Chapter 1.2
Trends and transitions

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Population size has increased globally throughout most of human history, stimulating rising demand for environmental resources. This relationship has proven to be so strong that virtually all assessments of sustainability begin with it.[1] Over the last two centuries, however, this driver of environmental change has been joined by that of increasingly high levels of individual consumption. This combination of forces has escalated demands on the environment to unprecedented levels and raises important questions about sustainability. What do current trends in population and human well being imply for those of the environment, informed by insights from past human-environment relationships? Can we bring about a future transition to sustainability, meeting the needs of a much larger but stabilizing human population while sustaining the life support systems of the planet?

This chapter addresses these and related questions. It begins with a review of the three major global transitions in human-environment relationships that have occurred since the appearance of *Homo sapiens*, setting the stage for understanding the broad character of human-environment relationships. The next section summarizes trends in population, human wellbeing and consumption during the latest and most important phase which started with the industrial revolution and continues today. This is followed by an overview of the implications of the recent expansion of demand for environmental services for stocks of natural capital. A concluding section looks ahead and discussed the prospects for completing transitions to sustainability.

2.1 Past Transitions in Human-Environment Relationships

The history of human-environment interactions has been highly nonlinear and consists of three distinct phases (Fig. 2.1).[2] Each phase is associated with major shifts in technology and societal organization (governance and economic systems) that fundamentally changed human-environment relationships and permitted quantum leaps in population and material wellbeing (Table 2.1). These shifts, however, came with the costs of successively rising demands on natural resources and the earth system.

The control of fire and improved stone tools initiated the first phase about 1million BP. Our species spread from Africa reaching a global distribution with an estimated number of 5.32 million circa 12,000 BP and in the process, affecting ecosystems and biota. These were a hardy folk with an estimated life expectancy at birth of 30 years near the end of this phase.[3] They moved throughout Eurasia and into the Australian and American continents as master hunters organized kin-based units. For the most part, their environmental impacts were highly localized with the exception of their likely role in the worldwide eradication of mega fauna during the Late Pleistocene.[4]

The domestication of plants and animals began in earnest by about 12,000 BP. This transition initially led to declines in life expectancy and health, attributed to dietary shifts from meat to cereals and increased exposure to disease vectors owing to compact settlement.[5] Throughout this phase, however, agriculture and permanent settlements increased material possessions and the complexity of social organization. Ultimately, feudal- to mercantile-like economies emerged in concert with city states, nation states, and empires. The sheer numbers of our species increased, as did life expectancy, which rebounded to near 40 years by the mid-1700s.[6] By the turn into the industrial phase, global populations reached about 769 million, with significant increases in the number living in cities, although the majority remained rural (Table 2.1). The demands for food, fiber, wood, and other resources from this population and its consumption triggered major changes in ecosystems worldwide, including deforestation, water flow infrastructure, and soil nutrients.[7] By the 17th century, major redistributions of biota were underway globally, with serious consequences for the environment, especially in the Americas, owing to the late introduction of herd domesticates and draught animals and the plow.[8] Deforestation, among other land changes, was the first major human source of CO_2 in the atmosphere.

The onset of the industrial revolution at the transition into the 19th century marked the beginning of phase three with its various forms of market and command economies. The latest part of this phase, detailed below, has culminated in extraordinary levels of production and consumption of food, goods and services, supporting over 6 billion people—a majority of them urban entering the 21st century—at unprecedented levels of material well being, life expectancy, and other indicators of human well being. Also unprecedented has been emergence of global market economies with powers that transcend the state, and the number of people living in democratic governance systems, with access to global information-communication and supported by international organizations of various kinds This phase also represents a quantitative and qualitative leap in regard to the technological capacity of humankind to affect the environment. Changes have occurred across a range of resources, with major losses in such stocks as tropical forests, fresh water, and biota, while the extensive use of fossil fuels and synthetic compounds are now directly affecting the global biogeochemical cycles (i.e., carbon, nitrogen).[9] Because these cycles involve elements and compounds that flow through the earth system, the release of sufficient quantities anywhere has the potential to affect the earth system everywhere, triggering systemic change, as in the case of global climate warming.[10]

2.1.1 Trajectories and Sustainability across the Phases

The three phases represent markedly different human-environment conditions with distinct consequences for both the human and environmental subsystems. These differences notwithstanding, the trajectories of certain human and environmental conditions have been remarkably persistent across the phases, particularly from the advent of domestication onwards. The resulting pressures on local and regional ecosystems have, however, not led to consistent outcomes, and examples of sustained as well as failed human-environment relationships dot the historic landscape previous to the current stages of phase 3 (treated in detail below).

2.1.1.1 Persistent Trajectories

Globally human population numbers and density rose throughout each phase, albeit under different growth rates. With the notable exception of the initial shift to agriculture, life expectancy increased across the phases as did the proportion of the population with enhanced material consumption, registered in urban settlements, for example. Increasing demands on natural stocks followed these changes as did technological and managerial advances to manipulate nature to provide more food, fiber, and fuel while reducing the vagaries in the production linked to environmental and other types of hazards. Human-induced environmental impacts grew in importance over all phases, but did not accumulate to a global magnitude until phase 3, with the possible exception of the megafauna die-off previous to 12,000 BP (above).[11] These changes involved the sustained burning of open woodlands and grasslands to expand "pasturage" and to increase the nutritional value of grasses for domesticated herd animals. Such interactions expanded globally throughout phase 2 and persist today. The resulting deforestation stands as the principal example of long-term, human-induced environmental change across all phases. The transformation of forests ratcheted into high gear with the expansion of cultivation in phase 2, especially in the mid-latitudes of Eurasia, and it continues today, foremost in the tropical realms.[12] The global reach and magnitude of deforestation was sufficiently large to make this loss the main source of CO_2 emission to the atmosphere generated by human activity until the advent of fossil fuel burning.[13] Phase 3, of course, marked a profound transition to fossil fuel energy and, ultimately, synthetic compounds that would rival nature in the biogeochemical cycles that sustain the earth system.

2.1.1.2 Sustained Relationships

Pre-industrial agriculture with high land-to-population ratios is not especially demanding on the environment and has been sustained for millennia. Examples of such sustainable agricultural practices include slash-and-burn or swidden systems of cultivation in parts of the tropical world and agropastoral and pastoral nomadic systems in arid lands. These extensive types of agriculture, however, cannot sustain large or densely settled populations, let alone produce surpluses sufficient to sustain large urban populations and the high-consumption character of developed economies. Meeting these higher demands requires intensive production, which invariably places high demands on ecosystem services and requires significant human inputs, such as soil nutrients and water. Some of the earliest emerging, intensive systems of cultivation have proven to be profoundly sustainable, supporting large population for millennia. For example, land taken to irrigated rice systems as early as 2500 BCE in eastern China[14] remains productive today, owing to the fine-tuned control of nutrient-rich waters.[15] Historically, such control required large investments in labor upkeep which, perhaps, provided only the slimmest of marginal returns in high-stress conditions.[16] Thus, while densely settled-intensive cropping conditions have been sustained over the long run, at best they have freed only a small fraction of the total population from farming activities.

2.1.1.3 Failed Relationships

If some systems of environmental use have been robust across phases 2 and 3, others have seriously degraded and even collapsed.[17] The demise of the lowland Maya civilization provides a prime example of a cultural collapse caused by environmental change and degradation.[18] Between 850-950 ACE, the Maya culture occupying the base of the Yucatán Peninsula not only collapsed but its densely settled heartlands were largely abandoned, remaining sparsely populated to this day. Proposed causes of this collapse and depopulation include increasing humidity-disease vectors, excessive slash-and-burn practices, and climate desiccation. Of these, recent work on $\delta^{18}O$ from lake cores suggest recurrent wet-dry episodes in the Yucatán, and an extreme arid period coinciding with the Classic Period collapse.[19] Interestingly, the Classic Maya developed through a prolonged period of increasing aridity. By the time of the collapse, however, different types of intensive cultivation with high labor input were practiced throughout the heartlands, resulting in significant deforestation. This apparently changed runoff and evapotranspiration, and perhaps amplified the desiccation in question. Give the size of the population, the stresses on crop production and potable water storage in this karstic terrain must have been large[20], and coupled with prolonged warfare throughout the heartlands, may well have moved the human-environment system towards a tipping point.[21]

Unlike the Maya case, the late twentieth century “death” of the Aral Sea in central Asia constitutes a well documented collapse of a lacustrine ecosystem triggered fully by human action. In this case, decisions made from afar in the command economy of the former Soviet Union converted more than five million ha of land along the sea’s only two tributaries to irrigated cotton cultivation. This decision was made in part to sustain a growing population, but also to gain “hard currency” on the international market, a currency necessitated by the otherwise closed, command economy of the country.[22] Poorly constructed canal systems, and inappropriate use of water and application of chemical inputs exacerbated evaporation and ground water pollution. The sea—which was the fourth largest body of fresh water in the world—rapidly lost 60% of its volume and 50% of its area, and doubled its salinity.[23] The consequences essentially killed the Aral Sea ecosystem and its fishing industry which supported 60,000 people, reduced local rainfall, and escalated various water-related health and respiratory problems for the local population. In this case, the ecological collapse of the sea did not result in a total human-system collapse as irrigated cultivation continues and various measures have been taken to combat human health problems and restore the small, northern part of the sea.[24]

2.1.2 Insights into Transitions

What insights do these examples of sustained and failed human-environment systems in the past offer in regard to current transitions in population, human wellbeing and environmental change? Foremost, our species has long been an agent of environmental change. This agency has increased in scope, magnitude, and pace in concert with major shifts in the human-environment condition, each involving increasing levels of population, consumption, and technology, and increasing complexity in the formations of economies and governance. With a few exceptions, the environmental impacts during phases 1 and 2 were local to regional in scale, and significant differences in the material standards of living persisted across time and space. Phase 3, in contrast, not only has increased the magnitude and pace of all kinds of cumulative change, but it affects the earth system directly through systemic change generated by the expanded use of fossil fuels and synthetic compounds.[25]

The extreme impacts during the third phase, one in which humans sometimes exceed nature as a driver of environmental change, have led some experts to suggest we have entered the "anthropocene".[26] In this phase the combined pressures from human actions have moved beyond impacts on the stocks of natural resources (e.g., arable land, fresh water) to affect nature's capacity to sustain the biosphere from ecosystems to the earth system (Steffen).[27] The conditions of the anthropocene that threaten environmental services, however, also provide opportunities to address environmental concerns without necessarily major negative consequences on human well being.

For these reasons, the reach into history for insights about current ecosystem sustainability must be undertaken cautiously and with appreciation for the antiquity of forecasts about humanity's doomed relationship with nature.[28] Drawing on the examples above, four broad insights seem apparent. First, most of the human-induced trajectories of environmental change that began in Phases 1 and 2 have been sustained and escalated into Phase 3. Slowing the rates of change, at least in terms of their impacts on ecosystem services, is crucial to attain sustainability in the future. Second, notwithstanding the longevity of sustainable systems of intensive cultivation, such a wet rice production, without modern inputs such systems are incapable of delivering the produce required by contemporary and future societal demands. Third, some regional environmental collapses in the past apparently involved high-stress production systems that encountered rapid environmental shifts, such climate change, with social conditions ill-suited to respond to the change. The spike in aridity that led to the collapse of the Maya, for example, occurred during a prolonged phase of regional warfare that surely played havoc with their labor intensive systems of production and water storage. Lastly, inappropriately applied technology, enforced by socio-political structures insensitive to environmental consequences, can rapidly destroy complete ecosystems, as exemplified by the Aral Sea case. Phase 3 capacities to counter the economic and health repercussions of such disasters, however, have prevented or at least stalled a collapse of most human subsystems.

