Chapter 28

Synthesis: Condition and Trends in Systems and Services, Trade-offs for Human Well-being, and Implications for the Future

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BOXES

FIGURES

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*This appears in Appendix A at the end of this volume.

28.1 Introduction

This chapter draws on previous chapters to present a portrait of the major changes in the condition of ecosystems, the services they provide, the drivers of change, and the prospects for sustainability. It is organized around major questions and issues rather than around services and systems per se. The time frame for considering these issues is generally the last several decades, although in some instances this has been expanded where data allow or if needed to illustrate some particularly important points.

The chapter examines some of the implications of the observed trends and trade-offs for the continued capacity of ecosystems to provide services for human well-being but does not consider different trajectories into the future or possible policy responses, as these are considered in the *Scenarios* and *Policy Responses* volumes of the MA. Finally, the chapter outlines some of the major needs for continued research and data, focusing primarily on the areas that most severely hampered the ability of the MA Condition and Trends Working Group to reach conclusions.

28.2 How Have Ecosystem Services Contributed to Recent Improvements in Human Well-being?

Substantial improvements in human well-being in many parts of the globe have been apparent over the last half of the twentieth century. (See Chapter 5.) World population has more than doubled over the last 50 years (see Table 28.1), and consumption of many ecosystem services has grown even more. (See Chapters 7–17.) Life expectancy has increased in most areas of the world and infant mortality rates have declined almost everywhere, with the exceptions of the former Soviet Union and sub-Saharan Africa. Famines have become less common, and hunger has declined in absolute terms, although it remains a significant problem in some specific regions. (See Chapters 6 and 8.) Arrayed against this aggregate pattern of gains is the growing disparity of wealth, both between and within countries, and the failure of Africa in particular to share in the decades of major economic gains and the growth in social and institutional capabilities. (See Chapters 5 and 6.)

Table 28.1. Global Population and Life Expectancy, 1950, 1975, and 2000 (United Nations 2003)

Population size	1950	1975	2000
		(million)	
Industrial countries	813	1,047	1,194
Developing countries	1,706	3,021	4,877
Africa	221	408	796
Asia	1,398	2,398	3,680
Europe	547	676	728
Latin America and Caribbean	167	322	520
North America	172	243	316
Oceania	13	22	31
World	**2,519**	**4,068**	**6,071**

Life expectancy, both sexes combined	1950–55	1970–75	1995–2000
		(years)	
Industrial countries	66.1	71.4	74.8
Developing countries	41.0	54.7	62.5
Africa	37.8	46.2	50.0
Asia	41.4	56.3	65.7
Europe	65.6	71.0	73.2
Latin America and Caribbean	51.4	60.9	69.4
North America	68.8	71.6	76.4
Oceania	60.3	65.8	73.2
World	**46.5**	**58.0**	**64.6**

Numerous factors have contributed to these overall global improvements in human well-being, including major gains in manufactured and social capital, increased efficiencies associated with research and technology development, and the emergence of more-effective national and international institutions. (See Chapter 3.) But the human capacity to exploit ecosystem services has played a central role, and people have been extraordinarily successful in most of the world in using those services to meet a wide range of needs, such as food, clean air and water, shelter and protection from natural hazards, and cultural fulfillment. As human populations and individual well-being have increased, so has the consumption of ecosystem services, leading to increasing demands on ecosystems to provide for people.

The use of ecosystem services has also changed in its nature, in large part due to research and technology development, allowing for more-efficient use and production of services such as clean water and food and for partial substitutes to be developed for other services, such as for some fibers and for some cultural services. However, the parallel increased efficiency of use of many ecosystem services has been offset by increases in the absolute amounts of consumption of services, giving rise to serious concerns about the sustainability of their supply. (See Chapters 7–17.) In addition, the increasing consumption of some ecosystem services is clearly resulting in trade-offs in other services and thereby in the availability of certain benefits to people around the world. Such trade-offs in services, and thereby human well-being, are occurring across temporal and spatial scales; some areas and some people have gained, but at the same time some areas and some people are losing out.

