of a small but very important subset of developing countries primarily from east and Southeast Asia.[28]

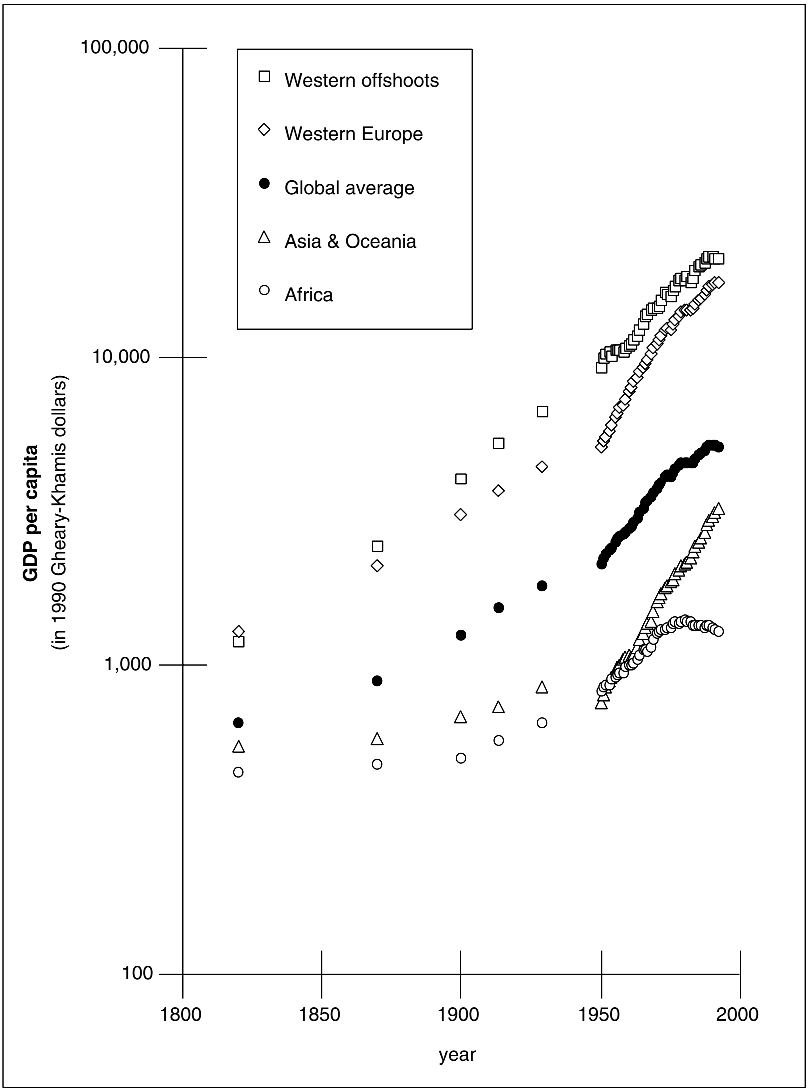

FIGURE 2.3 Gross Domestic Product (GDP) per capita, by geographic region. "Western offshoots" are the United States, Canada, Australia, and New Zealand. GDP is converted to a common standard, 1990 Geary-Khamis dollars, a method that uses estimates of purchasing power parity to compare national economies. Source: Maddison (1995).* Courtesy of the Organisation for Economic Cooperation and Development (OECD).
*See Maddison (1995) Table G-3, p. 228. Appendix B describes treatment of changes in GDP over time.

The relationship between economic growth and income distribution remains controversial among economists.[29] Within countries, developing countries have historically had higher levels of income inequality than more developed countries. There is evidence in some countries that increasing development has not contributed to the worsening of disparities in income distribution.[30] But in some poor countries that have experienced rapid growth, disparities in earnings and income level have widened. In the developed world—and particularly in the United States—the gap in incomes between the highest 20 percent and the lowest 20 percent of workers has tended to increase since the late 1960s.[31]

Greater Consumption

Trends toward increasing population and income have also meant trends towards increasing consumption worldwide. In general, extraction, production, and use of energy and materials have increased at rates exceeding the rate of population growth but more slowly than growth in GDP. At the same time, as consumption has increased, use of energy and materials has become more efficient on average.

Varying views of consumption on the part of scientists from different disciplines[32] have led to differing interpretations of consumption and its importance. For physicists, matter and energy are conserved, so consumption must be regarded as transformations of matter and energy that produce entropy or disorder. For economists, consumption is spending on consumer goods and services and is distinguished from the production and distribution of those goods. For ecologists, consumption is the process by which living species obtain energy and nutrients by eating green plants, which produce energy, or other consumers of green plants. And for some sociologists, consumption is a status symbol in that individuals and households use their income to improve their social status through certain kinds of purchases.

To further understanding of human consumption and encourage effective actions toward sustainability, the officers of the U.S. National Academy of Sciences and the Royal Society of London have issued a joint statement on consumption. They choose a variant of the physicist's definition, stating: "Consumption is the human transformation of materials and energy." Their statement goes on to note that "consumption is of concern to the extent that it makes the transformed materials or energy less available for future use, or negatively impacts biophysical systems in such a way as to threaten human health, welfare, or other things people value."[343]

For consumption as the transformation of energy and materials, data recording trends are limited. Yet there is relatively good global knowledge of energy transformations due in part to the common units of conversion between different technologies. Between 1970 and 1997, for example, the global consumption of energy increased from 207 to 380 quadrillion British thermal units (Btu).[34] For material transformations, on the other hand, globally aggregated data exist only for some specific classes of materials, including materials for energy production, construction, industrial minerals and metals, agricultural crops, and water.[35] At the national level, however, aggregate analyses are beginning to appear. In the United States, for example, it has been estimated that the mass of current material production and consumption averages well over 50 kilos per person per day (excluding water and extractive waste). Three-quarters of the material flow is split between energy and related feedstock conversion (38 percent) and minerals for construction (37 percent), with the remainder as industrial minerals (5 percent), metals (2 percent), and products of fields (12 percent) and forests (5 percent).[36] Of the 50 kilos, about half goes into the air and onto the land as waste. Adding in wastewater and materials associated with extraction may double the total mass of material consumption per person per day.[37]

In the absence of globally aggregated data, trends and projections in agriculture, energy, and economy can serve as surrogates for more detailed data on energy and material transformation, as suggested in Table 2.1. These data show that over the second half of the 20th century, while world population more than doubled, food production (as measured by grain production) almost tripled, energy use more than quadrupled, and the overall level of economic activity quintupled. Scenarios of current trends show these rapid growth rates of the last 50 years slowing somewhat over the coming 50 years. For example, in one such scenario of current forces and trends (see appendix, Chapter 3), over the next 50 years world population would less than double (1.6×), food and energy consumption would almost double (1.8× and 2.4× respectively) and the economy quadruple (4.3×).

TABLE 2.1 Actual and Projected Changes in World Population, Food, Energy, and Economy

	Actual 1950-1993	**Reference Scenario 1995-2050**
Population	2.2 ×	1.6 ×
Food (Grain)	2.7 ×	1.8 ×
Energy	4.4 ×	2.4 ×
Economy (GDP)	5.1 ×	4.3 ×

Sources: For actual, Brown et al. (1994), courtesy of Worldwatch Institute. For scenarios, Raskin et al. (1998) (see Chapter 3 of this report).

Thus, while future growth in population and consumption is projected to increase less than in the past, both history and future scenarios would predict consumption rate increases at well beyond the rates of population increase. Such scenarios build on a postulated "energy and materials transition" somewhat parallel to that of the demographic transition described above. In such a transition, societies will use increasing amounts of energy and materials as consumption rises, but over time the energy and materials inputs per unit of consumption will decrease.

For a Sustainable Future

Overall, the growth of wealth is as persistent as the growth of population. Like the leveling of population, growth in wealth is perhaps slowing, but barring severe disruptions to the global economy, growth should continue at rates well above that of population. Recent increases in wealth could be seen as leading to a world characterized both by the popular economics maxim—a rising tide raises all boats big and small—and by the increasing division between rich and poor in absolute as well as relative terms. It is difficult to foresee a sustainable future if the latter trend prevails. Regardless of distribution, increased wealth and income imply increased consumption. Sustaining the supply of energy and materials needed to support this level of consumption, making them available where most needed, and addressing the environmental problems resulting from their extraction, consumption and disposal may be the most significant challenges to a sustainability transition, especially as more people adopt the materials-intensive, consumptive lifestyle now enjoyed by most people in industrialized nations.

Technology and Work[38]

Changing Technologies

On the scale of generations, within the current scientific-industrial revolution, four 60- to 70-year periods of technologically driven economic development have taken place, marked by characteristic sectors of growth, emerging technologies, and concepts of management and industrial organization (Table 2.2). These emerging technologies provoke technological transitions, generally emerging slowly and growing rapidly toward saturation (in logistic growth curve) in the following period. While economists and technology historians differ on the details of period characteristics and timing, and may differ greatly in their explanations of the relationships of these phenomena to large-scale fluctuations in economic growth and recession, there is wide acceptance of the historical sequence of changing and emerging technologies. Most speculative of course is the fifth cycle, of which we are in the early stages and which coincides with the desired transition toward sustainability.