What do these insights bring to bear on the current human-environment condition, for example contemporary intensive agriculture? These cropping systems produce at unprecedented levels that surpass biological demand and support high-end consumption.[29] While concerns about the biophysical limits of plant production are real,[30] a strong case can be made that required levels of production can be made on less land than is currently used.[31] This prospect and the sustainability of the cultivation systems is predicated on high levels of inputs, including genetic manipulation of cultivars and "smart" farming,[32] and global distribution of output, both of which place agriculture in a complex industrial system with important socio-economic implications.[33] Breakdowns in the delivery and upkeep of these systems, as in the case of the Maya, and insufficient checks and balances in land management, as in the case the Aral Sea, will challenge the sustainability of this kind of cultivation.

The sustainability of this and other facets of the current and future human-environment condition are linked to various projected transitions. Will increases in global population level off? Will human consumption transition to a sustainable level? And what are the implications of these transitions for ecosystem goods and services? These issues are addressed below focused on the dramatic distinctions between the human-environment conditions of the last phase and those that preceded it.

2.2 Population, Human Development and Consumption in the Industrial Era

For most of human history, people's lives were harsh ("nasty, brutish and short"). Wars, famines, and epidemics made lives highly insecure and caused hunger and illness . Agricultural life was especially labor intensive, and food security was problematic. The ability to read or write, and consumption beyond the subsistence level was confined to the elite who composed a tiny fraction of the population. Over the past two centuries human well-being has improved dramatically in the developed world and substantial progress has been made in much of the developing world, despite very rapid population growth. This section summarizes these trends for the third phase.

2.2.1 Population

World population size increased at a slow and uneven pace for centuries before the onset of the industrial revolution, and did not reach 1 billion globally until about 1800. The modern expansion of human numbers started then but its pace was still modest for the next century and a half with the world total rising to 2.5 billion in 1950. During the second half of the 20th century, however, growth rates accelerated to historically unprecedented levels, especially in Africa, Asia, and Latin America (Fig. 2.2). As a result, world population size more than doubled to 6.9 billion in 2010. This ongoing population expansion is expected to continue for several more decades before peaking near 10 billion later in this century. By then the world's population will have increased tenfold since 1800.

2.2.1.1 Completing the Demographic Transition

A period of rapid population growth ending in a new equilibrium at a much higher population size is a central feature of a secular process called the *demographic transition*. This transition accompanies the development process that transforms agricultural societies into industrial ones. Before the transition's onset, population growth is near zero as high death rates more or less offset the high birth rates typical of agrarian societies before the industrial revolution. Population growth is again near zero after the completion of the transition as birth and death rates both reach low levels. During the intervening transition period, population growth is positive as the death rate drops before the birth rate.

The global demographic transition began in the 19th century in the now economically developed parts of the world (e.g., Europe, N. America, Japan) with declines in death rates. Large declines in birth rates followed in the early part of the 20th century. These transitions are now more or less complete. In fact, several countries in Europe and East Asia face significant population declines as birth rates have fallen below the death rates.

The demographic transitions in Africa, Asia, and Latin America started later and are still underway, but they are expected to end later in this century. Aside from the differences in timing between the developed and developing world, the transitions in the developing world have produced more rapid population growth rates in mid-transitions. In some developing countries (e.g., Kenya and Uganda) peak growth rates approached four percent per year in recent decades (implying a doubling of population size in two decades), levels that were very rarely observed in developed countries except with massive immigration. Two factors account for this very rapid expansion of population: the spread of medical technology (e.g., immunization, antibiotics) after World War II, which led to extremely rapid declines in death rates, and a lag in declines in birth rates in these still traditional societies. Birth rates are now falling in most developing countries and the average number of births per woman has declined from six to three over the past half century. This reproductive revolution is mainly due to declines in the desired family size of parents as the cost of children rose and child survival increased. Government intervention also played a key role. In China this took the form of a coercive and unpopular one-child policy, but most other countries implemented voluntary family planning programs. The aim of these programs is to provide information about and access to contraceptives at subsidized prices so that women who want to limit their childbearing can more readily do so. Despite ongoing declines in birth rates the population of the developing world is expected to grow by an additional 2.5 billion in the second half of this century.

International migration can also be an important source of demographic change of countries and continents. The most prominent example is the massive migration from Europe to the Americas in the 19th and early 20th centuries. In recent decades migration flows from the rest of the world have continued at a substantial pace into N. America, Europe and Australia, and into wealthy countries of the Middle East. However, migration contributes little to growth in most other countries and only 2.9 % of the world population was foreign born in 2004.

2.2.1.2 Crowding out Nature: Population Density and Land Use

The distribution of people across the world's land areas is extremely uneven. The main reasons are clear: people have long settled and flourished in favorable environments relative to disease, climate, water, soil quality and transport, and they avoid the large parts of the world where these conditions do not hold (e.g., deserts, circum polar regions, mountains). The proportion of land for human settlement and infrastructure takes up a modest 3% of land area of the earth, but croplands and pasture cover about 40% (Foley 2005). Virtually all of the world's prime cultivation land is used to grow food and fiber for humans and livestock.

After taking account of areas unsuitable for agriculture and human habitation, population density still varies widely among countries and regions. The number of people per square kilometer of potential arable land averages 158 worldwide. Asia is by far the most densely populated region with 551 people per km^2 of potential arable land. Europe's density (125) is less than a fourth of Asia's, and densities in L. America (58), N. America (65) and Africa (76) are still lower. The range of densities at the country level is of course even greater.

As expected, population density is correlated with the proportion of potential arable land that is used for growing crops: Asia as the densest region uses nearly all (90%) of its potentially arable land , while Europe and N. America use about half and L. America and Africa less than a quarter (Fig. 2.3). Population densities will increase over time as populations increase in size because land areas and their suitability for food production are not expected to change much over the next decades (but this may not be true later in the century as the impact of climate change becomes substantial). The link between density and intensity of land use may weaken over time with the globalization of agricultural production.

2.2.1.3 Moving to Cities

The development of agriculture and the domestication of plants and animals about 12,000 BP led to the growth of urban centers for trading surplus agricultural products, goods and services (Table 2.1). Most people, however, continued to live in rural settings and engaged largely in agriculture for local production. The current era of rapid urbanization began with the onset of the industrial revolution (Table 2.1). Employment opportunities in the expanding manufacturing and service sectors were often located in towns and surplus labor from the rural areas moved to cities in search of jobs and a better life. Urban areas were also attractive because they provided higher incomes, better access to schools, cultural opportunities, health care and social services.

Driven by these multiple forces, urbanization proceeded at a steady pace during the 19th and 20th centuries in the now developed areas of the world, but little changed in the rest of the world until the second half of the 20th century. In 1950 the percentage of the world population living in urban areas reached 29%, ranging from over 50% in Europe and North America, to just 15% in Africa and Asia. Over the past half century urbanization has proceeded at a record pace with the world average reaching 50% in 2010, and the proportions urban more than doubled in Africa and Asia (Fig. 2.4). These trends are expected to continue in coming decades with the proportion urban reaching between 80 and 90% in Europe and the Americas. Africa and Asia remain much less urban but nevertheless could reach 50% by 2050. By the end of this century the global rural-to-urban transition should be nearly complete with a large majority of people living in urban areas.

In recent decades the combined effects of overall population growth and rising urbanization, produced extremely rapid growth in the size of urban populations of the developing world. This expansion has been difficult to absorb in the poorest countries where urban infrastructure has been overwhelmed resulting in continuous traffic jams, lack of public transportation, clean water and sanitation, and overcrowded schools and health facilities. The chronic paucity of housing has led to the explosive growth of slum areas where the poor live in appalling conditions with virtually no access to infrastructure and services.

The rapid expansion of urban areas has a flip side: a reduction in the growth of the rural population due to outmigration. In fact, the size of the rural population of the world is projected to remain stable between 2005 and 2030. This trend will reduce direct population pressures on some rural environments, but not those required to produce for urban consumption. This trend also implies that nearly all of the 2.5 billion people expected to be added to the developing world in future decades will end up in cities that are often poorly equipped to absorb this massive influx of new inhabitants.

2.2.2 Human Development

In the social sciences the term "human development" refers to the attainment of a long and healthy life, a rise in knowledge and education and a growth in economic productivity.

2.2.2.1 Living Longer and Healthier

Before the 18th century mortality crises—mostly epidemics—were frequent, life expectancy was only about 30 years, and half of newborns failed to survive the first few years of life. One of the most notable achievements of modern industrial societies is the large rise in human longevity to about 80 years today.

The mortality transition started in England and Northern Europe early in the 19th century and life expectancy rose to around 50 years by 1900. Several factors contributed to this improvement in longevity: public health measures reduced exposure to water and food borne diseases, better nutrition improved resistance to disease and inoculation and vaccination prevented certain infectious diseases. Mortality decline accelerated after 1900 driven by a new set of factors: the institutional acceptance of the germ theory of disease led to range of measures to reduce exposure and transmission, and the development of antibiotics brought most infectious diseases under control. By the 1950s life expectancy in the most advanced countries had risen to 70 years and all but few percent of infants survived the first years of life. These countries have now reached the final stage of the mortality transition which involves the treatment and prevention of chronic diseases among the old—for example, heart disease, cancer, diabetes. Progress is being made in the treatment of these diseases and innovations in medicine, biotechnology, and drug development will no doubt continue. Nevertheless it is likely that future improvements in life expectancy will be less rapid than over the past century.

The developing world has experienced quite a different mortality transition. Mortality declines were small through the early part of the 20th century and by the early 1950s life expectancy was only 38 years in Africa and 42 years in Asia (Fig. 2.5). Latin America fared better with a life expectancy of 51 years. But over the past half century mortality conditions in large parts of the developing world have improved rapidly due to rising incomes, improved nutrition levels, access to medical care and especially the implementation of public health measures and the availability of antibiotics and other drugs. Today, life expectancy in L. America (73) and Asia (69) is similar to that of Europe in the 1960s. Africa still lags even though life expectancy has risen by about 10 years over the past half century. While low incomes, lack of access to adequate health care are partly to blame, the AIDS epidemic is the dominant reason for Africa's stalling life expectancy.

Over the past quarter century the HIV virus has spread to all corners of the globe, resulting in the deadliest epidemic of modern times. By the end of 2006, a cumulative total of twenty five million individuals had died of AIDS. By far the largest epidemics are found in southern Africa where close to one in five adults is infected. In contrast, other continents experience infection levels of only a fraction of one percent. The causes of the concentration of the epidemic in one region of Africa include a relatively high frequency of concurrent sexual partners, low levels of male circumcision, a high prevalence of other sexually transmitted diseases, and minimal use of condoms. In response to this unprecedented health threat a massive global effort has been mounted to reduce infections through prevention programs (which encourage abstinence, reduction in number of partners and condom use) and to extend the lives of infected individuals with antiretroviral therapy. These efforts are partly responsible for a major recent turning point in the epidemic: after a period of rapid spread the epidemic appears to have stabilized in most countries and the proportion of adults infected with HIV is no longer increasing. However, the death toll will reach much higher levels in the future because 33 million individuals are currently infected and about 2 million new HIV infections occur each year, mostly in Africa.

2.2.2.2 Expanding Knowledge

The creation of new knowledge about the physical world and the development of a range of technologies predicated on this knowledge were the main driving forces of the industrial revolution. Knowledge creation is now a worldwide industry involving millions of scientists producing millions of studies each year. New insights and technologies are being discovered at an exponential rate, thus yielding continuous improvements in economic productivity and human welfare.