Social and institutional issues are important in the effective use of ecosystem services. The enormous expansion of human capital has been crucial in securing both greater efficiency in and simply greater use of natural resources. Social institutions play an important role in facilitating growth, avoiding overexploitation, and managing environmental impacts. A decision-making environment with transparency, extensive flows of information, accountability, and minimization of corruption is a key to efficient uses of ecosystem services. The weight of evidence, however, suggests that current international disparities in income and wealth and in gender equality seriously constrain the development of institutional capabilities to support major future gains in human well-being. Well-functioning legal and judicial systems also contribute to sustainable development and the protection of environmental assets.

28.3 Which Areas Have Seen the Biggest Changes in Ecosystems over the Last Several Decades?

Changes in land cover, driven by the way people use land, are perhaps the most important single change in terrestrial ecosystems, affecting the supply of services. (See Chapters 21–27.) Although there has been a rapid expansion in the availability of data and information on ecosystems, there has not yet been a systematic examination, using global and regional observations, of the status and trends in land cover. This section summarizes a synthesis of the available information on rapid land cover change for about 1980 to 2000. Coastal and marine systems have also undergone dramatic changes during this period—for example, through the loss of mangrove forests and degradation of coral reefs in coastal areas (see Chapter 19), the declines in the abundance of marine fishes, and degradation of the sea bed in many areas (see Chapter 18). Of all the broad ecosystem types, inland waters are thought to be the most altered by human actions, particularly through the decline in water quality (see Chapters 7, 15, and 20) and the loss and fragmentation of wetlands (see Chapter 20).

The types of land use change included in the terrestrial analysis presented here are forest cover changes (deforestation and forest expansion), land degradation in drylands, and expansion of urban settlements. (See Box 28.1.) Information is also presented on recent changes in cropland extent.

Deforestation has been the most frequently measured process of land cover change on a regional scale; more datasets are available for the tropics than the boreal zones. During the 1990s, deforestation and forest degradation appeared to be more frequent in the tropics than elsewhere. (See Figure 28.1 in Appendix A and Chapter 21.) In particular, the Amazon Basin and Southeast Asia had large concentrations of deforestation ''hotspots.''

It is possible that areas of deforestation or degradation in the boreal or temperate regions (such as Canada or Siberia) are underrepresented. For example, forest degradation in Siberia, mostly related to logging activities, has been rapidly increasing in recent years. Moreover, the frequency of major fires, which are a natural disturbance factor in boreal forests, has increased globally since 1960. (See Chapter 16.)

There also remains uncertainty even within regions for which data are available. National statistical data indicating no net loss of forest can mask more detailed trends, such as a combination of deforestation in some regions and expansion of plantation forests in others. Some European countries, the United States, and Canada all experienced an overall increase in forest cover at the national level. (See Chapter 21.)

Most of the known areas of degraded dryland are found in Asia (see Figure 28.2 in Appendix A and Chapter 22), although not all the drylands of the world have been well studied. Major gaps occur in knowledge of dryland areas around the Mediterranean basin, in eastern Africa, in parts of South America (North of Argentina, Paraguay, Bolivia, Peru, and Ecuador) and in the United States. If all drylands were equally well studied, the global distribution of the most degraded land might turn out to be different, but the patterns currently observed in Asia would likely remain the same. The available data do not support the claim that the African Sahel is currently a desertification ''hotspot.'' (See Chapter 22.)

The most populated areas of the world are located in the Gangetic plain of northern India, on the plain and north plateau of China, and on the island of Java in Indonesia. The most populated cities, with more than 750,000 inhabitants, are mainly located on the eastern coast of the United States, in Western Europe, and in India and East Asia. The most rapidly growing cities are located around the tropical belt, however, rather than in temperate regions. (See Figure 28.3 in Appendix A and Chapter 27.)