In the current transition, several major technological trends since World War II have combined to change the nature of industry, consumption, and the world. Fossil fuels, including the liquid fuels used in transportation, have been cheap, and in real terms have become cheaper.[39] The availability of inexpensive fuel, the rise of the long-range electric distribution grid, the development and widespread commercialization of jet aircraft, and the proliferation of automobiles and long-range diesel trucks, along with the building of major road networks, have all revolutionized the availability of electricity and widespread transportation.

Experience with complex systems and processes of all kinds has led to increased understanding of their management and control, built in part on the research and development of national defense and weapons systems during the post–World War II period. [40] These advances include the control of process chemistry, material synthesis, robotics, telecommunications (including power systems, nets, and grids), structural design and construction at all scales, and, most recently, biological technology (both medical and agricultural) and design.

Smaller, More Efficient, and More Mobile

The rise of global communication systems, combining radio, satellite, and fiber systems, has come along more or less in parallel with the rise in transportation. The development of digital computing and the microchip, with continually decreasing size, energy requirements, and cost per digital transaction, have made computation, memory, word, logic, and number processing easily available worldwide. Combined with communications systems, transactions can not only be done at long distances, but computing chores can be divided among sites. Thus, it is no longer necessary for data gathering, analysis, and control to be in the same place. Engineers in different parts of the world can work simultaneously on designs, and a machine can be controlled remotely from any distance.

These technological changes have enabled the improved and systematic pursuit of greater efficiency in the use of energy,[41] materials, and money at all scales in large and complex systems. Efficiency in the use of materials has resulted not only from control over materials' properties, but from improvements in their design, which result in more efficiency in their use. [42] In addition, reuse of materials through the recycling of old products has become an important and more efficient source of materials.[43]

TABLE 2.2 Characteristics of Major Technological Complexes

	1770-1830	1820-1890	1880-1945	1935-1995	1985-2050
Growth sectors	Water power Ships Canals	Coal Railroads Steam power Mechanical equipment	Cars Trucks Trolleys Chemical Industry Metallurgical processes	Electric power Oil Airplanes Radio and TV Instruments and controls	Gas Nuclear Information Telecommunications Satellite communications Laser communications
Emerging technologies	Mechanical equipment Coal Stationary steam power	Electricity Internal combustion Telegraphy Steam shipping	Electronics Jet engine Air transport	Nuclear Computers Gas Telecommunications	Biotechnology Artificial intelligence Space communication and transport
Management		Economy of scale Interchangeable parts	Administrative management	Professional management	Participatory and interconnected systems management
Industrial organization	Concept of the industrial firm Division of labor	Concept of mass production Interchangeable parts	Concept of management structure and delegation	Concept of decentralization	Concept of systems structure

Source: Grübler and Nowotny (1990). Courtesy of Inderscience Enterprises Ltd.

Lessened Work

For those who toil, the great technological revolutions of agriculture and industry initially meant longer hours and harder work. The industrial revolution led to a painful restructuring of agricultural societies, but much later, it led to great improvements in health, longevity, and living and working conditions. For the industrialized world, there has been a dramatic and consistent drop in hours worked over the 150 years of increasingly reliable records. Within the long-term trend, however, there is much variation by age, sex, and education—a reflection of the growing divisions of income and opportunity. For example, while average hours worked have also declined in the United States from 40.2 to 39.2 hours per week over the last 35 years, hours worked (compensated) have risen for college educated men and have dramatically increased for women.[44] Indeed, the stresses of the two-worker household and the second job have led to concern about overworked Americans.[45]

Currently, knowledge of the control and management of complex systems, along with computers and communications, has propelled the use of the robot and automatic control into new and increasingly pervasive forms. This advance has made possible the economic replacement of labor by controllable, semi-intelligent and, perhaps, intelligent machines, first for physical labor, increasingly for routine bureaucratic work, and eventually, perhaps, for most or all routine intelligent work. In addition, societies are beginning to separate the control of processes from the location of the processes themselves. This arrangement enables the separation of the people in control from the entity being controlled, and more generally enables the separation of people from their work. Ultimately, this capability may allow the production of the required goods and services for a very large population by a small number of people who may be in scattered locations.

We are not sure how to organize such a radically changed economic and social system. In most industrialized countries (other than the United States), endemic unemployment has become a way of life and a matter of high concern. Also, mechanization tends to displace lower skilled workers, so unless displaced workers are retrained and new jobs are created, this trend will increase problems for the already poor. Whether such unemployment is only temporary and part of a restructuring between periods of growth or represents a new and long-term result of technological change and globalization is of continuing concern and speculation in the industrialized world.[46]

For a Sustainable Future

Periodically, industrialized countries replace their lead technologies in a process of early adoption, rapid diffusion, and saturation. Industrial history suggests that humanity is in the early stages of still another such transition. The emerging technologies of this transition, for the most part, augur well for needed technological changes as they include evolving energy sources and transmissions, new materials, and the substitution of information for energy and materials. The characteristics of these technologies and the move away from the production of commodities to the provision of services offers the potential for skipping over the dirty (more polluting), intermediate stages of economic development. Trends toward using fewer materials, or "dematerialization," will be furthered by research in molecular and submolecular technologies: microelectronics, biotechnology, and nanotechnology materials. Such technological transitions have always been accompanied by changes and disruptions in the nature of work, even if they lead to an overall reduction in working hours and an increase in unobligated time. Such disruptions may make more difficult the employment of many workers in the next two generations.

Connectedness and Diversity

Increasing Connectedness

The larger population of the future will be closely connected through ties of economic production and consumption, migration, communication, transportation, and interlinking technologies, together often described as "globalization." The expansion of major regional common markets, free-trade blocs, and the ensuing flows of goods, capital, and technology will likely be accompanied by flows of people between countries. New information technologies and mass communication techniques will continue to penetrate many different geographic, temporal, linguistic, cultural, and political barriers.

Since 1950, trade between nations has grown at more than twice the rate of the economy (GNP), and as of this decade, 20 percent of the world's goods and services pass over a border on the road from production to consumption.[47] This pace will accelerate as the two current free-trade blocs in North America and Europe are joined by others in Latin America and Asia and global free-trade efforts continue. Prevailing economic opinion sees these rapid increases in trade as the engine of development; in the long run, most participants in such trade will be better off. Yet many in industrialized countries see increased trade as a continuing threat to their own standards of living, imperiling their welfare systems and leading to large unemployment. For the developing countries that are capable of combining their prevailing low wages with flexible and efficient production, the opportunity exists for rapid growth and perhaps a long-term redistribution of the world's wealth with increased trade.

Trade in money and capital now moves quickly with electronic movement of funds, worldwide currency markets, and a 24-hour sequence of open financial markets. Private currency traders set exchange rates, once the purview of governments, and trade $1.3 trillion a day, nearly 100 times the volume of world trade. Private capital flows grow twice as fast as trade, and for U.S. investors, international portfolio transactions exceed 1.5 times U.S. GDP.[48]

The exchange of words, images, and ideas has also accelerated substantially during the past 50 years. Globally, the exchange of words, as measured by minutes of international telephone calls, quadrupled in the last decade.[49] The number of televisions per 1,000 persons worldwide has increased from 153 in 1988 to 228 in 1995.[50] The number of Internet users worldwide has increased from 26 million in 1995 to 205 million in 1999 and is expected to reach 350 million by 2005.[51] With the exchange of words and images comes the transfer of ideas and culture, which in current technology is dominated by English words and images of industrialized countries' lifestyles and their consumer products.

The spread of cultural ideas about the desirability of consumption into distant places enlarges markets and fuels energy and materials transformations at rates far exceeding population growth. While modern technology enables communication that may be freighted with these values, it also distributes a culture of environmental concern that builds on universal concerns for the fate of the earth. Increased communication links those who have environmental concerns to common international efforts, to shared information, and to growing numbers of environmental NGOs (nongovernmental organizations). Such links have had a large impact on shaping public attitudes and opinions, and ultimately on influencing public policy and political will. Changes in attitudes and beliefs, influenced by the proliferation of communication, seem under way in at least three important sets of ideas: (1) that cohabitation with the natural world is necessary, (2) that there are limits to human activity, and (3) that the benefits of human activity need to be more widely shared.[52]

Flows of people—temporary, permanent, and forced—have also increased, although most of these movements are poorly measured. According to the most recent worldwide estimates of the number of international migrants, dating from 1990, perhaps as many as 120 million people cross a border annually, or about 2 percent of the world's population. This figure represents a growth rate in migration of 1.9 percent per year since 1965, when the global estimate of cross-border migration was 75 million persons per year. The percentage of people who migrate with the intention of becoming permanent or long-term residents of a foreign country remained relatively stable at between 2.1 and 2.3 percent of the world's population from 1965 to 1990; but the number of countries hosting a significant proportion of migrants (e.g., more than 300,000 migrants or more than 15 percent of population 1965-1990) has increased.[53] Within countries, massive migrations continue, often from countryside to city, from places of limited to greater opportunity. Between 40 and 60 percent of urban growth is attributed to internal migrants from the countryside.[54] Increasingly, some movements of populations are forced, with about 20 million refugees in 1997 seeking asylum in other countries and more forced to move within their own.[55] The rate of increase in refugees is more rapid than the rate of increase in world trade.