To take advantage of this expanding knowledge base, economies require a well-trained labor force. Developing economies at first need workers with an ability to read and write, and later they require workers with more advanced skills acquired in high school or college. Global literacy rates have risen dramatically, although large geographical discrepancies exist. Near universal literacy has now been achieved in the developed world, but in the poorest regions of the world less than half of the adults are literate (Fig. 2.6). Nevertheless, parents everywhere now demand that their children get an education as the path to a better life. The massive investments made in schooling in recent decades have raised literacy among young adults (15-24) to 85% in the developing world. In addition, the traditional emphasis on schooling boys over girls is declining, and gender differences in literacy levels have narrowed substantially. It is noteworthy that schooling does more than teach the basic skills of reading, writing and arithmetic: it is an important agent of social change, in part by teaching middle class (often western) values, and amplifies the loss of population from rural areas.

The recent information revolution has created many new opportunities to acquire knowledge about the outside world. In the Middle Ages news took weeks or months to travel from one continent to the next. Then came reliable postal service, the telegraph, telephone, radio, television and, finally, the internet. Over time the cost of telecommunication has declined by orders of magnitude and anyone anywhere in the world with a PC and internet connection now has instantaneous access to news, music, video and stock quotes from around the world. Vast amounts of information have become quickly searchable and users of information have turned from passive recipients to active searchers and contributors. The internet is currently dominated by the Western world and by the English language, but other cultures and languages are gaining rapidly. The rising interconnectedness of all corners of the globe creates common interests and values, reduces political, cultural and geographic barriers and facilitates the integration of traditional societies into the global economy.

2.2.2.3 Increasing Productivity and the Changing Nature of Work

Technological innovation combined with improvements in education and health result in a more productive labor force. This in turn leads to a complete transformation of the occupational structure of the labor force as countries industrialize. At the beginning of the transition nearly all workers are employed in agriculture. As agricultural productivity rises, surplus labor shifts to manufacturing of goods, and the subsequent rise in the productivity of manufacturing shifts workers further to services. Over time, farmers are turned into office workers. Today, populations of regions and countries are at different stages of this transformation (Fig. 2.7). The proportion of the labor force engaged in agriculture ranges from 63% in Africa (down from 83% in 1950) to just 3% in N. America (down from 13% in 1950). In future decades the rest of the world will likely move closer to the astonishing productivity of farmers in N. America.

The productivity revolution has also permitted an increase in leisure time. In much of the industrialized world the number of hours worked per week has declined to below 40, vacation time has risen to several weeks per year and the average age at retirement has declined to below 65. Within these long-term trends, however, there is much variation by country. For example, in the US and Japan working hours are longer, vacations shorter, and retirement later than in Europe.

2.2.3 Standards of Living and Consumption

The industrial revolution created enormous wealth and raised standards of living for billions of people. Key driving forces of this revolution included capital investments in machinery, factories and infrastructure, and the invention of many new technologies in farming, manufacturing, transportation, telecommunication and computing, all of which raised the productivity of a healthier and better educated labor force. Changes in many institutions were also important: economic (market pricing of labor, goods and services; free trade within and between countries), legal (property rights and contracts), political (representative government and voting rights) and social (role of the family). Consumption became "democratized", allowing an ever greater proportion of a significantly enlarged, global population to consume beyond basic needs. This consumption, in turn, places increased pressures on resource stocks with significant environmental consequences.

2.2.3.1 Rising Incomes

Although the term standard of living encompasses multiple non-economic dimensions, the most commonly used measure of standard of living today is the *gross domestic* *product* per person, or GDP per capita. A country's GDP is the value of all the final goods that are produced by its residents in a given year. It is a measure of an economy's total output, but when a commodity is produced and sold, the price paid for the purchase finds its way into someone's pocket. So, GDP can be measured also by adding up everyone's incomes - wages, salaries, interests, profits, and government income. GDP and national income are therefore two sides of the same coin.

Global income per head today is nearly $8,000 a year (adjusting for differences in the cost of living across the world). But for most of humanity's past, people have been abysmally poor. At the beginning of our Common Era (CE 0) per capita income of the world was approximately $467 a year (in 1990 prices).[34] This estimate implies that the average person two thousand years ago enjoyed not much more than a dollar a day, a figure deemed by the World Bank as the line below which a person is in extreme poverty. The distribution of income at that time was remarkably equal: almost everyone, everywhere was very poor. These general conditions prevailed for many centuries with very limited progress. Regional disparities became significant only from the beginning of the 19th century: income per head in Western Europe had by then become three times that in Africa. But world income per head was still only $660 a year, meaning that it had increased at a rate of less than 0.02% annually over a 1800 year period. This represents negligible progress by contemporary standards..

Regional disparities in income have widened since 1800 (Fig.2.8). The ratio of the average incomes in N. America and Africa has risen from three in the beginning of the 19th century to more than 17 today - about $31,000 compared to $1,1780 per year. Real GDP per capita in the US has grown 25 times in size in 200 years, implying that the average annual growth rate of income per person there has been about 1.7%. Average incomes per capita have also risen by an order of magnitude in L. America and Asia. In sad contrast, income per capita in one of the world's poorest countries, has changed little over time.

If one were to line up countries according to GDP per capita today, two clusters would emerge: one poor, the other rich. One large cluster of countries (in sub-Saharan Africa, the Indian sub-continent, South East Asia, Melanesia, and Central America) - with a total population of 2.3 billion - produces an average $2,100 a year per head, while another, smaller, cluster (Europe, North America, Australia, and Japan) - with a total population of a bit under 1 billion - enjoys an average annual income of $30,000. Middle-income nations are spread thinly between the extremes (China, Brazil, Venezuela, and Argentina are prominent examples). The world would appear to be polarized. Moreover, with the possible exception of India, there is little sign that the poor world will catch up with the rich world in the foreseeable future. During the past four decades, real per capita GDP has grown at an average annual rate of 2.4% in rich countries, whereas it has grown at 1.8% in poor countries. Worse, within the poor world sub-Saharan Africa has experienced a small decline in real GDP per capita during the past four decades.

Disparities in incomes are also large within countries. In most contemporary populations a tiny percentage of high income workers earn as much as the combined incomes of the bottom half of workers. Worldwide, more than 1 billion people live on less than $1 a day, and 2.5 billion on less than $2 a day. Poverty rates have declined in recent decades in Asia and L. America but have risen in Africa. Under-nutrition and ill health are both cause and consequence of poverty: lack of income limits the ability to buy food and health care, and under-nutrition and frequent illness deprive workers of productive employment. Other key causes of poverty include government mismanagement, absence of property rights, corruption, lack of environmental resources, and violence. It is important to note that the basic needs of people for food and housing and access to health care, clean water and electricity can be met with little impact on the environment. Economic growth is expected to continue for the foreseeable future, driven largely by gains in productivity and supported by the globalization of production and consumption. The ongoing massive expansion in the flow of goods, capital, and services is made possible by declining costs of transportation and reductions of trade barriers. The drop in the costs of goods and services from this globalization process has benefitted most consumers around the world, but wages of low skilled workers in the developed world have suffered due to competition from low cost producers in the developing world.

2.2.3.2 Consuming Food

For most of human history the supply of food calories was close to the subsistence level of around 2000 calories per capita per day. Over the past century the quantity and quality of food available to human kind have seen enormous improvements, first in the developed world and more recently in the developing world as well. Today, this supply has reached over 3400 cal/cap/day in the developed world and obesity has become a health problem. In the developing world caloric supply rose from 2111 to 2654 cal/cap/day between 1961 and 2000.[35] The quality of the diet has also improved greatly and the typical diet has become more varied, with larger portions of protein and animal products. Malnutrition and under-nutrition have declined sharply but remain wide spread in the poorest countries.

These diet trends have improved the standards of living for most people, but, together with an expanding population size, they have led to huge demands on agricultural land with undesirable consequences such deforestation and the runoff of pesticides and fertilizer.

2.2.3.3 Consuming Energy

Energy is the lifeblood of modern economies. It powers industry, transportation, and residential and commercial buildings. World energy consumption in 2006 was 12 billion tons oil equivalent per capita and has risen steadily over time as economies expanded. Per capita energy use varies widely among countries and is highly correlated with GDP per capita. Sources of energy today are dominated by fossil fuels (oil, coal and natural gas) with small contributions from hydroelectric, nuclear and biomass. This mix has evolved over time with the shares of coal and firewood declining and those of oil, natural gas and nuclear rising. Over the next few decades the share of oil is projected to decline modestly and that of renewable energy to grow due to higher fossil fuel prices and government subsidies.

2.2.3.4 Declining Energy and Carbon Intensity

Energy intensity measures the amount of energy used to produce a unit of economic output. Over time, energy intensity has declined in most economies as economic output has grown more rapidly than energy consumption. In addition, energy intensity is lower in the developed than in the developing world. There are two reasons for these trends and patterns. First, economies become more efficient over time due to technological improvements in energy-using devices (e.g., lighting, and motors) and greater reliance on lighter materials (e.g. the substitution of plastics for steel). Second, energy intensity varies strongly among industry sectors: highest for agriculture and manufacturing and lowest for services. Over time, as economies develop, the most energy intense sectors decline in relative size and the less energy intense ones rise. Projections expect continued declines in energy intensity in future decades thus providing a partial offset to the upward trend in population size and standards of living.

The environmental impact of energy consumption is mainly attributable to the byproducts of the combustion of fossil fuels. The industrial production of carbon dioxide--the main greenhouse gas-- reached 28 billion metric tons worldwide in 2006 and is growing at a rate of 3% per year. Other pollutants include soot, heavy metals, and oxides of sulfur and nitrogen and carbon . Some of these can be captured before they are released (e.g., by catalytic converters on vehicles and scrubbers on power plants) but no practical way exists today to sequester carbon dioxide. *Carbon intensity* measures the amount of carbon emitted per unit of consumed energy. The carbon intensity level of an economy depends on the proportion of energy derived from fossil fuels as well as on the mixture of fossil fuels: coal produces the most carbon and natural gas the least. Carbon intensity has declined over time in most economies as the mix of fuels has moved towards greater reliance on oil, gas and nuclear. Declining energy and carbon intensities are part of a more general trend toward the dematerialization of economies i.e. the reduction in the quantity of materials (wood, metals, cement, plastics, etc.) required per unit of economic output.

The overall demand for energy is expected to continue to rise at a steady pace for many more decades. In the developed world, where energy use per capita is highest, future growth in energy consumption will be slower than in the past because the demographic transition is complete and economies are becoming more efficient and service-oriented.

In the developing world, energy use will rise very rapidly because population growth continues at a substantial pace, economic growth is rapid and energy intense sectors dominate. Minimizing the environmental impact of this rising demand (primarily for fossil fuels) requires slowing down the growth in fossil based energy use. Deliberate restrictions in the growth in standards of living–the main driving force–are unacceptable, and any future reductions (or slower increases) in the release of greenhouse gases will therefore have to come from slower population growth (by encouraging lower birth rates in developing countries), from reductions in energy intensity (by improving energy efficiency) and from decreasing carbon intensity (by substituting natural gas for coal and by moving to renewable sources such as solar, biomass, and nuclear).

In the future, larger populations with higher standards of living will require much more energy than today. Declines in energy intensity of GDP and in carbon intensity of energy will offset the impact of this trend, but are not expected to be sufficient to halt a rise in fossil fuel consumption. As a result much stronger intervention is needed to forestall the potential disastrous environmental impacts of fossil fuel use, in particular climate change (see chapter x).