Data availability to determine cropland expansion and abandonment varies regionally. However, it is likely that the largest and most rapid areas of cropland increase are found in Southeast Asia, followed by Bangladesh, the Indus Valley, parts of the Middle East and Central Asia, the region of the Great Lakes of eastern Africa, and the southern border of the Amazon Basin in Latin America. (See Chapter 26.) North America accounts for most of the main areas of decrease in cropland (in the southeastern United States), followed by Asia (eastern part of China) and South America (parts of Brazil and Argentina). Areas of decrease in cropland extent are located in most other continents, although Africa is the only continent where no decrease in cropland was identified. Data quality issues are extremely important in evaluating these trends, and a graphic presentation of these changes, together with the associated data and an assessment of the data, is available at www.MAweb.org.

BOX 28.1

Constructing the Land Cover Change Maps

Deforestation and forest degradation. The map of the main areas of deforestation and forest degradation is based on three types of data sources: expert opinion gathered through formal procedures, remote sensing-based products, and national statistics. To avoid the coarse scale of national statistics, priority was given to the remote sensing and expert opinion data. The final map identifies, for each "forested" grid cell, how many input datasets covered the area and how many times it was considered as a main area of deforestation or forest degradation by these different datasets. A second color code represents the reliability (estimated in terms of convergence of evidence) of the information—that is, the frequency of detection as a hotspot relative to the number of data sets covering the area (see legend for color code). The information based on (sub)-national statistics provides average annual rates of deforestation and should be considered as secondary to the other sources because it is not at a fine resolution. When that rate is higher than 3% per year, the area is considered as rapid change.

Desertification. The map of the main areas of degraded land is constrained by lack of reliable data compared with the maps on deforestation and cropland extent. Most available data are quite heterogeneous in terms of monitoring methods or indicators used.

Changes in urban extent. While urban areas are defined as any region with population density greater than a threshold, the impact of urbanization on land cover is better measured by the change in built-up area. The final map shows the spatial distribution of the population density in 1995 and identifies the most populated and most rapidly changing cities of more than 750,000 inhabitants.

28.4 What are the Main Drivers of Change That Affect Ecosystems, Ecosystem Services, and Associated Human Well-being?

The human and environmental forces that drive changes in ecosystems, and thereby changes in ecosystem services and human well-being, are highly variable from place to place. As such, generic explanations or statements of causality are difficult to create. Driving forces are almost always multiple and interactive, so that a one-to-one linkage between particular driving forces and changes in ecosystems and ecosystem services is usually not possible. (See Chapters 3, 4, and 11.) Similarly, the linkage between particular changes in ecosystem services and various indicators of human well-being is often not well understood. (See Chapters 5 and 7–17.) In both cases, the causal linkage is almost always highly mediated by other factors, thereby complicating statements of causality or attempts to establish the proportionality of various contributors to changes. Analyses of driving forces generally distinguish between direct factors (the immediate causal agents of change) and the more indirect underlying factors that themselves cause change in the direct drivers. (See Chapter 3.)

Drivers of biodiversity loss are reasonably well understood, at least qualitatively. It is *well established,* for example, that habitat conversion, degradation, and fragmentation on land (usually for agricultural expansion) and in the oceans (mostly associated with fishing activities) have been the most important direct drivers of biodiversity loss globally in the recent past. Although habitat change will continue to be an important threat to biodiversity, the impacts of climate change, invasive non-native species, pollution, and nutrient overload are all increasingly important. (See Chapter 4.)

Some other linkages between drivers and impacts are also well known. In the case of impacts on human health, for example, it is known that burning wood, charcoal, and dung in poorly designed stoves has serious adverse effects on indoor air quality and is thought to be responsible for some 1.6 million deaths per year, almost all in developing countries. (See Chapters 9 and 27.) There is a complex set of driving forces affecting the increasing risk of infectious diseases in humans, including logging, dam and road building, agricultural expansions, urban sprawl, and pollution of coastal areas. (See Chapter 14.) With regard to adverse impacts on inland waters, land use change, nutrient overload, and pollution have been the key human driving forces. (See Chapter 20.)