The rise of the global transportation network has made the location of most material goods nearly irrelevant (though this does not equate with access); generally, products are easily transportable and only land and ecosystems stay put. Fresh fruit and vegetables, fish and meat, as well as furniture, vehicles, building materials and other products may reach their consumers from anywhere in the world. Because the rise of the computer and the global communication network have made knowledge widely available, worldwide distribution has been greatly facilitated, though inaccessibility of material goods continues to be a serious problem for many countries with mostly lower income populations.

The increasing connectedness of the world population also presents environmental threats.[56] The rapid movement of peoples and products makes possible the rapid transmission of infectious diseases that affect people, crops, and livestock and of biological invasions that destroy native biota as well as crops.[57] Environmental changes related to extractive processes for mines, fields, forests, and the sea are accelerated, as tropical forests are exploited for industrialized country consumption and as coastal forests and farmlands are destroyed in shrimp aquaculture. Environmental problems associated with manufacturing are exported to countries with weak environmental regulations or where rapid industrialization uses older technologies that do not incorporate recent advances in energy efficiency or industrial ecology. Most feared of all may be the rapid increases in consumption fueled by aggressive marketing and rooted in cultural change as well as economic growth. Often these changes combine to bring about destructive effects, such as the recent fires in Southeast Asia, where drought from El Niño, fires to clear land for palm oil production, and massive urban air pollution combined to shroud portions of four countries in health-impairing, accident-causing smog.

Persistent Diversity

Although the exchange of words, ideas, and cultures will increase in the next half-century, the increasing connectedness of the human population will not make all people alike. New opportunities for human development may increase personal and societal diversity as well as the availability of material things. Places of wealth or opportunity toward which people and products gravitate become more diverse by drawing people from different regions and cultures.[58] In response to such increased connectedness of diverse peoples, and the corresponding infiltration of outside values into societies, strong ethnic, nationalistic, and religious movements can emerge to counteract homogenization and reassert traditional cultural values.

Trends in urban centers, which hold wealth or opportunities toward which migrants are drawn, show that diversity is increasing in cities: there are 20 or more languages available to schoolchildren for bilingual education in some countries, and the shelves of supermarkets are laden with foods from many parts of the world. With the collapse of the Soviet Union came a dramatic increase in nationhood, but this was only the latest in a process of decolonization seen since the end of World War II, with the number of nations more than doubling from the 73 countries at that time to the 190 today. In these newer nations, old claims persist and new claims arise for regional autonomy or national independence. The much-reported resurgence of Islamic religious vitality and conflict tends to obscure equally tense religious differences between and within the majority of the world's religions.[59]

Are these differences among people and nations—in wealth, ethnicity, religion, and opportunities, differences that divide people, create inequities, and encourage conflicts—likely to persist and perhaps grow? Current trends in some measures of human development, such as the earlier-discussed trends in health and human rights, show decreasing inequity; wealth measures are indicating stable or growing disparities; and either despite or because of the Cold War's end, conflicts remain and emerge, and may be increasing. Some observers also see trends in the diminution of social capital—in the common bonds, activities and organizations that create community and mutual support.[60] In addition, it is not apparent whether increasing divisiveness is a persistent trend, similar to trends in connectedness, or an artifact of communication in which news of conflict and division is selectively and rapidly disseminated, or has been constant and is only more readily revealed as greater global divisions diminish.

Changing Institutions, Shifting Power

Connectedness and diversity are reflected in institutional innovations and shifts in power.[61] At a global level, new institutions of governance have emerged, transnational corporations and financial institutions have grown and consolidated, and NGO networks have collaborated and expanded. At the subnational level, government has devolved, privatization is common, and civic society in many places has been strengthened. Power has shifted from the central, national state both upwards to the global and downward to the local as well as to civic society and private enterprise.

The power shift from central government is paralleled by an expansion of private property rights and market relationships. In less-developed countries, such shifts have been marked by declines in shared common-property resources and increases in individually held and marketed resources.[62] Labor relationships have similarly shifted through various institutions from labor tied to place or person to labor free to circulate, for example, in China.[63] In the former socialist economies of Europe and Asia, and in the social democracies of Europe, once centrally held property is increasingly privatized.

For a Sustainable Future

Increasing connectedness will fuel growth in some parts of the world, diminish it in others, and amplify the forces that drive increased consumption. In addition, it will export to some developing and recently industrializing countries many of the environmental problems of the industrialized world and, with some delay, the institutions and technologies to control them. Connectedness, while creating common elements of culture in most places and increasing the similarity of places, can also increase diversity, particularly in urban areas that attract migrants. The diversity of the human experience offers possibilities for alternative lifestyles and new possibilities of addressing our common future, but divisiveness between diverse communities makes common tasks much more difficult. Ultimately, divisiveness may lead to war—the greatest threat to human development and the environment.

HUMAN ACTION AND ENVIRONMENTAL TRANSFORMATIONS

Rates, Scales, and Multiple Stresses[64]

Rapid Global Change

The world has experienced human-induced changes in local, regional, and global environments for much of the past 10,000 years, but most of that change has occurred during our lifetime.[65] Recent analyses comparing modifications in the environment over the last 300 years to changes over the last 10,000 years demonstrate the unprecedented nature, scale, and rate of human-induced changes in the earth's environment.[66] In the last 300 years, humankind has demonstrated the capacity to change the environment on a scale that equals or exceeds the rate of natural environmental changes, as human population, economic growth, and technological capability have combined to create human-influenced ecosystems on much of the land and coastal areas of the earth.

Human actions have significantly altered biogeochemical cycles, of both land and water, along with biotic diversity. In 13 worldwide measures reconstructed by the *Earth Transformed*[67] project— including carbon, carbon tetrachloride, lead, nitrogen, phosphorus and sulfur; deforested area, sediment flows, soil area loss, and water withdrawal; and flora, marine mammals, and terrestrial vertebrates—most of the change has been extraordinarily recent. For 10 of the 13 measures, half of all the change over the last 10,000 years took place within our lifetime (Table 2.3). Overall, since the dawn of agriculture roughly 100 centuries ago, an area the size of the continental United States has been deforested by human actions. In addition, half of the ecosystems of the ice-free lands of the earth have been modified, managed, or utilized by people. Water in an amount greater than the contents of Lake Huron is withdrawn each year for human use. As a whole, many flows of materials and energy that are removed from their natural settings or synthesized now rival the flows of such materials within nature itself.

Other related studies by biologists and systems analysts have assessed the degree to which humans dominate ecosystems.[68] For example, researchers[69] analyzed sunlight as the basic source of energy for nearly all life on earth. Using three different definitions of the proportion of the net primary productivity that should be assigned to human "appropriation," the study suggested that as much as 40 percent of the photosynthesis on land, in the form of plant biomass, is being used by humans. Using the same framework, researchers[70] estimated the fraction of fresh water "coopted" by humans; while this estimate depends on assumptions that de-

TABLE 2.3 Magnitude, Recency, and Rate of Change in Human-Induced Transformation of Environmental Components

Rates	**Magnitude of Change Since 10,000 Years Before Present**	
Changes Since 1950	**50% Total Change Reached in the 19th Century**	**50% Total Change Reached in the 20th Century**
Rates Decelerating	Terrestrial vertebrate diversity	Carbon tetrachloride releases Lead releases Sulfur releases Human population Marine mammals
Rates Accelerating	Deforested area loss	Carbon releases Nitrogen releases Phosphorus releases Floral diversity Sediment flows Water withdrawals

Source: Turner et al. (1990b). Courtesy of Cambridge University Press.

fine how various flows of water are to be counted, their estimates range upward from 23 percent of the annual flow accessible to humans. A related estimate of water needs[71] suggests that growing food to feed the existing human population a vegetarian diet already claims half the water used by humans. The most recent of these studies[72] summarizes the body of work on human dominance of ecosystems.

The central thrust of these analyses is that humans are now recruiting significant fractions of sunlight, fresh water, and life forms to their purposes, with the fraction rising to over half in some instances. These estimates, while inexact, portend that expansions in the human claim on the planet's life support systems cannot be indefinitely extended, especially as human numbers rise through the remainder of the demographic transition.

Taken together, do these massive and recent human-induced environmental changes threaten the life support systems of the earth for human life? Although for the earth as a whole the entire system has not likely been irreparably damaged, in some regions, according to available studies, environmental threats from human activities loom. In a recent comparative study, six of nine regions—located in Brazil, China, Europe, Indonesia, Kenya, and the United States—were found to have "current human uses and levels of well-being [that] appear to be environmentally unsustainable over the middle-to long-term future."[73] Two regions—one in Nepal and one in Mexico—appear environmentally unsustainable in the near-term future, and the Aral Sea region in Central Asia is already unsustainable.