2.3 Environmental Implications

In the midst of the industrial phase of human-environment interactions, global demands on the stocks of natural capital of all kind are large and increasing. In addition, they have triggered a shift in potential adverse environmental consequences by threatening the functioning of natural systems and the capacity of these systems to deliver the environmental services expected of nature, with impacts on the stocks themselves.[36] Five examples below illustrate these impacts.

2.3.1 Land Cover

Only about 22% of the ice-free surface of the Earth can be considered “wildlands” absent significant human changes in land cover. In contrast, about 75% of the ice-free surface of the Earth shows significant human alteration, from rangelands to dense settlements (Fig. 2.9).[37] Agricultural lands, both pasture and crops, take up as much as 40% of the terrestrial surface.[38] a figure that is expected to rise to 50% by 2050.[39] In the last half of the twentieth century arable land per capita dropped from 0.42 ha to 0.23 ha, while food production increased 160%.[40] About 88% of this increase is attributed to the intensification of cultivation, and is matched by a global increase in irrigated lands of nearly 70% and in fertilizer use, about 700%, as well as other chemical inputs.[41]

Rangelands and croplands have been taken largely from land-covers that were otherwise drylands and forest, respectively. Arid land covers occupy about two fifth of the land surface of the Earth.[42] Inappropriate intensive management of arid lands degrades them through the process often referred to as desertification, estimated to be operating on 10-20% of the world’s drylands (6-12 million km^2 of arid and semiarid lands).[43] Arid land degradation reduces local ecosystem services, primarily regarding the scarcity of freshwater for agropastoral activities, but also the resilience of dryland ecosystems to recover from natural disturbance, such prolonged drought. Significantly, climate projections indicate that the arid lands will increase in aridity with climate warming.[44]

Since the beginning of the Holocene the global area of forest has declined by about one-half, leaving only about 30% of the terrestrial surface of the earth covered by forests, 36% of which the FAO estimates to be “primary” in the sense that no visible human changes have been detected in native species and ecological processes.[45] The calculations of forest-cover change are contested, resulting in large part from the different definitions and measurements of them. The current FAO definition is generous: any area equal to or larger than 0.5 ha in which crown cover is 10% or greater. Given this definition, the 1990s witnessed a loss of 8.9 m ha^{-yr} of forest, accounting for forestation gains, while 7.3 million ha^{-yr} were lost between 2000-2005, of which 6 million ha was taken from primary forest cover (Table 2.2). Agriculture remains the overwhelming proximate activity associated with this change (Fig. 2.10).

The trajectory of change in forest cover during the 1990s varies across regions and biomes (Table 2.2). Simplifying, the temperate and boreal forests of the advanced economies of in Europe and North America have gained in area or held steady, and those for West Asia have remained steady, although recent logging in western Siberia may offset the forestation programs underway in China. By far the largest losses in forest cover worldwide have been and remain those of tropical biomes. From 2000-2005, tropical deforestation was progressing at annual rates of loss equal to or exceeding $1\%^{-yr}$ throughout the tropical world; Amazonia alone lost about 4.3 m ha^{-yr} during this time, accounting for forest regeneration.

These and other land-cover changes (e.g., dense settlements and villages cover about 7% of the Earth's ice free surface)[46], have profound consequences on almost every aspect o the environment, both locally and globally. Locally, they often degrade ecosystem services, foremost the capacity to regenerate soil nutrients or aquifers, maintain soil moisture and regulate climate, both temperature and precipitation, preserve pollination and biotic diversity.[47] Globally, land-cover changes substantially affect all of the major biogeochemical cycles of the Earth system, terrestrial albedo (surface reflectivity of solar radiation), and atmospheric aerosols, among other important factors that directly affect climate and rank just below industrial emissions as the principal source of anthropogenic climate change.[48]

2.3.2 Terrestrial Water and Oceans

Perhaps no stock of natural capital is under greater stress globally than is fresh water, with its far-ranging implications for human health, economic activities, local to regional rainfall, and, climate change, recognizing that water vapor is a powerful greenhouse gas. Only 2.5% of the approximately 1,385 million km^3 of water on earth is fresh, but the overwhelming majority of this small proportion is locked up in the polar ice. In addition, the distribution of available fresh water is highly unequal worldwide, best captured by the global distribution of water balance, or the relationship between water inputs, outputs, and storage (Fig. 2.10). Climate warming will affect this distribution, although some of the impact will be obscured by natural climate variability.[49] Global Climate Models cannot yet address regional outcomes adequately.

Humankind currently consumes about one-half of the accessible freshwater and 8% of annual renewable freshwater in the world.[50] In 2003 about 4,500 km^3 of water was withdrawn globally, of which 2,100 km^3 was used (i.e., not immediately returned to the water cycle). These levels of withdrawal and use increased about six-fold throughout the last century, and continue to increase despite recent declines in per capita water consumption in much of the developed world and projections indicating that annual per capita global consumption will decline by 2,700 m^3 from current rates.

The overwhelming largest use of water globally is for agriculture (70%), followed by industry (22%) and domestic consumption (8%)(Fig. 2.11). Currently, about 2,000-2,555 m^3 of water are withdrawn annually for irrigation. Total withdrawals from groundwater is estimated to exceed replenishment by 160 billion m^3 per year, lowering aquifers and leading to waterlogging and salinization of about 10% or 30 million ha of irrigated lands worldwide. UN projections suggest the demand for freshwater by 2025 will exceed the stocks currently available by 56%.

The implications for future water demands are large indeed, raising the possibility that tipping points may loom regarding human consumption and ecosystem functioning. Hydraulic infrastructure, such as dam and reservoir construction, fell dramatically during the 1980s and 1990s as the optimal locations were saturated and the social and environmental costs of these efforts were recognized.[51]. In the face of global climate warming, the UN estimates as many as 3 billion people worldwide will suffer from water scarcity by 2025. The largest impact is expected in those regions of the world already experiencing scarcities and projected to experience declines in precipitation, especially Africa.

Some parts of the water system show strong signs of response to these conditions. The global mean growth in water consumption (per decade) appears to be falling in the first decade of the new century to 10% from the previous four decades of 20%.[52] This decline in the rate of water consumption has been triggered in large part by the saturation of demand and falling per capita consumption in the developed world, suggesting to some that “soft pathways” towards more sustainable water withdrawals are possible.[53] This possibility, however, must be weighed against increasing water demands in the developing world and the need for water in intensive cultivation systems of the future.

Large water withdrawals combined with intensive use of land have a profound effect on rivers and on ocean services, especially the provisioning of fisheries. Increasing numbers of large rivers have significantly dropped the volume of water delivered to the sea, and from time-to-time fail to reach the sea in their above ground flow. The Colorado River of the arid, western U.S. is an exemplar, but some rivers in well-watered regions absent significant agriculture also fail to flow to the sea in some years, as in the case of the Ipswich River of the northern suburbs of Boston.[54] This draw-down in freshwater deliveries to the sea is a direct result of the scale of upstream water withdrawals for human consumption and use as well as land-cover changes that affect surface runoff characteristics, both of which are exacerbated by complex systems of management and governance, often involving international boundaries.[55] Climate warming, unsurprisingly, is expected to increase these delivery problems, in the case of the Colorado River because of decreased snow packs in the Rockie Mountains. Delivery of freshwater to the continental shelves is essential to the maintenance of the major fisheries of the world.

This threat also involves the deteriorating quality of the water delivered, which contain increasing quantities of nitrogen, largely from runoff from agricultural lands. The amount of pollutants of this kind is triggering increasing algal blooms, which in turn kill fish and poison shellfish.[56] The large amount of nitrogen runoff from farmlands carried down the Mississippi River now generates an annually occurring hypoxia or dead zone in the Gulf of Mexico in which oxygen levels fall below that required for most life (Fig. 2.12). The area now affected exceeds 20,000 km^2 in the prime shrimping zone of the Gulf. In addition, as much as 50% of mangrove ecosystems—an intermediary land cover between land and oceans essentially to much marine biodiversity—has been significantly altered or destroyed by human activity.[57]

In addition, overfishing is degrading the food provisioning service of the oceans at increasing rates . An estimated two-thirds of the fish stock in ocean fisheries globally have now been depleted or are on the brink of being depleted.[58] The consequences for fishing stocks and marine ecosystem supporting them are expected to be affected by changes in the oceans due to climate warming. This warming, of course, portends even larger systemic changes within the oceans with the potential to affect the thermohaline circulation and thus the climates of the world.[59]

2.3.3 Biogeochemical Cycles and Synthetics

Perhaps no marker is more telling of current human-environment than that of changes in biogeochemical cycles, or the flow of chemical elements through the Earth system. These naturally occurring flows maintain the states of the earth system, foremost that of climate.[60] Heretofore, changes in these cycles were driven by the great forces of nature, either changes in the reception of incoming solar radiation at the outer boundaries of the atmosphere or outputs from tectonic activities. The industrial phase, however, elevated human activity as a forcing function on these cycles equivalent to, and in some cases exceeding, nature. Industrial production and consumption now affects all of the critical cycles, such as carbon, nitrogen, phosphorous, and water (above).[61]

Of these, the carbon cycle has drawn the most attention because the sheer quantity of carbon released from sinks or reservoirs stored within the lithosphere as coal, oil, and natural gas or maintained in soil and above ground biomass. The extraction, production, and consumption of fossil fuels, coupled with deforestation and agriculture (above) has generated a massive new source of carbon flowing to the atmosphere, triggering increases there in CO_2. Since the first measurement of atmospheric CO_2 in 1957, its concentration has increased from 315 ppm to 378 ppm (2005) and is increasing rapidly (Fig. 2.13).[62] Methane CH_4, a more potent greenhouse gas than CO_2, has also increased dramatically to 1774 ppb (2005) compared to its preindustrial concentration near 700 ppb.[63] Its increase is driven by land changes and industrial production, in that order.

Humankind now surpasses nature as the principal factor affecting the nitrogen cycle, a consequence of fixing N_2 for fertilizer use through the Haber-Bosch process and in the combustion process of fossil fuel use. Given the role of chemical fertilizers in global food production, it is estimated that use will exceed 135 Tg/yr by the year 2030, up 125 Tg/yr from that used in 1950.[64] This release has several important consequences on the Earth system: nitrous oxide, like methane, is a more potent greenhouse gas than carbon dioxide; and nitrogen oxide amplifies ground-level ozone that reduced plant growth, especially in the major agricultural areas worldwide adjacent to major industrial zones.[65]

The release of synthetics—chemical compounds that do not exist in nature- has also risen to unprecedented levels. Most known is the case of CFC (chlorofluorocarbon) production, produced in mass in the middle of the last century for a wide variety of industrial uses, including refrigerants, propellants, and cleaning solvents. CFC's reaching the stratosphere break down the ozone layer that protects the Earth from ultraviolet radiation from the Sun. xxx

2.3.4. NPP, Atmosphere and Climate

The total production of organic compounds from atmospheric and aquatic carbon dioxide is known as gross primary production, and the rate at which plants produce net useful chemical energy for other species, is called net primary production or NPP. The net primary production for the Earth is estimated to be 104.9 Gt C/yr , split relatively evenly between the oceans and land.[66] Human activity affects the Earth's gross and net primary production; in some cases, such as arid land irrigation, it may increase both, but in most cases production is decreased. The human appropriation of *terrestrial* NPP (HANPP) is estimated as 15.6 Gt C/yr, just under one-quarter of the NPP estimated to be generated by the potential vegetation of the Earth's surface (Fig. 2.14).[67] This appropriation, again largely a product of the current phase of human-environment relationships, reduces energy available for other species as well as affecting biotic diversity, water and carbon flows, and capacity of ecosystem to provided various services.