Population growth, economic development, and increasing consumption and production are all important indirect drivers of change in ecosystems and ecosystem services. However, increasing attention is being given to the role of government policies relating to, for example, investments in rural roads, irrigation, credit systems, and agricultural research and extension, which have often served to expand food production. (See Chapter 8.) Policies that restrict trade, capital, and labor flows have conditioned access to international markets and have structured the international food system and global patterns of food production and consumption. Small-scale food producers in many poorer countries have been particularly affected by many such policies, as have general patterns of nutrient cycling. (See Chapter 12.)

28.5 Is There Evidence That Changes Made to Ecosystems in Order to Increase Provisioning Services Have Altered Regulating, Cultural, or Supporting Services?

The growth in human well-being at the global scale over the last several decades has come in large part because of increases in provisioning services from several major ecosystems. These changes have been particularly significant in cultivated systems, where the largest changes in the recent past have been as a result of intensification rather than the large-scale conversion of uncultivated land to agriculture (see Chapters 8 and 26), and in coastal and marine systems, where changes have occurred due to increased fish harvest and the increasing addition of nutrients in coastal systems (see Chapters 8, 12, 18, and 19). Over the last 50 years forests have also been changed dramatically, with the largest changes in tropical and sub-tropical forests, where there has been substantial clearing and transformation of previously forested land for agricultural and timber production. (See Chapters 9 and 21.) Changes in forests in the temperate and boreal zone, while regionally important, have generally been small in the recent past compared with changes in the sub-tropics and tropics, and they have often involved increases in forest cover. (See Chapter 21.)

This section explores the major changes in ecosystem provisioning services over the last several decades and the trade-offs that have come as a result of the increased focus of human management on provisioning services. Over the past 50 years, there have also been substantial changes in some of the regulating, cultural, and supporting services that ecosystems provide, and those that are considered to be the most important are presented here. In some cases, these have been the direct result of managing ecosystems primarily for their provisioning services. In other cases, they are the direct result of transformation of ecosystems and habitat to other uses entirely. The major trade-offs in other services for the enhancement of provisioning services have come from the influence of ecosystems on atmospheric composition and climate feedbacks, nutrient cycling, the spread of disease, and biodiversity itself.

28.5.1 Food

Globally, ecosystems have met the rising demand for food over the last 50 years. The availability of basic food items such as cereals has increased faster than population growth, and the price of staple food items for many people is lower. (See Chapter 8.) There are significant regional differences in the accessibility to food, however.

Marine capture fisheries are the exception to the general increase in food availability. Globally, fish catches have declined over the last 10–15 years, and prices for fish from capture fisheries have risen. (See Chapters 8 and 18.) Although the cultivation of some of the targeted marine species has the potential to offset this decline at cheaper prices than for capture fisheries, the current high dependence on wild capture fisheries suggests that this potential will not be realized in the next few years.

The last 50 years has witnessed major successes in global agriculture, largely the result of improved crop varieties, synthetic fertilizer, irrigation, and other agricultural technologies, although expansion of land area under cultivation has played a role in many developing countries, particularly in sub-Saharan Africa. (See Chapter 26.) Food production from croplands has outpaced population growth over the last several decades when viewed in the global aggregate, with increases in food output per capita most rapid in East Asia. Yet in the world's poorest regions, especially in sub-Saharan Africa, yields have not benefited from advances seen elsewhere, and food insecurity persists. In sub-Saharan Africa, per capita food output has declined. (See Chapter 8.)

The intensification of agriculture underlies the enormous increase in the flow of food provisioning services over the last several decades, including of crops, livestock, and aquaculture. The trade-offs associated with the increases in this service are many, most prominently:

- major impacts on nutrient cycling, as rapid growth in the application of excess synthetic fertilizer contributes nitrogen and phosphorus to inland waters and coastal systems (see Chapters 12, 19, and 20), and
- loss of biodiversity in cultivated systems with monocultures associated with intensive agriculture (see Chapters 4 and 26).