In addition to regional and global indications of unsustainability, the intensity of human use of the natural world makes it virtually certain that environmental threats will continue and that surprises are inevitable, for example, in the form of new and reemergent plant and animal diseases. By definition, environmental surprises cannot be foreseen, but the structural conditions that encourage their emergence and proliferation can be described. Environmental surprises should be expected as trade continues to expand, with the accompanying movement of peoples, life forms, and goods; as new molecular-level technologies in biology and materials are deployed; as older technologies are applied in new, untried settings; and as humans respond to existing environmental problems, in responses that have sometimes produced unexpected and unwanted consequences.[74]

Shifting Problems and Policies

In the upcoming decades, there may also be shifts in the nature of environmental problems, their scales, and the societal policies to reduce or ameliorate them. Since the 1950s, 6 of the 13 indicators shown in Table 2.3 have changed at a decelerating rate, while the remainder still seem to be accelerating in change.[75] The deceleration occurs for those environmental components most subject to government regulation, suggesting increased efficacy of environmental policies.

The idea of environmental transitions was framed in an analysis[76] that identified three different trajectories that environmental problems may follow with a rise in per capita income. Characteristic problems of developing countries such as inadequate water supply and sanitation decline with rising income. Air and water pollution increase and then decrease (an inverted U-curve) as governments with seemingly greater resources have regulated and taxed enough facilities to bring down pollutant concentrations. But as income increases, so apparently does material consumption, which leads to increased trash production and carbon dioxide emissions. These activities show no signs as yet of abating.

These curious irregularities[77] have stirred a great deal of debate by suggesting that, in some cases, environmental quality can improve with prosperity. The inverted U-curves have come to be called "Kuznets" curves by analogy with a pattern noticed by economist Simon Kuznets in the 1950s—income inequality appeared first to rise and then to fall in the course of early industrialization.

These findings suggest that a transition toward sustainability may be characterized by a change in the relative importance of environmental problems, with the most serious concerns perhaps shifting from dirty water and lack of sanitation, to air and water pollution, and then to climate change. The scale of concern may increasingly shift from household, neighborhood, and village, to urban area and region, and finally, to region and the world. Policy emphases should correspondingly shift, whether in the areas of public health, pollution abatement, source reduction, or efficiencies in reducing consumption and reusing and recycling materials.

For a Sustainable Future

Human domination of natural systems is already so extensive in many places, however, and our dependence on natural resources so deep, that permanent management of ecosystems appears to be the only practicable alternative for a sizable fraction of the natural world. Instituting and sustaining management on large scales to serve so many partially competing ends is a feat achieved in only a few places for relatively brief periods. At smaller spatial scales, however, and for some significant problems, including safe drinking water and industrial air pollution, there are encouraging signs of effective control as societies marshal the social will and economic capabilities to address these problems. Transitions in the relationships between humans and nature are inevitable; whether they will result in a sustainable economy and ecology cannot be discerned from the trends themselves.

Global Atmosphere and Climate[78]

Declining but Stabilizing Stratospheric Ozone

Human activities have altered the chemical composition of the atmosphere locally, regionally, and globally. Although these changes are small in terms of percentage changes, even a small amount of change in the composition of the atmosphere can have noticeable and serious environmental impacts. These effects result in part from the high reactivity of compounds such as ozone and oxides of sulfur and nitrogen, and in part from the fact that the greenhouse gases and stratospheric ozone play crucial gatekeeper roles for the earth's life support systems.

Human use of chlorofluorocarbon gases (CFCs), beginning in the 1930s, has released a small but potent quantity of these industrial chemicals into the atmosphere. As CFC molecules drift to the upper atmosphere, they are broken down by solar ultraviolet radiation and release chlorine atoms. These atoms interact catalytically with the layer of ozone (O_3) in the stratosphere, with each chlorine atom on average destroying a large number of ozone molecules before reacting to form relatively inert compounds that are subsequently transported down to Earth's surface and removed in precipitation and on land and water surfaces. For this reason, a small quantity of CFC gases can have a substantial effect on the stratospheric ozone layer. This layer is an important component in the life support systems of the planet in that it screens all life forms from harmful solar ultraviolet radiation.

The discovery of the atmospheric chemistry of the chlorofluorocarbons, followed just over a decade later by the discovery of the seasonal ozone hole over the Antarctic and its chemical explanation, spurred governments all over the world to enter into a treaty to reduce CFC emissions.[79] In response, the Montreal Protocol of 1987 and its subsequent amendments have led to sharply decreased emissions of CFCs and other ozone-destroying compounds, including brominated chemicals such as halons. Atmospheric amounts of several of these key compounds are now observed to be decreasing.[80] However, data on total stratospheric ozone amounts do not yet clearly demonstrate recovery of the ozone layer.

Increasing Greenhouse Gases—A Warmer Climate

Greenhouse gases, which include carbon dioxide (CO_2), nitrous oxide (N_20), methane (CH_4), and halocarbons (CFCs, HFCs, PFCs), are expected to modify the earth's climate, with effects unfolding over time scales of decades to centuries.[81] These gases have increased steadily with the use of fossil fuels over the course of industrialization, with a total increase in CO_2 of more than 30 percent over preindustrial levels in the past century and a half. Ninety percent of energy sold today comes from fossil fuels.[82] Total energy use has tripled in the past 50 years, with the share from nonfossil fuel sources slowly rising as the use of nuclear generators and hydropower has increased.

While carbon dioxide and methane increases are expected to have the biggest impact on climate, some of the most uncertain aspects of climate change are the direct and indirect radiative effects of sulfate and carbonaceous aerosols (particles) in the climate system and their related impacts on tropospheric chemistry and human health. These particles enter into the processes forming clouds, which result in more reflection of solar radiation and more absorption of the infrared radiation. The magnitude of this effect is uncertain but is believed to be substantial. The increase in global average surface air temperature from 1860 until the present is shown in Figure 2.4. Recent decades are the warmest in the instrumental record. The global temperature increase is generally consistent with

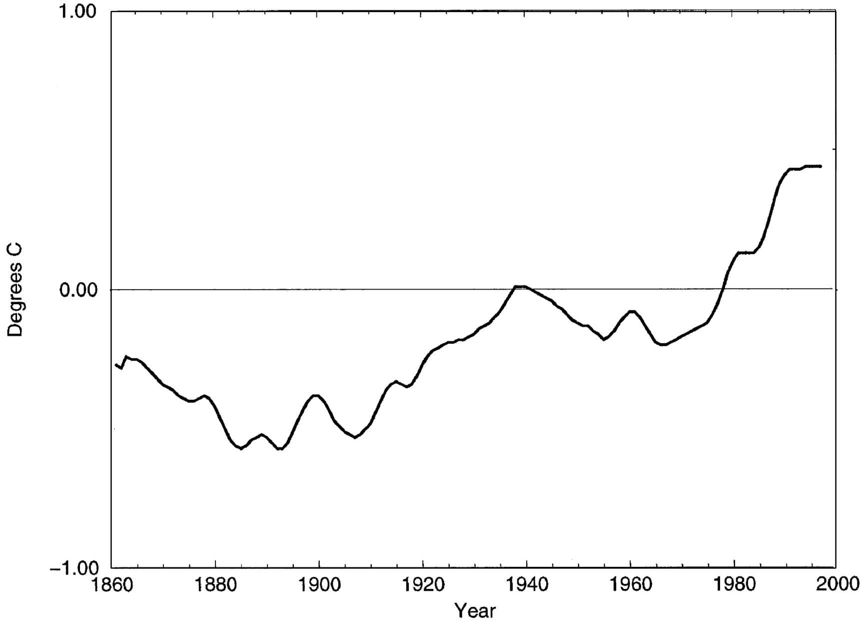

FIGURE 2.4 Annual global mean temperature for land areas from 1861 to 1997. The curve shows anomalies with respect to the mean temperature for the 30 years 1961-1990.
Source: Global Historical Climatology Network (GHCN); Peterson and Vose (1997). Courtesy of the National Climatic Data Center.

climate model calculations of the combined effects of the observed increases of greenhouse gases and aerosols. Because of the long atmospheric lifetimes of most greenhouse gases and the thermal inertia of the oceans, it is widely acknowledged that even rapid reductions in contemporary greenhouse gas emissions would still leave the world committed to significant climate change at an average rate of warming greater than any seen in the last 10,000 years. Of course, most places on earth would not experience the global average. Rather, they would likely experience more extreme weather patterns of variation due to the regionality of climate and sea level change and the impacts of natural variability at the annual to decadal scale. These changing finer scale patterns cannot now be predicted with confidence, but could eventually entail significant changes in the frequency of heat stress episodes, the severity of droughts, and the competitive balance among species.[83]

Increasing and Decreasing Regional and Local Air Pollutants

Industrialization has been accompanied by increases in air pollution, mainly from the combustion of fossil fuels. These pollutants are mostly redeposited locally, although there are important cases of long-distance transport of pollutants by horizontal and vertical winds. Tropospheric ozone—the ozone in the lowest and densest part of the atmosphere where humans live—is produced by the oxidation of many precursor gases, including carbon monoxide, nitrogen oxides, and hydrocarbons. Other important pollutants, including oxides of sulfur and aerosols such as soot, result from the burning of coal and oil. As noted above, some of these pollutants have been successfully managed regionally as income levels have risen.