Human-induced changes in land-cover and albedo, the hydrologic cycle and oceans, biogeochemical cycles, and NPP constitute forcing functions operating in concert with natural ones, to change climate, or average weather conditions. They do so directly by affecting greenhouse gas emissions to the atmosphere or altering Earth's radiative heat (e.g., albedo) and indirectly by affecting the functioning of various parts of the Earth system (e.g., NPP) which, in turn, directly affect the atmosphere. With the exception of one hypothesis about land change in the early anthropocene (above),[68] the ascendancy of human activities to this function is product of recent centuries, especially the last 100 years. The IPCC's Fourth Assessment contends that that atmospheric conditions are unequivocally leading to climate warming, that this warming since the mid-20th century is very likely due to anthropogenic forcings, foremost greenhouse gases, and that these forcings will continue to grow, generating about a 2°C increase in average Earth temperature for each of the next two decades, with subsequent additional increases[69] The amount of warming will be determined in part by what we do now in regard to the human-induced forcings. The expected warming levels will profoundly affect the Earth system and change its environmental services, with impacts on, for example, the phenology of flora, migration of biota, sea level rise, ocean dynamics, and ecosystem functioning.

2.3.5 Biodiversity Loss

Biodiversity refers to the number, range and variability in biota; losses occur within and between species and among ecosystems. Experts concur that global environmental change has triggered significant losses in biotic diversity; indeed, the term "mass extinction" has been applied to this loss. The number of species on the planet is uncertain, with estimates ranging from 5 to 30 million, of which 484 plant and 654 animal species have become extinct since AD 1600.[70] The mass extinction label applies, however, due to the increasing pace of change in the principal factors that trigger biota loss—habitat modification and conversion, alien species invasion, overexploitation of natural resources, and pollution—especially as they involve those terrestrial biomes of high biotic diversity, such as tropical forests (above). Extinction rates are now100 to

1000 times faster than before the entry of humans. Substantial declines in the number of vertebrate species have already occurred (Fig. 2.15)

Interestingly, only 200 plant species have been domesticated, of which no more than 20 provide about 80% of the global food supply. It is not in this sense, however, that biodiversity loss has become a global environmental concern. Rather, it is the role that biodiversity plays in the functioning of ecosystems and thus their capacity to provide expected services.[71] The precise role of this diversity remains the subject of on-going research regarding its import on such issues as primary productivity, landscape resistance to invasive species, and species redundancy.

Global climate change has already begun to affect biotic diversity in regard to phenology and frequency of pest and disease outbreak. As warming advances poleward, species will need to migrate, but the assemblages of species in extant ecosystems will not likely migrate at the same speed or equally overcome impediments to migration, such as landscape fragmentation. Sensitive ecosystem, such as coral reefs and mangrove forests, appear to be highly vulnerable to climate change.

2.4 Transitions to Sustainability

Can the pace of demographic, social and economic and environmental change continue or are we living in the middle of unique transitions that will end in relative stability later this century? Or will ecosystems be pushed beyond the breaking point leading to massive discontinuities?

The term transition refers to secular change in an indicator, in this case starting with an initial acceleration, leading to a peak in growth, followed by declining rate of change and eventual near stability. The preceding discussion suggests that population related transitions will largely end by the second half of this century (Table 2.4). Global population size, life expectancy, literacy, proportion urban and labor force participation in agriculture are in such transitions and are expected to approach plateaus or periods of much slower growth in the future. The rich countries have already completed these transitions and other countries are expected to catch up with the leaders over time. Once approximate worldwide stability is reached in these indicators later in this century the population of the developing world is projected to be larger by around 3 billion, but the current gaps in life expectancy level, literacy and urbanization are expected to be much smaller than today.

In contrast, upward trends in key economic variables–in particular, in standards of living and consumption--will likely continue because innovation and productivity have no limit and with the spread of free markets, new technology and responsive governance an ever increasing proportion of the global population will reach higher standards of living. The resulting rise in the demand for natural resources will be difficult to meet and will lead to further adverse environmental impacts. However, declining energy and carbon intensity will offset this impact to some extent.

Transitions in the depletion of natural capital stocks may also be underway, but this is less clear and varies by type of stock. For example, the possibility of a global forest transition has been advanced based on observations of forest-cover recovery in Western economies.[72] The thesis posits that development—captured in the population, consumption, human well being transitions noted above—transfers economic activities away from primary production, concentrates population in urban areas, and permits intensive cultivation on less land. One result is more land available for forest recovery, be it for recreational activities, ecosystem service enhancement, or some other use. Historically, this transition simply moved the locus of deforestation from the developed area to one predicated on forest resource extraction, illustrated today by tropical deforestation. Trends in forest area and density, however, suggest that a global forest transition may be underway.[73] Among the 50 countries of the world holding the most forest globally, only a few experienced both major losses in forested area and forest density between 1990 and 2005 (Fig. 2.17), while 36% of countries increased forest area and 44% increased forest density. If this transition is a reality, it likely reveals the process of dematerialization—producing more with less.

Should we expect major transitions also to take place in water withdrawals, greenhouse gas emissions, appropriation in NPP, and loss of biotic diversity? Will these and other environmental impacts stabilize in order to secure the major environmental services expected of nature? The history of human-environment relationships indicates that the answer lies in the balance between the level of demands for natural capital, the technological capacities to deliver on these demands, and prevailing governance structures.[74] Projected slower rates of population growth and increases in the saturation of per capita consumption of natural resources globally suggest that the rates of demand for natural capital may level off as well, potentially generating various environmental transitions.

Environmental transitions, however, must be weighed in the context of the large uncertainty regarding the long-term consequences of the environmental changes underway. Global forest cover may level and even increase in area and density, but the resulting forests have been and continue to be changed in composition and structure, affecting the array of ecosystem services from them. Global climate change, in turn, especially through impacts on biotic diversity, compounds this issue as well as those pertaining to water scarcity, agricultural production, and the conditions of drylands. Large uncertainties exist in the tipping points beyond which ecosystems can deliver their expected services, be they fresh water or climate change. Such tipping points must be assessed in terms of the sheer level of sustained demands for natural capital and emissions form their production, in concert with global climate change.

2.5 Conclusion

The epochal phases of human-environment relationships illustrate how changes in population, consumption, governance, and technology have been linked to environmental change. The first two phases preceding the current, industrial one suggest, over the longhaul, reduced rates of growth in factors generating demands for resource stocks. The current phase, of course, differs from the previous phases in at least two ways: populations and consumption levels, and thus pressures on natural capital, are much larger and will remain so, and technological changes have opened the door to direct impacts on biogeochemical cycles. Together, the kind of stress placed on ecosystems and the earth system is now unprecedented, even with the various socio-demographic transitions underway, raising the possibility of environmental feedbacks that humankind has yet to encounter. In the past, periods of rapid change in population, consumption and the environment have been followed by periods of relative stability. The key questions now are: Can the future needs of an expanding human population be sustained by a transformed earth system? How do we bring about a transition to sustainability in the current industrial phase of the human-environment system without reaching catastrophic tipping points? Are technology and governance the key? The following chapters address this challenge

FIGURES

Figure 2.1: Phases of Human-Environment Interaction (from Deevey 1960).

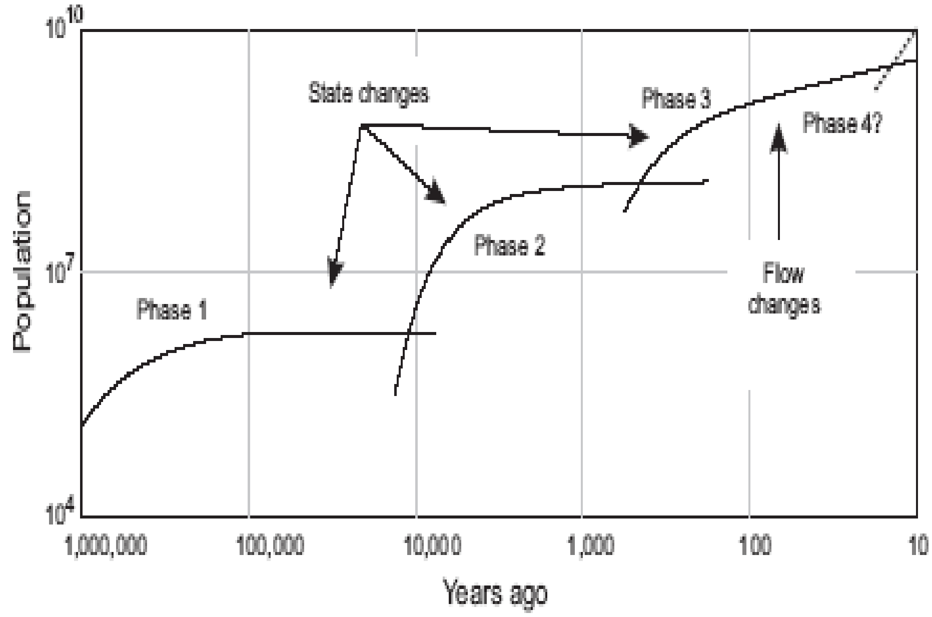
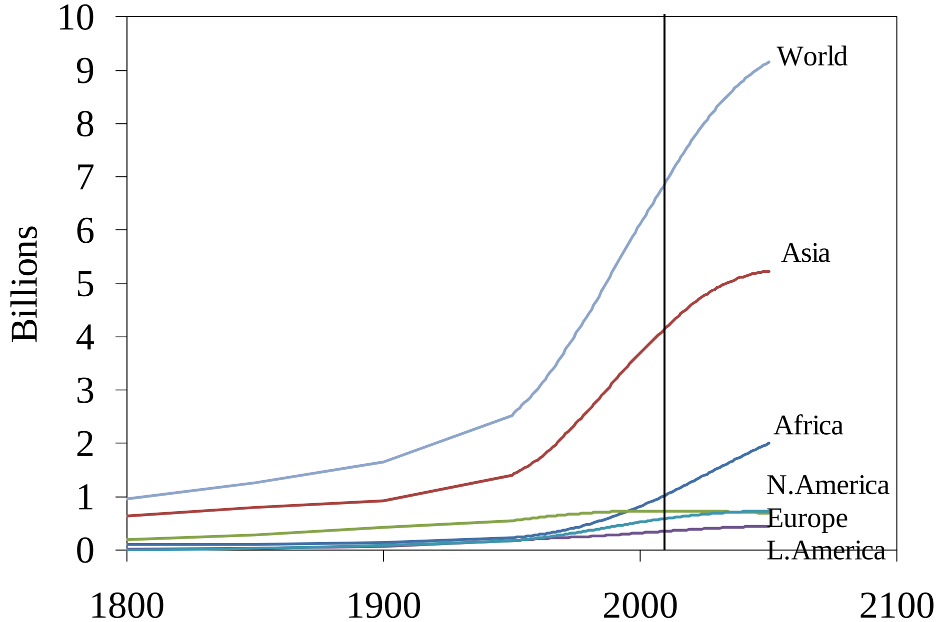
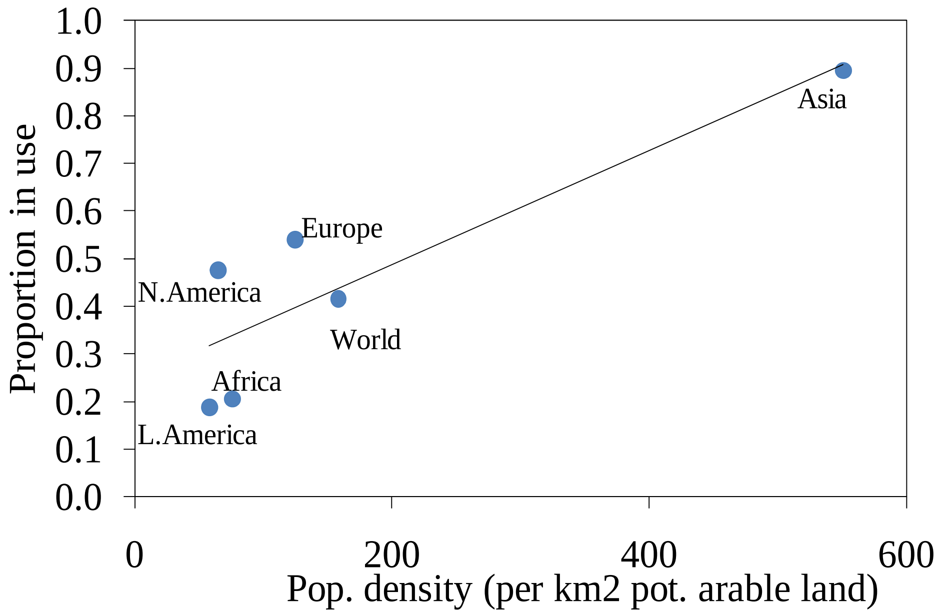