The increase in land area under cultivation associated with agricultural extensification has involved a different set of trade-offs, most notably:

- habitat fragmentation and loss of biodiversity as land (mainly forest) is cleared for cropland (see Chapters 4 and 21), and

- impacts on atmospheric composition, particularly the greenhouse gas carbon dioxide, and climate regulation as biomass is cleared for cropland (see Chapters 13, 21, and 26).

Over the long term, declines in supporting and regulating ecosystem services, such as soil fertility, water cycling, and genetic resources, potentially undermine the ability of food production to keep pace with population growth in the absence of new, major technological advancements in agriculture. Those relying on subsistence agriculture are among the poorest and the most directly vulnerable to reductions in these ecosystem services, as their lack of economic resources limits access to alternative food sources. (See Chapter 7.)

28.5.2 Water

Over the last 50 years, people's access to water has also improved globally, although—like food—there are regional differences in quantity and quality of supply. (See Chapter 7.) The regulating and provisioning of water and its associated benefits (such as for food production through irrigation, or energy production through hydropower) has been a key factor in improving human well-being. The provisioning services of cultivated and dryland systems in particular have been possible primarily through the delivery and regulation of water through irrigation and flood control. The capacity of ecosystems to provide clean and reliable sources of water, however, is in decline in many parts of the world. (See Chapters 15, 16, 20, 21, and 24.)

Human well-being has improved through managing water use, controlling floods, providing transportation, irrigation, generating hydroelectricity and pollution control. The trade-offs for these improvements have included habitat fragmentation and loss, biodiversity loss, increases in certain human health risks, and declines in sediment supplies to the coastal zone. Levels of organic pollution (such as human and animal wastes and excess fertilizers) and inorganic pollution (such as pesticides, heavy metals, and PCBs) are increasing, much of which is from cultivated and urban systems. (See Chapters 15, 26, and 27.) Many of these pollutants are ultimately deposited in freshwater, coastal, and marine systems, affecting aquatic habitats, fish stocks, and the health of local human populations. (See Chapters 15, 19, and 20.)

The deterioration of the quantity or quality of fresh water is especially acute in cultivated systems, dryland systems, urban systems, and wetlands. (See Chapters 20, 22, 26, and 27.) The per capita availability of water has declined significantly since 1960 and the trend is expected to continue, albeit more slowly, until at least 2010. (See Chapter 7.) Economic development, including food provisioning and other water uses, will be most affected in those areas experiencing or at risk of water scarcity, particularly drylands. (See Chapter 22.)

28.5.3 Fish

Total fish supply has increased over the last 50 years but the cost to the sustainability of fish stocks and to the quality of many coastal and marine environments has been high. (See Chapters 18 and 19.) Technological changes followed by economic subsidies have fueled the expansion of fisheries into every ocean. Many fishing fleets are continuing to fish further offshore and deeper to sustain catches and to meet the growing demand for fish products, and this has led to a number of targeted stocks in all oceans having collapsed due to overfishing. (See Chapter 18.) More recently, the demand for selected marine products throughout the year has fueled the growth of inland, coastal, and offshore aquaculture, with consequential impacts to ecosystems. For example, the development of shrimp aquaculture has accounted for a significant loss of coastal habitat, in particular mangroves, in many tropical countries. (See Chapters 8 and 19.)

Globally, per capita consumption of fish is increasing, especially in Asia and the Americas, while in Europe and Africa consumption growth is moderate. Aquaculture production is increasing in both freshwater and marine systems at a rate of approximately 1 million tons per year , and it now supplies almost one third of all fish consumed, thereby sustaining increasing per capita consumption. (See Chapter 19.) However, much of the increase in marine aquaculture is in high-value species such as shrimp and salmon and therefore is not necessarily meeting the needs of poor consumers. Capture fisheries also provide employment and subsistence opportunities for many of the world's poor, many of whom are without access to property or property rights.