Over the past century, as industrialization has spread from the OECD countries into the developing world, measured amounts of ozone at the earth's surface and throughout the troposphere have increased and then stabilized, as pollution-control technology has been developed and adopted. These trends slowed and/or vanished in North America and Western Europe during the 1980s and 1990s.[84] By contrast, tropospheric ozone amounts continue to increase over Japan. The likely cause is increasing emissions of ozone precursors, principally nitrogen oxides and carbon monoxide from combustion in China, Taiwan, Korea, and Japan.[85]

Similar patterns have been observed in sulfur and nitrogen compounds, the principal pollutants in acid rain.[86] In at least one advanced country, data show that reduced sulfur dioxide emissions have led to decreased amounts of sulfate in atmospheric aerosols (and presumably to decreased precipitation of sulfuric acid). Researchers[87] reported that aerosol sulfate measurements from 1979 to 1996 at Whiteface Mountain and Mayville in New York declined about 45 percent and 30 percent respectively, from corresponding amounts averaged over the period from 1981 to 1991. During this time, upwind emissions of SO_2 from the U. S. Midwest declined by about 35 percent.

The data records are less clearly interpreted for carbon monoxide in the troposphere.[88] Measurements of CO in surface air show decreases in the early 1990s, and globally averaged amounts have decreased by 2 to 5 percent per year.[89] The cause of this decrease is not clear.

For a Sustainable Future

It has been possible in some instances to manage pollution of the atmosphere so that damage is stabilized or even reversed. This is taking place at the global scale with stratospheric ozone, at the regional level for acid rain in Europe, and in numerous urban areas via regulation and pollution control technology. That pollution control has been possible in these instances does not, of course, assure sustainable future conditions in the atmosphere, but clearly shows the direction of what is possible. In the short run, however, air quality conditions continue to worsen in a large number of areas, especially in Latin America and Asia.

There is a large international research and monitoring effort to study the atmosphere and its modification by humans. Most of the expertise is concentrated in the developed countries, however, and an important element of a transition toward sustainability will be continued effective transfer of scientific and technical resources to developing countries.

Managing climate change in a sustainability transition will have to account for the trend of rising energy consumption, together with the predominant role played by fossil fuels up to now. Large-scale departures from that trend will entail far more than a new technology, including global markets and infrastructures to handle new means of generating energy and to integrate them into existing technological systems and markets. In response to the 1992 Framework Convention on Climate Change goal (see Chapter 1) of stabilizing "atmospheric concentrations of greenhouse gases at a level which would prevent dangerous human interference in the climate system," governments have so far only adopted the near-term objective of stabilizing emission rates. This means that the atmospheric concentrations of greenhouse gases will continue to grow. While scientists cannot predict exactly the impacts of such trends, persistent addition of greenhouse gases to the atmosphere is very likely to make achieving a sustainability transition harder. The changes in energy use required to substantially mitigate the risk of global climate change will require considerable changes in existing infrastructure and institutions. Comparably significant changes may be required to reduce the vulnerability of societies to such climate changes that do occur.

Oceans[90]

Stable Oceans, Changing Coastal Zones

Although humans have intensively exploited fish and other living resources, mined minerals, and released pollutants, the open seas have so far been relatively less affected by human activities.[91] This fact is a reflection of the size of the world ocean, which covers 71 percent of the earth's surface, and the relatively modest presence of humans on the seas so far. An important exception is the status of some high seas fisheries (e.g., swordfish and orange roughy) which are harvested at unsustainable rates; and many estuaries, coastal zones, and confined seas have been degraded or extensively modified, with few instances of successful recovery. Also, the effect of long-term changes in atmospheric forcing on oceans, as perhaps may be seen in the recent greater extremes of El Niño and the widespread environmental consequences, is increasingly of concern.

Humans have extensively altered coastal zones, largely as an indirect effect of developing adjoining land and littoral areas.[92] As the near-coastal human population, including the residents of most of the world's megacities, continues to increase, these effects will increase. In addition to residents of the coastal zone, many additional people flock to the coast for recreation and tourism, increasing the environmental pressures from roads, commercial development, waste disposal, marinas, and other recreational facilities. The resources of coastal ecosystems are very often intensively exploited for seafood and energy resources.

Coastal ecosystems are often affected by activities that occur far inland, through changes in the delivery of water, nutrients, and chemical contaminants from rivers and atmospheric deposition.[93] Large areas of important coastal waters such as the Chesapeake Bay, the northern Gulf of Mexico, Long Island Sound, and Lake Erie, in the United States and the North Sea and the northern Adriatic Sea, in Europe have experienced increased plankton blooms and depletion of dissolved oxygen as a result of nutrient overenrichment from both point-source (sewage discharges) and diffuse inputs (agricultural and urban runoff and atmospheric inputs) during the latter half of this century. At present, coasts are affected by the continued rise in sea level worldwide, at about 1.8 mm per year for over a century. These values are an order of magnitude greater than the average experienced over the last few millennia.[94] This worldwide rise, if combined with local land subsidence, results in a large local rise in relative sea level, flooding of coastal areas, and increases in beach erosion. Also, coastal environments are among the areas most susceptible to the consequences of global climate change that could affect sea level, freshwater runoff, frequency and intensity of storms, and temperature patterns.[95]

Other longer term physical and biological responses of the oceans to climate change are possible, including the disruption of North Atlantic deepwater formation, a condition that has been associated with significant climate variability in the past, and the effect of warming polar oceans on sea-ice melting, which can alter ecosystem processes including primary production.

Declining Valued Marine Fisheries

The human impact on marine life was long assumed to be small because of the great numbers of species in the oceans and their large populations. This view has been proven wrong as fisheries around the world have been overexploited during the last 40 years.[96] In the United States, approximately one-third of those species whose status is known are overfished.[97] Studies in marine ecology and fisheries demonstrate that humans have caused at least local extinctions, together with many other ecosystem modifications that are difficult or impossible to reverse.[98] Along with the declines in catch, it is likely that ecosystem impacts caused by humans are increasing in severity.

Current levels of fisheries overexploitation are associated with the failure of fishery management to contain human fishing pressures within sustainable limits.[99] Fishery failures are usually attributable to direct causes, including a lack of political will, scientific uncertainty, destructive fishing practices, and excessive levels of fishing capacity that create pressure to abandon conservative levels of exploitation. The 1996 passage of the Magnuson-Stevens Fishery Conservation and Management Act in the United States introduced a number of more conservative elements into the U.S. federal fisheries management system, including a requirement to eliminate overfishing, to define and protect essential fish habitat, and to reduce bycatch.[100] The next reauthorization, due in 2000, is likely to further broaden the precautionary approach to fisheries management and to strengthen coordination with other statutes that protect marine species.

Human activities affect marine species indirectly as well, notably through the degradation or modification of habitats used by marine species at some point in their life cycles. Pacific salmon, for example, a migratory species that spawns in freshwater, has been substantially affected by logging, grazing, farming, urbanization, and dams in the U.S. Pacific Northwest.[101] More generally, sedimentation and pollution resulting from the large-scale conversion of land and coastal regions to human purposes (e.g., conversion of mangroves to rice farming) have affected coastal areas and the composition of river waters (e.g., runoff from poultry farms as in Chesapeake Bay) flowing to the sea. These actions have affected the abundance and diversity of marine life through changes in the quantity of coastal wetlands and the quality of estuarine waters, a primary source of marine productivity.[102]

Fishing itself can affect marine ecosystems, especially the habitats of fish and other marine species, by changing bottom topography and associated benthic communities. Large-scale changes in coral reef ecosystems in the Caribbean and in community structure in the Bering, Barents, and Baltic seas, on Georges Bank, and in other regions have been attributed to fishing. Together with increasing introductions of exotics and increasing pollution, fishing and other human activities will continue to effect the loss of goods and services from marine ecosystems.[103]

For a Sustainable Future

Although the open seas have been modified comparatively little by human activity, there are serious problems that need to be addressed for a successful transition to sustainability, including the unsustainable harvest of some marine fisheries. There is no indication that humans will moderate their transformation of the nearshore marine environment. Coastal zones, along with tropical forests, are the regions of the earth currently undergoing maximum human transformation. The trend of the marine environment is, in sum, one of continuing human modification, much of it inadvertent.