Figure 2.2: Population size, 1700-2010, and projections to 2050



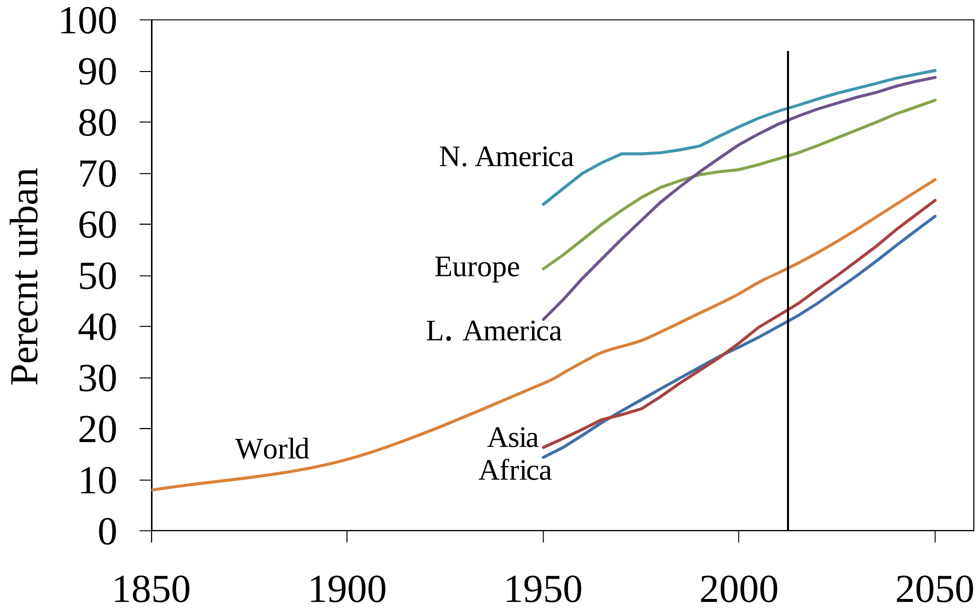
Source: United Nations 2009; Demeny 1990

Figure 2.3: Proportion of potential arable land in use by population density,1995



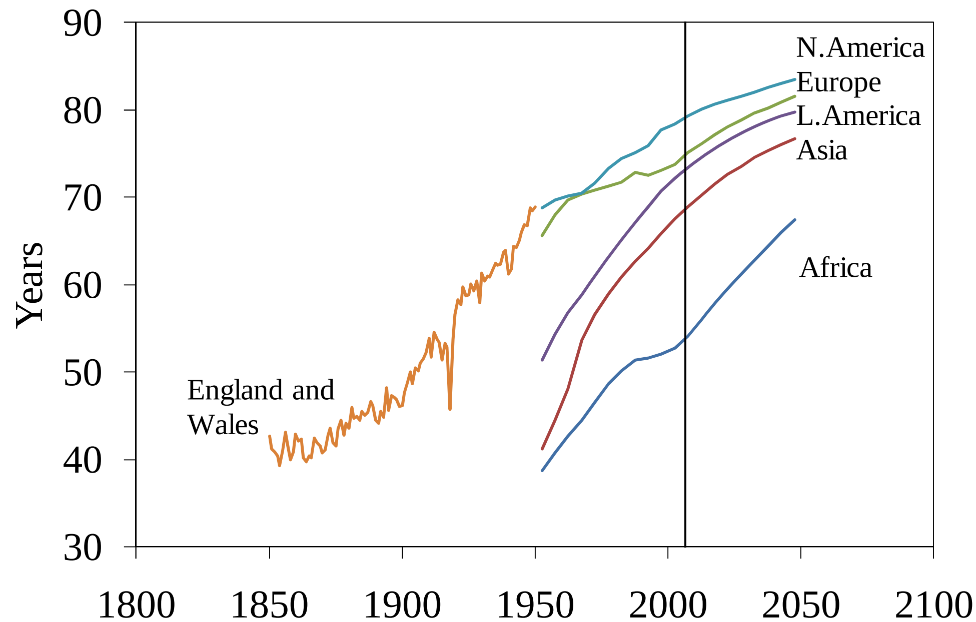
Source: United Nations 2009; United Nations 2007.

Figure 2.4: Percent urban 1950-2010 and projections to 2050



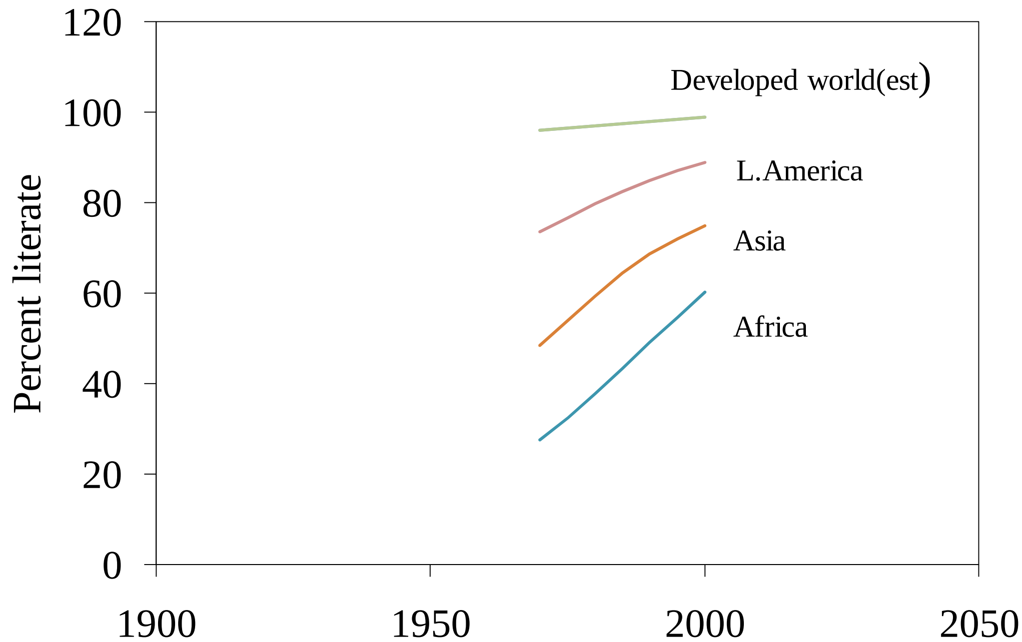
Source: United Nations 2010; Berry 1990

Figure 2.5: Life expectancy, 1950-2010 and projections to 2050



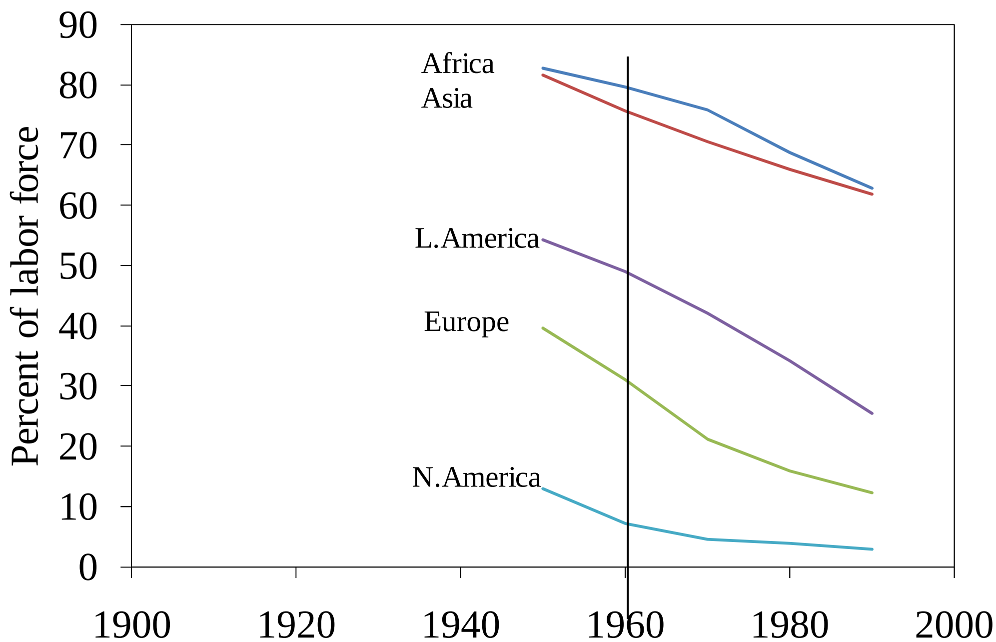
Source: United Nations 2009; Human Mortality Database 2006