Provisioning of fish for food directly and indirectly (via fishmeal, animal feed, and fertilizers) has in many places resulted in degradation of coastal and marine systems and of other ecosystem services. (See Chapters 18 and 19.) Overfishing of many fish stocks in shallow coastal shelf systems has changed highly diverse, complex, and robust coastal ecosystems into systems of reduced diversity and resilience. (See Chapter 19.) Due to fishing pressures, for example, the Gulf of Thailand has changed since 1970 from a system with a high diversity of fish, including top predators, to one dominated by small, short-lived species that support a low-value fishery from which catches are mainly used for feed in the high-value invertebrate aquaculture industry. Such a reduced-diversity system may be more sensitive to external impacts and has a lower capacity to deliver ecosystem services. (See Chapter 11.)

Many coral reefs have shifted to algal-dominated systems where recovery is highly unlikely due to a combination of overfishing, disease, and climate change. (See Chapter 19.) The impact of destructive fishing practices such as bottom trawling and bombing exacerbates the problem of overfishing and restoration of depleted stocks. (See Chapter 18.) Although our understanding of the impact of overfishing in deep water and pelagic systems on regulating and supporting services is limited, the exploited species in some deepwater systems such as seamounts that were fished in the 1970s have not been recorded since then (see Chapter 18), suggesting that such systems are unable to recover over the short to medium term.

Overfishing has also affected the cultural services provided by marine and coastal systems. Many communities whose culture is based on a long history of fishing are in decline, with many fishers and their families migrating to urban areas. Those who choose to remain find that their social and economic conditions often decline. (See Chapter 18.)

28.5.4 Atmospheric Composition and Climate Feedbacks

Ecosystems influence air quality and climate, both through natural processes that maintain the status quo and through management-induced changes that can be either detrimental or beneficial to human well-being. (See Chapter 13.) Ecosystems play an important role in cleansing the atmosphere of pollutants. Changes in ecosystems as a result of human activity are one of the main drivers of change in climate and air quality, along with fossil fuel burning and industrial emissions, and concentrations of key greenhouse gases and other atmospheric constituents will continue to change in the future as a result of human impacts on ecosystems.

The most important changes in ecosystems leading to changes in atmospheric composition and climate feedbacks have been land clearing for agriculture, ranching, and urbanization—mostly through deforestation and biomass burning, although draining of wetlands has also been important, as has the increase in rice cultivation and livestock production. (See Chapters 9, 13, and 21.) These activities have resulted in an increase in concentrations of many trace gases in the atmosphere that subsequently change the chemistry of the troposphere and reduce the atmosphere's own capacity to remove pollutants (atmospheric cleansing capacity). These trace gases also act as pollutants themselves, act as fertilizing agents, change ozone concentration in the troposphere, and affect global climate (through impacts on radiative forcing, greenhouse gases, and cloud formation). Finally, ecosystem changes such as decreasing forest cover alter the physical properties of Earth's surface that in turn influence climate and hydrology, although these effects have likely been relatively smaller than the direct effects on atmospheric composition. (See Chapter 13.)

28.5.5 Nutrient Cycling

Nutrient cycling has been affected significantly in the last few decades, mainly from large-scale changes in agriculture and its inputs. (See Chapters 12 and 26.) As such, most of the trade-offs with other services can be tracked by focusing on areas where agriculture has changed substantially.

Changes in the extent and management of cultivated lands are nothing new. Before the Industrial Revolution, both because human populations were smaller and because there was a need to maintain forests and woodlands for fuel, the expansion of agricultural land was relatively small. Between 1950 and 1980, however, more land was converted to cropland than in the 150 years between 1700 and 1850 (see Chapter 26), due to both the needs of growing human populations and the availability of coal as an energy source. Cropland expansion has been estimated at about 1,200 million hectares over roughly the last 300 years.

With the exception of many tropical regions, which have experienced recent expansion of croplands, much of the potentially productive agricultural land appears already to have come under cultivation, thereby limiting potential for further expansion. (See Chapter 26.) Instead, there have been major increases in the intensification of the management of cultivated lands, including the increased addition of nutrients. This is reflected in part in the available data for the application of nitrogen-based fertilizer and in the observation that cropland yields have largely continued to rise on a per-hectare basis even as the rate of cropland expansion has dropped in much of the world. (See Chapters 8 and 26.)