Despite serious attempts at conservation and management[104] the unsustainable use of fisheries persists, sometimes until the fishery collapses economically. For decades, scientists have called for managing fisheries from an ecosystem perspective, and some steps have been taken in this direction that appear to be feasible in some fisheries.[105] In many other instances, the appropriate application of ecosystem concepts remains difficult or impossible under current institutional conditions.[106] Sustainability of the oceans will above all require an integrated and adaptive ecosystem-based approach to management, incorporating such elements as conservative single-species management, reductions of excess fishing capacity and assignment of fishing rights, establishment of marine protected areas and appropriate institutions, consideration of bycatch and discards in fishing mortality estimates, and other information needs.[107] Such an approach may help to ensure the production of goods and services from marine ecosystems, and, at the same time continue to provide food, revenue, and recreation for humans.[108]

Fresh Water[109]

Slowing Global Withdrawals, Regional and Local Scarcity

From 1940 to 1990, withdrawals of water for human use (i.e., removals from a natural source for storage or use) increased by more than a factor of four, reflecting a long-term trend of increasing withdrawals per capita.[110] The rate of withdrawal, an average of 2.5 percent per year, has been more rapid than population growth. Per capita availability of fresh water on a global basis fell from 17,000 m^3 in 1950 to 7,300 m^3 in 1995,[111] while per capita freshwater demand rose until the mid-1980s.[112] One result was a large global investment in and construction of dams and transport systems. However, since the mid-1980s, absolute water withdrawals have slowed and per capita water withdrawals have declined worldwide.[113] In the United States, water withdrawals in 1995 had declined nearly 10 percent from their highest level in 1980. In fact, actual global water withdrawals have been consistently less than estimates of withdrawals predicted between 1967 and 1996.[114] Nevertheless, with increasing population growth, there is no reason to be complacent about water withdrawals.

Although fresh water is a renewable resource (through groundwater recharge, surface runoff from local rainfall, in-flow from nearby regions) and global water supplies are abundant, regional water resources are unevenly distributed among countries, and local supplies or stocks are finite. In some areas with low supply, the continued high withdrawal causes serious local water shortages and harm to aquatic ecosystems.[115] Nearly one-third of the world's population is found in countries stressed by pressure on the availability of water resources (i.e., consumption levels that exceed 20 percent of available supply).[116] The unmet demand in developing countries for household water use remains high—nearly 1.2 billion people do not have access to safe and reliable water.[117] Developing countries that have both high water stress and low per capita income have the greatest potential problem of unmet demand, because they use most of the available water for intensive farm irrigation, have few financial resources to shift investment from irrigation to other sectors, and have few pollution controls.[118] Thus, most of the nations especially vulnerable to water scarcity are located in the arid or semiarid regions of Africa and Asia and the Middle East.[119] Altogether, 26 countries—approximately 232 million people—are considered "water scarce."[120]

While water is a renewable resource because of the characteristics of the hydrologic cycle, various human actions can lead to nonrenewable or unsustainable water use. Groundwater aquifers can be pumped faster than the rate of recharge,[121] leading to declining aquifer levels, land subsidence, or, in coastal areas, contamination from salt water intrusion. Similarly, land use and landscape modifications can affect both the quality and quantity of water in a watershed that is available on a renewable basis.

If treated properly, water can be reused so that withdrawals alone do not accurately measure the degree of human pressure on water resources.[122] As the quality of water declines because of increasing water contamination (e.g., from human settlements, industry, and agriculture) and land use changes (e.g., from practices that enhance water runoff from the surface, such as clearing forests or paving roads), however, water supply declines. Competition for scarce water resources, especially between rural and urban users, is increasing, with potentially serious implications for food production as urban areas with greater political strength will tend to out-compete local farmers.[123]

Where water is abundant, economic growth has been accompanied by the expansion of infrastructure to transport fresh water and wastewater. Methods of treating wastewater to render it clean enough for reuse by human settlements downstream have also been developed, usually after a delay of decades.[124] Water is expensive to transport, and the large capital investments required to move water usually dictate wells and recycling when there is not enough surface water at hand. Meeting the needs of development in such regions of surface water scarcity requires that water come from wells, sometimes from nonrenewable aquifers, from distant rivers and, more recently, from careful husbanding and recycling.[125]

Shifting Usage, Declining Quality, Increasing Efficiency of Use

As countries have industrialized, there has been a shift in water usage from agriculture to industry, commercial activity, and households, with domestic consumption increasing greatly with increasing affluence.[126] This trend is expected to continue with the share of agricultural use of water declining, though the amount of water use in agriculture is expected to increase with increasing worldwide demand for food, especially in developing countries.[127]

Water use per person appears to rise with income to a point beyond which additional income per capita leads to declining per capita water use in households and industry. But water use per capita is not in direct proportion to national income, because increased use in one sector (industry) may be offset by decreases in another (agriculture) in the course of development. Increased efficiency in water use can play an important role. In recent years, rising per capita income in higher-income developing countries is correlated with lower per capita consumption of water in industry and households.[128]

Water quality has steadily improved in most of the developed countries because of regulatory controls and investments in water treatment and sanitation. However, water quality in developing countries is declining, especially in urban areas, because of rapid industrialization and increased contamination by toxics.[129] In many areas of the world, water withdrawn for human use is groundwater from wells and natural outlets. Industrial toxins, if not carefully controlled, can spill and enter aquifers, contaminating groundwater. Where groundwater reserves are a major source of water supply (e.g., 50 percent of domestic supplies in Asia), expanding mining or industrial development can lead to problems of contamination.[130]

Water is a basic human need and the failure to provide clean drinking water and sanitation services to all is one of the most fundamental failures of development in the 20th century. As of 1994, according to the UN, 1.2

billion people lacked access to clean drinking water, while nearly 3 billion lacked access to sanitation services. This failure to meet basic human needs for water causes between 5 and 10 million deaths a year, mostly of small children and the elderly, from water-related diseases. Some efforts to eradicate water-related diseases have been successful. For example, guinea worm (dracunculiasis), which is a parasitic disease that can be eliminated through providing clean drinking water, is on the verge of elimination in Africa and Asia where it used to be prevalent.[131] Cholera is not as easily eradicated with improved water supply, but it can be prevented by removing the bacterium with sewage and water treatment and treated by oral hydration therapy. However, fatality rates are often high in parts of Africa and Asia because of the lack of treatment facilities and preparedness.[132] In 1991, an extraordinary spread of cholera in Latin America has been linked to dumping of contaminated bilge water from a ship in the harbor in Lima, Peru, the lack of adequate facilities for providing clean water and sanitation, and the increase in algal blooms resulting from the warmer water, heavier rain and higher nutrient runoff associated with El Niño.[133]

For a Sustainable Future

In a transition to sustainability, water use seems likely to rely increasingly on efficiency in use and supply, closed cycles, more effective means of preventing and controlling water pollution, and more appropriate water pricing.[134] These trends also imply more efficient use of energy, the continuing decline in the construction of large projects, and increasing innovation and use of water-saving technologies. Thus, the stresses on water accessibility and use will require that water use must grow evermore efficient and that balances must be struck to achieve a successful sustainability transition. For example, water could increasingly be a source of conflict between users (agriculture, industry, households), between ecosystems and regions (uplands, flood plains, dam sites, cities), and nations (Middle East, Nile valley, South Asia) in places of potential regional and local scarcity. Where hydrological systems match regions rather than national boundaries—for example, in the Middle East—efforts are needed to forge regional plans for water resources.[135]

Land[136]

Increasing Intensification of Agriculture

Over the past 300 years, land planted with agricultural crops has increased nearly fivefold, to about 15 million km^2 .[137] This net increase in cropland has been accompanied by a net decrease of forested land of similar magnitude. Another vast area of land has been lost to productive use since the emergence of agriculture 10,000 years ago, as a result of erosion, salinization of irrigated lands, desertification, and permanent conversions of arable land to cities, roads, and reservoirs. During the 20th century, the rate of loss of productive land has accelerated sharply, to a rate of 70,000 km^2 per year, an annual loss the size of Sierra Leone.[138] An underlying factor in the acceleration of farmland conversion to nonagricultural use is that, with a rapidly growing economy, the market value of land for alternative use is growing at a far faster pace than its value for agricultural productivity. Except for a very elite set of crops, the value of land for photosynthesis will be less than for most alternative uses, considering the cash and energy flows through most nonagricultural enterprises per unit of land.