Figure 2.6: Adult literacy rate, 1970-2000



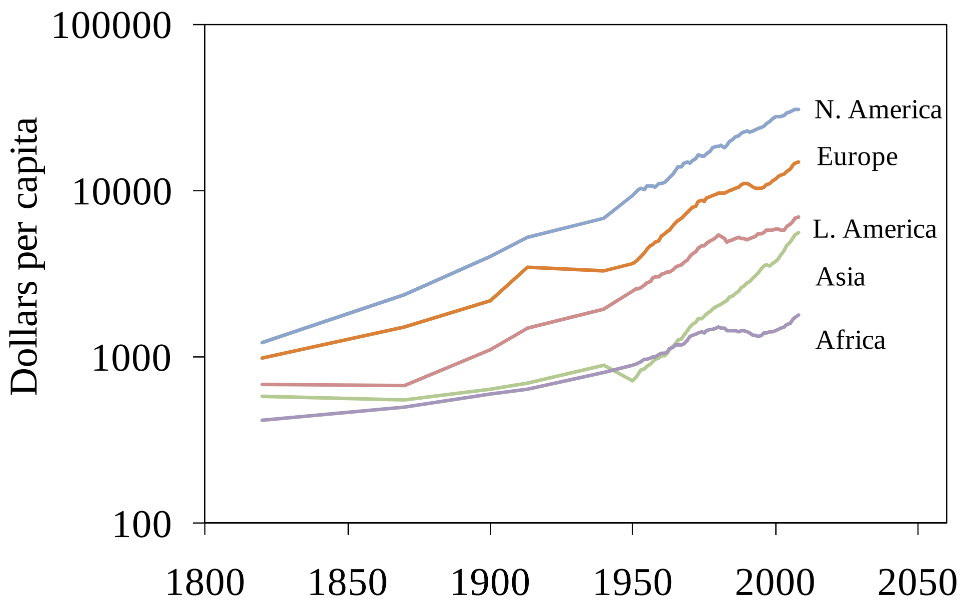
Source: United Nations 2007

Figure 2.7: Percent of labor force in agriculture, 1950-1990



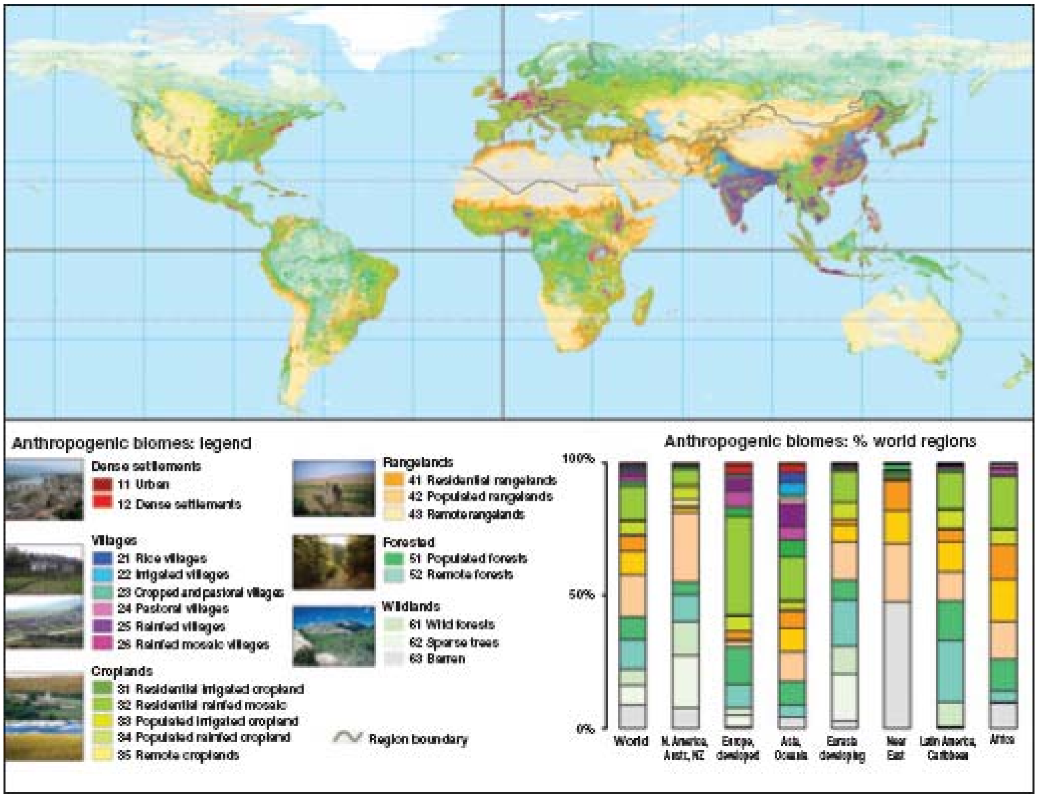
Source: United Nations 2007

Figure 2.8: GDP per capita (1990 dollars), 1820-2003



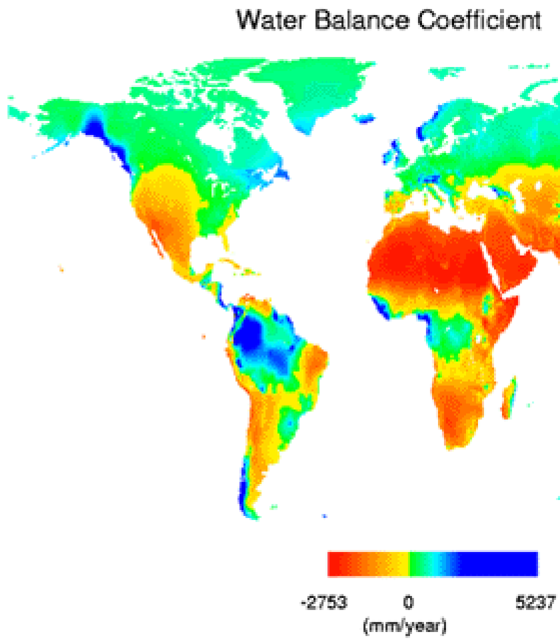
Source: GGDC 2010

Figure 2.9 Anthropogenic Biomes



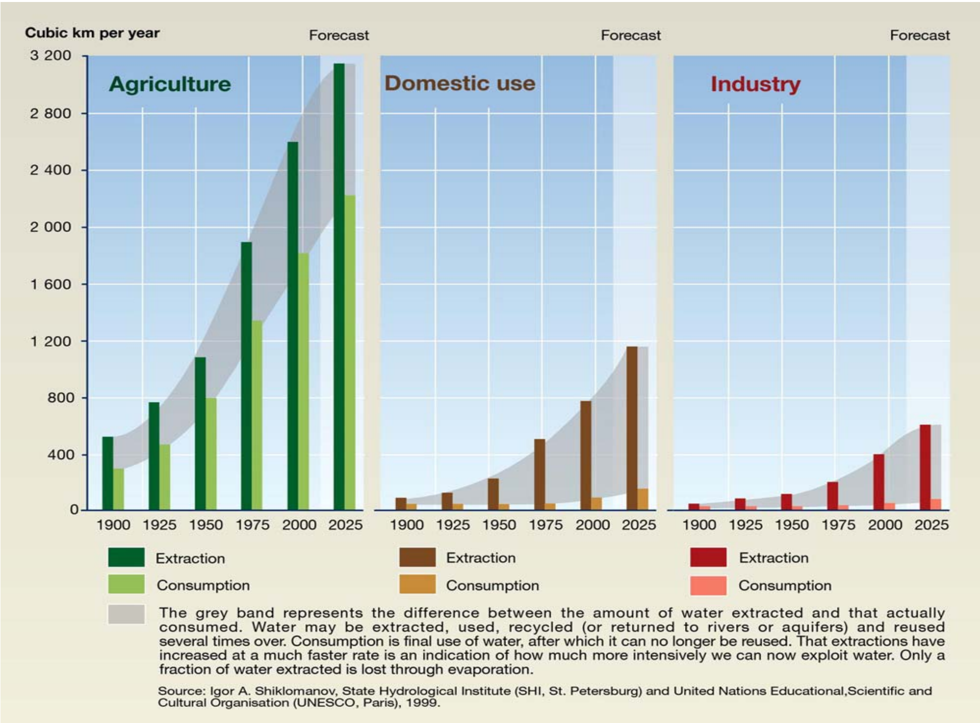
Source : Ellis and Ramankutty 2008

Figure 2.10



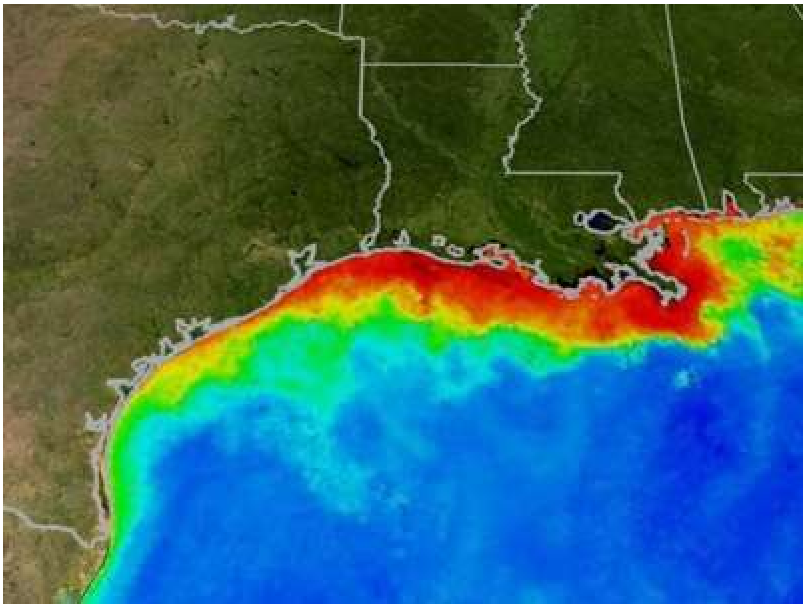
Source : GAIM: IGBP

Figure 2.11



(2008) http://www.unep.org/dewa/vitalwater/jpg/0211-withdrawcons-sector-EN.jpg

Fig. 2.12 Hypoxic or 'Dead' Zone in the Gulf of Mexico



2.13 Rise in Atmospheric CO2: The Mona Loa Results (source: http://www.esrl.noaa.gov/gmd/ccgg/trends/

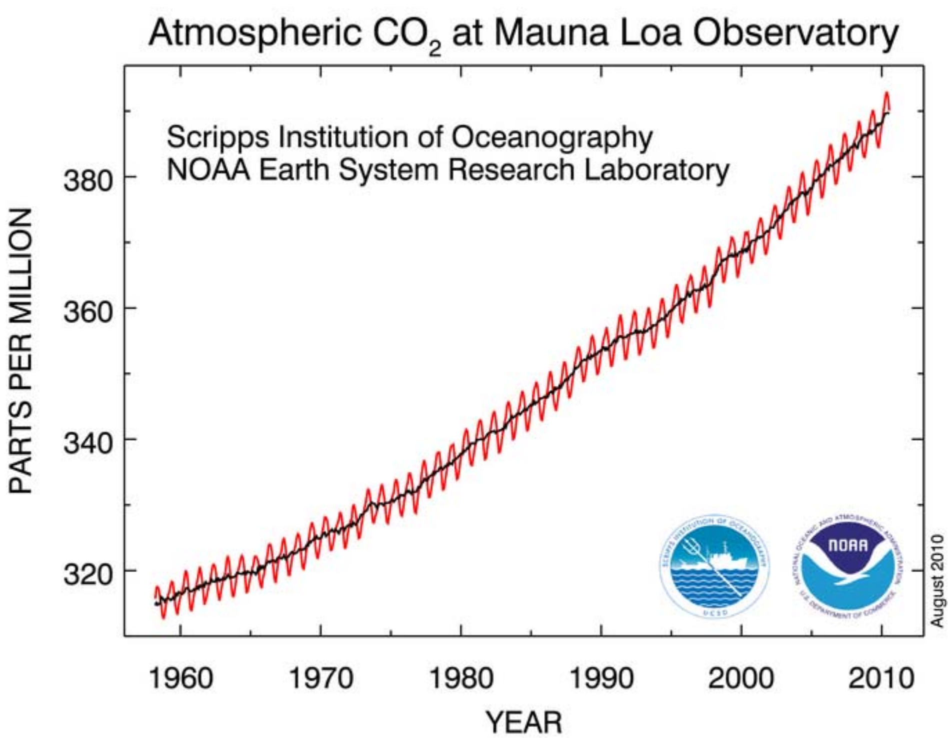
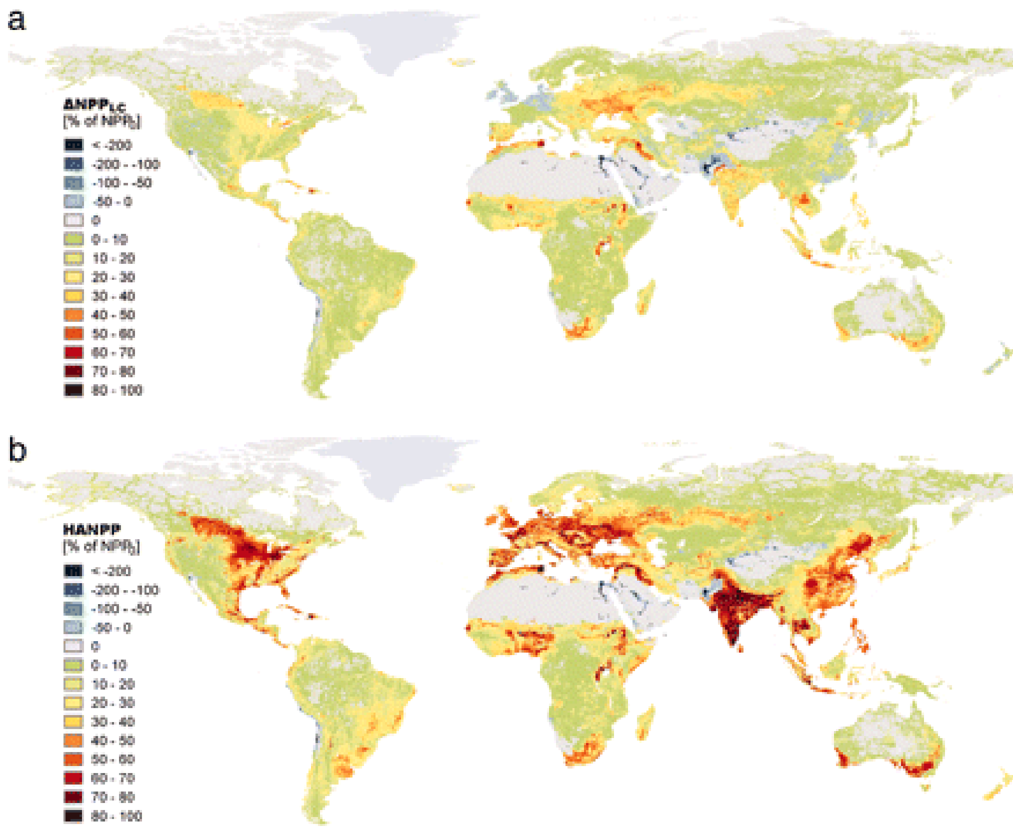