The changes in the nitrogen cycle have been dramatic. Fertilizers spread on agricultural land, enhancement of N-fixation by planted legumes, biomass burning, fossil fuel combustion, land clearance, and wetland drainage have contributed to a doubling of natural inputs of nitrogen to ecosystems. (See Chapter 12.) The increase of biologically available nitrogen due to these sources, coupled with the leaching of phosphorus fertilizers and wastes, has led to substantially increased eutrophication in a number of aquatic systems. (See Chapters 19 and 20.) The increase in number, extent, and severity of periodically anoxic zones in estuarine systems around the world, for example (see Chapter 19), is a direct consequence of this trade-off.

Impairment of the nutrient cycling service is due to a disruption of a number of regulatory mechanisms that operate at different spatial and temporal scales. (See Chapter 12.) In soils, for example, synchrony between nutrient supply and demand by plants is a complex system whose stability requires a minimum biodiversity of plants and soil organisms. The intermediate storage of nutrients in soil aggregates is often decreased by a severe depletion of the abundance and diversity of the plants and soil organisms that create this structure. Another effect of human activities on nutrient cycling has been the impairment or removal of the buffers, such as riparian forests and wetlands, that naturally ensure a close cycling of nutrients and thereby reduce losses to other compartments of the biosphere. (See Chapter 12.)

28.5.6 Spread of Disease

Historically, many diseases have emerged from altered ecosystems or domesticated animals (such as tuberculosis, measles, plague, and HIV), while other disease agents are in the process of adapting to human-dominated systems. Newly resurgent diseases deserve special attention if they have recently increased in incidence or emerged in a new geographical location, if they are of major public health importance and economic impact, or if they are difficult to control (such as antibiotic-resistant strains). Among these, malaria, leishmaniasis, dengue, and schistosomiasis are of major concern for the tropics; West Nile virus and Lyme disease in North America and Europe; and Japanese encephalitis in Asia. (See Chapter 14.) Also, food- and water-borne diseases stemming from intensive livestock or fish production are a growing concern. (See Chapter 8.) Approximately 75% of all emerging diseases are zoonotic (coming from animals), thus stressing the importance of further investigation of the role of biodiversity and ecological dynamics that are now recognized as central to disease prevention.

The most important drivers of ecosystem change that have affected infectious disease risk include tropical deforestation, road building, expansion of irrigation and dam building, local and regional weather anomalies, intensification of animal production systems, urban sprawl, poor sanitation, and pollution of coastal zones. (See Chapter 14.) The groups most vulnerable to disease risks from these changes include poor populations with little shelter or sanitation, which increases exposure to these risks, who have few financial resources to respond adequately. Activities such as international trade and travel have also led to an increase in infectious diseases. West Nile virus and monkeypox in North America and SARS globally are prime examples.

The magnitude and direction of altered disease incidence depends both on the type of land use change and the size of the human population exposed. Migration to a newly accessible forest or shoreline of a dam, for example, results in higher potential for disease epidemics. And the type of land use change, whether from mining, irrigation, dam construction, deforestation, or other causes, will promote specific diseases depending on geographic location. Major changes in habitat can both increase or decrease the risk of a particular infectious disease. (See Chapter 14.)

While many systems, such as forests, drylands, or cultivated systems, contain a distinct set of infectious diseases, several major diseases (including malaria and dengue) are more ubiquitous occurring across many ecosystems. For example, malaria is transmitted by 26 differing species of Anopheline mosquitoes that are each dominant in varying habitats and geographic locations. While *Anopheles gambiae* and *An. funestus* are the primary malaria vectors in Africa, *An. darlingi* is the primary carrier in South America, and *An. dirus* is in parts of Southeast Asia. Each species responds differently to a specified land use change, and it is therefore difficult to generalize ecosystem change effects across many regions.

On the other hand, some diseases such as yellow fever can be transferred across ecosystems. The natural zoonotic cycle of yellow fever occurs between mosquitoes and monkeys high in forest canopies, but the disease can move into savanna, agricultural, and even urban areas facilitated by human economic activities such as logging or forest clearing for crops and livestock.