The discussion of hunger earlier in this chapter records an extraordinary achievement of the 20th century rising agricultural outputs that have outpaced human population growth and dramatically reduced the incidence of famine. This advance has been accomplished over the last 50 years by the large-scale application of scientific and practical knowledge to farming, with dramatic results in many poor nations such as India and economically impressive rises in agricultural production in rich countries such as Australia and the United States. The intensification of agriculture has been rooted in the identification, development, and widespread adoption of high-yielding varieties of cereal crops, the use of fertilizers and mechanized equipment in developing countries, and irrigation. High-yield varieties and fertilizers form the foundation of the Green Revolution in Asia and Latin America.[139] The declining real cost of food for the past several decades, associated with more efficient agricultural production, has increased food accessibility, thus reducing the incidence of famine.[140] An additional benefit of the increasing intensification of agriculture may be that, by lifting global yields by 1.5 percent per year over the period of a transition to sustainability, approximately one-quarter of the 1.4 billion hectares of cropland can be spared for nature.[141]

However, although the world has come to depend on these enhancements in food production, it is unclear whether they are sustainable.[142] In future decades, the food supply must continue to expand within a range set by basic needs, expanded incomes, and dietary preferences, and at the same time, it must do so with reduced environmental consequences. High-productivity agriculture is built on the use of monocultures, often of genetically identical plants, nourished by irrigation water and fertilizers, protected by pesticides, all delivered by technological and market mechanisms managed and paid for by humans.[143] Many such ecosystems are difficult to sustain because of several factors. The low species diversity and high concentration of nutrients provides a setting that favors specialized predators and weed species. Biological regulation by soil organisms is altered, so that decomposition is interrupted and additional nutrients must be supplied. And the application of water and fertilizer during times when growing crops cannot use them leads to waste and pollution.[144] Technologies that minimize erosion, water use, salinization, chemical pollution, and other environmental damage are available, but have not been broadly utilized.[145]

Clearing of Tropical Forests, Regrowing Temperate Zone Forests

Forests currently cover approximately 40 million km^2, about three-quarters of their area before the emergence of agriculture.[146] They occupy more than twice as much land area as agriculture and harbor two-thirds of all plant species.[147] Traditional agro-ecological economies remain both widespread and significant in the tropics; forests are home to millions of people who combine subsistence agriculture on small plots with hunting, gathering, and commercial harvest of materials from the surrounding forest. In temperate zone countries, including parts of China, Russia, and the United States, many forests have regrown during the 20th century, both through deliberate replanting and as agricultural lands have become uneconomical to farm. However, these increases are more than offset, in terms of area cleared or wood cut, by deforestation in tropical countries and land clearing in response to the prices of land for nonforest uses.[148]

Forest land is cleared for many reasons—for timber, during mining, and to make land available for agriculture. Data on rates of deforestation are sometimes controversial because of the difficulties in obtaining data in many regions of the world, but the estimated gross global deforestation rate is roughly 100,000 km^2 per year, yielding 5 billion m^3 of wood and fuel.[149] Forest soils and standing timber are major storehouses of carbon, and the steady removal of carbon dioxide from the atmosphere by long-lived forest plants is a substantial counterweight to the burning of fossil fuels.[150] Forests also provide countless other goods and services; some of these goods, like cacao, play important roles in world markets, while others, including watershed services and medicinals, are valued only by localized human populations. If the rainforests were, for example, an extremely rich and valuable source of pharmaceutical precursor opportunities as many believe, their preservation should be assured by market forces which would not allow their destruction. Unfortunately, to date, they have been only occasionally such a resource.[151] Thus, while the management of forests for specific goods or services ranges from tightly regulated in some instances to uncontrolled in others, it is evident that managing for sustainable, multiple-purpose use of forestlands remains elusive.[152]

For a Sustainable Future

Over the past 50 years humans have altered the earth's lands substantially. To the benefit of our species, agricultural output has been raised dramatically and the regrowth of cleared forests has dominated landscapes in some regions. Much of the increased agricultural output takes place on existing cropland through intensification of production, thus releasing more marginal land for forest and grassland regrowth and reducing further land conversion. But these gains must be seen against the risks and losses of the past half-century. Decreases in tropical forest area and the intensification of agriculture both result in stresses on biodiversity and on ecological systems. Some of these stresses—for example the loss of soil organic matter and of pollinator species, and the changes in biogeochemical and hydrological cycles—are not visible to the casual observer, but their long-term consequences for life support systems warn that a sustainability transition is likely to require wide-ranging shifts in the values ascribed to land and the way people manage its living resources.

Species and Ecosystems[153]

Decreasing Diversity, Increasing Invasions

In the geologic record, paleontologists have found five mass extinction events, each of which drastically reduced the number of species on earth. Each time, enough life forms survived to repopulate the earth's waters and lands. The impact of human activities on the planet has now accelerated the loss of species and ecosystems to a level comparable to a sixth mass extinction.[154] This loss of species diversity is the first driven by a living species.

Rates of species extinction have been estimated to be 100 to 1,000 times as high as before large-scale human dominance of ecosystems.[155] Today, 11 percent of birds, 18 percent of mammals, 5 percent of fish, and 8 percent of plant species are threatened by extinction.[156] These rates of loss are driven primarily by the alteration of natural habitats. In a given region, the loss of species can be much higher than the proportional loss of land area if habitats are fragmented by roads or other human clearings that isolate patches of unconverted land. Depletion of species in these remaining patches can be delayed, but is still inevitable in the absence of human intervention.

In addition to causing extinctions, human activities also introduce species into ecosystems in which they have not been present. In some situations, these so-called exotic species proliferate, and the introduction of a new species can transform the ecological relationships of habitats and further stress endangered species. For example, an estimated 20 percent of the world's endangered land vertebrates are threatened by invading exotic species.[157] Biological invasions of this kind are usually inadvertent, but their frequency can be high. Introduction of exotic aquatic species by human action, often accidentally, such as transporting a species to a distant location in the ballast water of ships, has affected the species composition of heavily traveled coastal areas and bays.[158] For example, in San Francisco Bay, California, an average of one new species has been introduced every 36 weeks since 1850, a rate rising to every 12 weeks over the past decade.[159] As a result, the life-forms visible to humans in that bay are predominantly nonnative.

Efforts to prevent or control the transfer of exotic species across marine ecosystems are rudimentary, although there has been some progress since the problem came to light more than a decade ago.[160] Such accelerating rates of depletion and change will not continue for long: habitats are finite and the loss of species is irreversible. Efforts to slow rates of depletion and change require recognition of the value of the system or what is lost when replaced by exotics, whether in terms of provision of resources and services or on aesthetic or ethical grounds, as well as recognition of the potential economic and environmental costs of invasive species. Yet the value placed on species and ecosystems has been historically uneven. A very small suite of edible and useful species has been valued, conserved, and propagated by humans. These number in the thousands out of tens of millions of species. The far larger ecological assemblages within which these well-known, valuable species live have been neither understood nor managed.

In a small number of cases, endangered species have recovered when protected by human efforts. For example, the bald eagle and marine mammals in North America have rapidly rebuilt their numbers and many populations of marine mammals worldwide are recovering. These recoveries have taken place under conditions where habitats required by the species were either intact or readily protected and where there the public will to preserve or conserve them was strong. Such circumstances do not currently apply to most regions of the world where species are threatened.

Losses of Ecosystems and Ecosystem Services

Just as land conversions and land degradation can lead to losses of species, these trends affecting species can result in degradation or loss of ecosystems and ecosystem services. On a global basis, freshwater, coral reef, and forest ecosystems (the latter just discussed under "Land" above) have suffered enormous assault from human activities.

Covering less than 1 percent of the earth's surface, freshwater ecosystems have lost the largest proportion of species and habitat when compared with other ecosystems on land or with the oceans.[161] Increasing trends of overfishing, dam building, river development, and contamination, as human activities expand, will continue to place greater threats on freshwater ecosystems.[162] Many estuaries and bays have deteriorated because of activities associated with land development as well as fishing pressure, with resulting declines in ecosystem services. For example, the depletion of the oyster population in Chesapeake Bay through overexploitation has had a profound effect on the Bay—the oysters once filtered a volume of water equal to that of the entire bay about once a week; they now filter that volume in about one year's time. This circumstance has adversely affected the water quality of the estuary and has impacted many species that live in it, including those consumed by humans.[163] Similar human development along coasts, together with associated pollution from agriculture and other land-based sources and harmful fishing practices, has caused 58 percent of the world's coral reefs to be in jeopardy of loss, changes in species composition, or other major ecosystem effects.[164] These losses challenge the livelihood of local communities that depend on the reef for food, tourism, and protection against damaging storms. For global forests, expanding populations, together with the increasing need for fuelwood and land for agriculture, have resulted in a net loss of some 180 million hectares between 1980 and 1995. Despite reforestation efforts, the rates of deforestation remain high in many areas of the world.

The decrease and decline of freshwater ecosystems, coral reefs, and forests represents incalculable losses of ecological services, including the recycling of nutrients, water, and wastes; the mitigation of climate and temperature extremes; the management of watersheds; and the support of local communities and cultures.[165]

For a Sustainable Future

Without active efforts to conserve biodiversity, pinpoint the vectors of and control bioinvasions, and protect natural ecosystems, the trends of increasing loss of species, ecosystems, and ecosystem services will continue and threaten both the long-term stability of ecosystems and the quality of life for humans that depend on those systems for their livelihood. For a sustainable future, efforts will be needed to strengthen the barriers to the free flow of species given growing global trading, to avoid intentional introductions of exotics, to protect and preserve ecosystems as well as endangered or threatened species, to improve mechanisms and information systems for detecting changes and assessing threats, and to promote science for conservation.