Figure 2.14 Human Appropriate of Net Primary Productivity



Human-induced fires excluded. (*a*) Land-use-induced reductions in NPP as a percentage of NPP_0. (*b*) Total HANPP as a percentage of NPP_0. Blue (negative values) indicates increases of NPP_{act} (*a*) or NPP_t (*b*) over NPP_0, green and yellow indicate low HANPP, and red to dark colors indicate medium to high HANPP.

(From Haberl et al. 2007).

Figure 2.15 Loss of Biotic Diversity

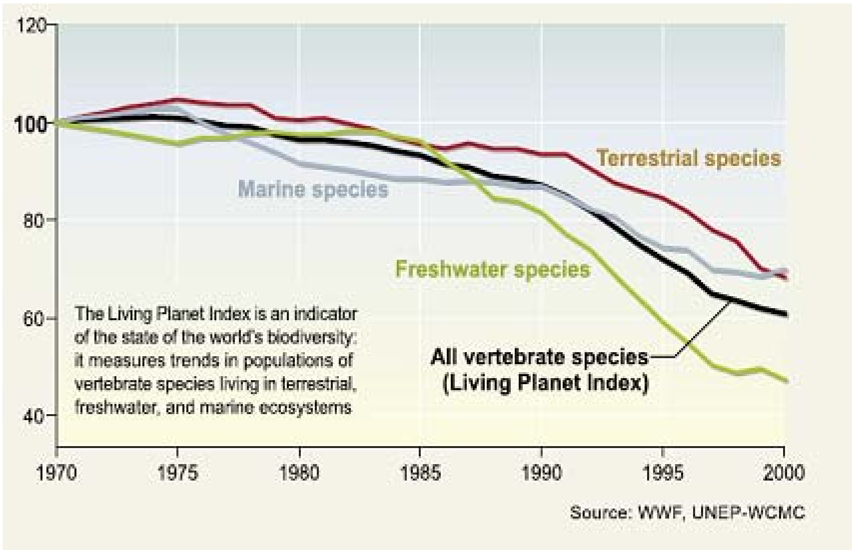
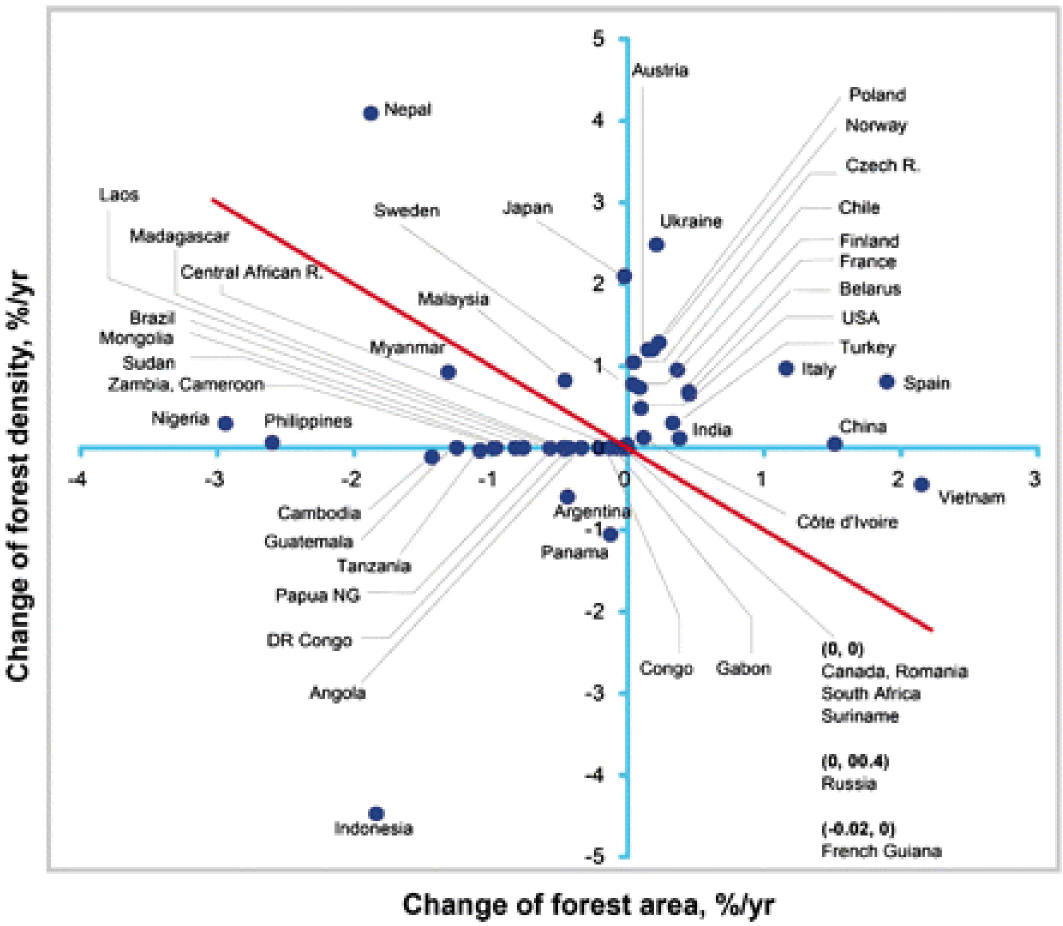


Figure 2.16 (PNAS 2006) A synoptic chart of changing forests during 1990–2005 in the 50 nations with the most growing stock reported in 2005. On the chart, the horizontal axis or longitude is the relative change of forest area (*a*), and the vertical axis or latitude is the relative change of growing stock density (*d*). Volume (*v*) was positive in nations above the diagonal line, $a = -d$, because growing stock was increasing.



TABLES

Table 2.1

Global Conditions in the Three Human-Environment Phases

	Phase 1: 1 mil.-12,000 BP	**Phase 2: 12,000 BP to 1760 ACE**	**Early Phase 3: 19th to 20th Century**
Population			
Population size (m)	0.125 – 5.32	5.32-769	769-6,086
Global Density (km^2)	.00425-.04	0.04-5.7	5.7- 45
% Urban**	0	<10% (1760)	10-50
Human development			
Life expectancy	Up to 30	20 - 35	35-63
Consumption			
Technology	Stone tools & fire	Domestication	Industrial-science
Energy consumption	Low - biofuels	Low - biofuels & water	High – fossil fuels
Governance	Kinship, bands, tribes	Stratified to nation-state	State, international, corporate
Stocks of natural capital			
Fresh Water	High	High	Major alterations
Forest	High	Major losses	Major losses
Agricultural land	None	Major gains	Major gains
Dryland	None	Alteration through burning	Major degradation
Biodiversity	High with exception of megafuana loss	High in general; low in domesticates	Major losses in general and reduced number of domesticates
Major Environmental Impacts	Megafauna extinction	Major deforestation & exchange of biota; grassland expansion; some dryland degradation	Major alteration of ecosystems globally & matching nature in biogeochemical cycles

*Population and density taken from Deevey (1960) and Unidted Nations 2007
** Chandler (1987: 521). Phase 2 estimate dated to 1700; Phase 3, to 2000

Table 2.2

Change in forested land 1990-2000 by region

	total land area (million ha)	*total forest 1990 (million ha)*	*total forest 2000 (million ha)*	*% of land forested in 2000*	*change 1990-2000 (million ha)*	*% change per year*
Africa	2 963.3	702.5	649.9	21.9	-52.6	-0.7
Asia and the Pacific	3 463.2	734.0	726.3	21.0	-7.7	-0.1
Europe	2 359.4	1 042.0	1 051.3	44.6	9.3	0.1
Latin America and the Caribbean	2 017.8	1 011.0	964.4	47.8	-46.7	-0.5
North America	1 838.0	466.7	470.1	25.6	3.9	0.1
West Asia	372.4	3.6	3.7	1.0	0.0	0.0
world	**13 014.1**	**3 960.0**	**3 866.1**	**29.7**	**-93.9**	**-0.24**

Source: compiled from FAO 2001b Note: numbers may not add due to rounding

Table 2.3Estimates of land area belonging to vulnerability classes and corresponding number of impacted population. Note: The global population density map is limited to latitudes 72°N to 57°S.

Vulnerability Class	Area Subject to Desertification		Population Affected	
	Area (million km^2)	Percent (Global land area)	Number (Millions)	Percent (Global Pop.)
Low	14.60	11.2	1,085	18.9
Moderate	13.61	10.5	915	15.9
High	7.12	5.5	393	6.8
Very High	7.91	6.1	255	4.4
TOTAL	44.24	34.0	2,648	44.0

Table 2.4 Prospects for completing transitions in the 21st century

	Transition ends by 2050-2100?
Population	
Population size	Yes
Density	Yes
Proportion urban	Yes
Human development	
Life expectancy	Yes (to slower pace)
Expanding knowledge	No, continued growth
Human productivity	No, continued growth
% labor in agriculture	Yes
Consumption	
GDP per capita	No, continued growth
Energy consumption	No, continued growth
Energy intensity	No, continued decline
Carbon intensity	No, continued decline
Stocks of natural capital	
Fresh Water	Yes
Forest	Yes
Agricultural land	Yes
Dryland	?
Biodiversity	?

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[10] Turner et al. 1990
[11] Another possible exception is the Ruddiman hypothesis. Ruddiman (2003) makes the case that sufficient deforestation had taken place by 8000 BP and irrigated rice cultivated by 5000 BP to have affected global warming through increased concentrations CO_2 and CH_4 in the atmosphere. This claim is highly contested (EPICA 2004).
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[23] Perera 1993
[24] Pala 2006
[25] Turner et al. 1990
[26] Crutzen and Steffen 2003
[27] These changes affect the kinds of environmental services from nature. While cumulative changes focus on provisioning services (e.g., food, water), systemic changes directly affect the functioning of environmental systems by affecting their provisioning and supporting services. These services are elaborated in Chapter 3. MEA 200x
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