Though people have been motivated by aesthetic and cultural considerations to preserve special natural places for millennia, the scientific understanding of conservation biology has taken clear form only in the past decade and a half.[166] As these two currents of human activity converge, there has been growing awareness of the need to conserve ecosystem processes. It is therefore necessary to work at the scale of whole landscapes, with explicit attention both to the preservation of critical ecosystems and to the interactions between human activities and the managed and unmanaged ecosystems among them.[167] An open question for a transition toward sustainability is whether a reformulated idea of conservation of this kind will prove workable in enough places to salvage the biological richness of the planet. Moreover, the ability to assess and monitor the well-being of the earth's living resources and the services they provide is far from proven, yet efforts in those areas will be essential to understand the roles of species and ecosystems for a sustainable future.

Disease Organisms and Vectors[168]

Emerging and Reemerging Diseases

The 1980s and 1990s have seen the emergence of 30 new diseases,[169] the resurgence of "old" diseases (e.g., tuberculosis), and the redistribution of old diseases on a global scale (e.g., cholera). These trends are in large part related to human activities associated with land use, especially agricultural practices; water storage and use (see Fresh Water section for a discussion of cholera), including irrigation; and urbanization. The intensification of agricultural production has not only increased crop yields, but the related practices of irrigation, land conversion, and habitat disturbance have also increased the risk of infectious diseases such as malaria and schistosomiasis. Some 30 diseases have been linked to irrigation practices (e.g., malaria and Japanese encephalitis with Asian paddy-rice agriculture, mosquito-borne diseases with farming in Central and South America).[170] The incidence of schistosomiasis is believed to have risen over the last 50 years because of the expansion in irrigation systems in hot climates.[171] A tripling of the prevalence of schistosomiasis in Ghana in the late 1950s and early 1960s is believed to be related to the construction of agricultural impoundments which provide habitat for the intermediate host organism.[172]

Forest land conversions have been associated with higher incidences of malaria and leishmaniasis, through habitat creation conducive to tick and other insect vector breeding. The forest fringes are places where contact between disease organisms and human populations are most efficient in disease transmission. [173] Rising surface temperatures associated with deforestation in Africa are believed to be responsible for accelerating the life cycle of the mosquitoes.[174]

Although commonly believed to be a disease of the past, nearly 3 million people died from tuberculosis in 1995, an indication of the continuing influence of the disease with increasing poverty and homelessness in urban areas, and the importance of multidrug resistance.[175] With an apparent leveling off in 1996, the TB epidemic is expected to continue to pose human health problems for developing countries.[176]

In addition to infectious diseases, a series of new diseases of chemical origin have emerged worldwide in recent decades. There have been dramatic episodes of such disease, for example, the disaster at Bhopal where several thousand persons were killed by acute exposure to the pesticide intermediate toluene diisocyanate (TDI). Also, there are chronic lower level exposures of populations to chemical toxins such as organic mercury, which has the power to damage the nervous system; benzene, which causes cancer; and polychlorinated biphenyls (PCBs), which can impair infant development. New diseases of chemical origin are often first seen in populations occupationally exposed to toxic chemicals, inasmuch as exposures in these groups are typically heavier than in the general population and occur earlier than in the population at large.

For a Sustainable Future

The emergence and reemergence of infectious diseases have important implications for sustainability, especially with expanding populations in areas where diseases are expanding. There will be an enormous challenge to containing the spread of disease while transportation and trading systems grow and while human populations grow and expand into new ecological settings, thereby establishing contact with previously isolated microbes and other infectious agents. Clearly, better systems of surveillance and recognition of emerging diseases are needed, coupled with integrated modeling and the use of geographically based data systems, and also measures for intervention (vaccine and drug development, vector control, and education) to manage future outbreaks.[177] These approaches will enable the medical community to take more anticipatory approaches and help optimize preventive strategies.[178] Also, better management of the interactions between humans and the environment, especially changes in agricultural practices and water management, will be needed to ensure a sustainable future.

CONCLUSIONS

Based on our analysis of persistent trends and transitions, the Board concludes that **certain current trends of population and habitation, wealth and consumption, technology and work, connectedness and diversity, and environmental change are likely to persist well into the coming century and could significantly undermine the prospects for sustainability. If they do persist, many human needs will not be met, life support systems will be dangerously degraded, and the numbers of hungry and poor will increase.** Some of these current trends present significant opportunities for advancing a transition toward sustainability, as well as threats to that transition. All, however, bear watching. Among social trends the Board reviewed that may merit particular attention in efforts to navigate a transition to sustainability are expanding urbanization, growing disparities of wealth, wasteful consumption, increasing connectedness, and shifts in the distribution of power. Environmental trends of special concern include the buildup of long-lived greenhouse gases in the atmosphere and associated climate changes, the decline of valued marine fisheries, increasing regional shortfalls in the quality and quantity of fresh water, expanding tropical deforestation, continuing losses of species, ecosystems, and their services, the emergence and reemergence of serious diseases, and more generally, the increasing human dominance of natural systems.

Even the most alarming current trends, however, may experience transitions that enhance the prospects for sustainability. Trends are rarely constant over time. Breaks or inflections in the long-term trends mark periods of transition. Transitions relevant to the prospects for sustainability are already underway to varying degrees in specific places and regions around the globe: the demographic transition from high to low birth and death rates; the health transition from early death by infectious diseases to late death by cancer, heart disease, and stroke; the economic transition from state to market control; the civil society transition from single-party, military, or state-run institutions to multiparty politics and a rich mix of governmental and nongovernmental institutions. Environmentally, some significant positive transitions have occurred in specific regions. These include shifts from increasing to decreasing rates of emissions for specific pollutants, from deforestation to reforestation, and from shrinking to expanding ranges for certain endangered species.

Individual, local trend reversals such as these clearly do not make a sustainability transition. But they do show that efforts to catalyze or accelerate relevant shifts can have significant implications for meeting human needs in ways that sustain the life support systems of the planet.

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ENDNOTES

1 This discussion applies generally to both quantities and rates of change in quantities of interests (e.g., population size and population growth rates). Depending on circumstances, the transitions or breaks of interest may reflect either first or second derivatives for the quantity in question.
2 UN (1997a).
3 Speth (1992).
4 Gell-Mann (1994).
5 UN (1999).
6 Bongaarts (1994); Bongaarts and Bruce (1997).
7 See UN (1994a, 1999).
8 UN (1999).
9 UN (1999).
10 National Research Council reports (for most recent list and full texts, see http://www.nap.edu) related to trends in urbanization include:

Clean Air and Highway Transportation: Mandates, Challenges, and Research Opportunities. Transportation Research Board. (1997).

Managing Wastewater in Coastal Urban Areas. Committee on Wastewater Management for Coastal Urban Areas. (1993).

Meeting Megacity Challenges: A Role for Innovation and Technology. Committee on Meeting Megacity Challenges. (1999).

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Transit-Focused Development. Transportation Research Board. (1997).

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Urban Policy in a Changing Federal System. Committee on National Urban Policy. (1985).

11 UN (1999).
12 UN (1998).
13 Beckman (1988); WRI (1996), p. 151.
14 WRI (1996).
15 Beckmann (1988).
16 UN (1995).
17 WRI (1996), pp. 8-9; UN (1995).
18 UNDP (1995), pp. 134-35.
19 UNDP (1995), Ch. 1.
20 World Bank (1999).
21 UNDP (1995), Ch. 3.
22 Rostow (1961).
23 Ausubel and Herman (1988).
24 National Research Council reports (for most recent list and full texts, see http://www.nap.edu) related to wealth and consumption include:

Environmentally Significant Consumption: Research Directions. Committee on the Human Dimensions of Global Change. Eds. Paul Stern, Thomas Dietz, Venon Ruttan, Robert Socolow, and James Sweeney. (1997).

Linking Science and Technology to Society's Environmental Goals. National Forum on Science and Technology Goals. (1996).

25 Maddison (1995).

26 UNDP (1996).

27 UNDP (1996), p. 13.

28 Baumol et al. (1994).

29 Bruno et al. (1995).

30 Bacha (1978); Adelman and Robinson (1989)

31 UNDP (1998).

32 NRC (1997).

33 Councils of the Royal Society of London and the National Academy of Sciences (1992). Not all growth in consumption is necessarily resource-depleting, or "less available for future use," or environmentally damaging in that it "negatively impacts biophysical systems in such a way as to threaten human health, welfare, or other things people value." However, there is no readily accepted methodology for separating out resource-depleting or environmentally damaging consumption from general consumption, or to identify harmful transformations from those that are benign. Increasingly, almost any human-induced transformation turns out to be either resource-depleting or damaging to some valued environmental component, or both. At best, there may be methods of separating consumption into more or less damaging and depleting classes.

34 DoE/EIA (1998a,b, 1999).

35 NAE (1997).

36 Wernick and Ausubel (1995).

37 Wernick (1996).

38 National Research Council reports (for most recent list and full texts, see http://www.nap.edu) related to technology and work include:

Automotive Fuel Economy: How Far Should We Go? Committee on Fuel Economy of Automobiles and Light Trucks. (1992).

Bridge Builders: African Experiences with Information and Communication Technology. Office of International Affairs. (1996).

Building an Effective Environmental Management Science Program: Final Assessment. Committee on Building an Environmental Management Science Program. (1997).

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