Large preserved natural systems, due to their physical and biological characteristics, are relatively unreceptive to the introduction of many invasive human and animal pathogens that are brought in through human migration and settlement. For example, schistosomiasis, Kala-azar, and cholera have been introduced in the Amazon region but have not been able to become established in the natural forest system. (See Chapter 14.)

Higher levels of biodiversity can reduce the risk of some vector-borne diseases via a ''dilutional effect'' or by maintaining natural predators. (See Chapters 11 and 14.) The former effect has been documented in the case of Lyme disease in North America and is likely true for many diseases where the capability of an animal host to be infected and carry a disease agent varies greatly across the intermediate animal hosts on which an insect vector must feed. Schistosomiasis in Lake Malawi provides a good example of the relationship of disease emergence to natural predators, as it rose rapidly following overfishing of fish predators on the snail intermediate host for the parasite that causes the disease.

28.5.7 Biodiversity

It is *well established* that losses in biodiversity are occurring globally at all levels, from ecosystems through species, populations, and genes. (See Chapter 4.) The current documented rate of species extinction is two orders of magnitude higher than the average rate of species extinction from the fossil record, and there is a continuing trend for conversion of naturally occurring, species-rich ecosystems into more intensively managed habitats with reduced biodiversity. Losses at the population level are variable but substantial in certain systems, such as marine, freshwater, and agricultural systems, and more common in large and long-lived species. Figure 28.4 (in Appendix A) presents the aggregate global trends in populations of well-studied species. The extent of loss of genetic diversity is less well understood and is mainly inferred from declines in higher levels of biodiversity organization, although recorded losses in agricultural genetic diversity are widespread. (See Chapters 4 and 26.)

There are some instances where biodiversity is increasing, in terms of extent of habitat and species composition, such as in temperate forest areas in the northern hemisphere. (See Chapters 4 and 21.) However, available data show aggregate global declines in both the distribution and diversity of biomass. Although widespread, losses of biodiversity are currently particularly prevalent in areas of high species richness, such as tropical forests and coral reef systems. (See Chapters 4, 19, and 21.) Inland waters are also likely to be experiencing high levels of biodiversity loss in most parts of the world. (See Chapter 20.) Habitat conversion (generally for agricultural expansion), degradation, and fragmentation continue to be the most important direct drivers of biodiversity loss globally, although there is an increasing impact of invasive non-native species, of nutrient pollution, and of climate change in many systems. Island systems in particular have historically been affected by the introduction of exotic species, with widespread negative impacts on native island biodiversity.

The impacts of current trends of biodiversity loss on human well-being are multifaceted. While people benefit directly from components of biodiversity in the form of provisioning services and are therefore affected directly by declines in availability of those elements of biodiversity that are providing those goods, the more fundamental role of biodiversity is in the functioning of ecosystems and thereby in the capacity of ecosystems to provide the full range of ecosystem services. (See Chapters 4 and 11.) Both the amount of living material (biomass) and its diversity and distribution play important roles in determining the capacity of systems to provide services now and into the future. Evidence suggests that decreases in the amount of live biomass have directly affected the capacity of some ecosystems to provide services, such as the capacity of tropical forests to regulate local and regional climate (see Chapter 13) and to protect from natural hazards (see Chapter 17) or the capacity of marine, coastal, and inland water systems to provide food (see Chapters 8, 18, 19, and 20). And these services show declining trends.

Current understanding of the consequences of losses in the diversity of biomass is poor and on the whole is limited to a selection of species that play particularly obvious roles in ecosystem functions, such as pollinators for the provision of food services. (See Chapter 11.) The consequences of losses in most rare or restricted-range species are likely to be subtle. Indeed, some provisioning services, such as timber and food, appear most efficiently produced from less diverse systems, such as forest plantations and agricultural landscapes, as evidenced by the wide coverage of cultivated systems. (See Chapter 26.)

However, all ecosystem services are ultimately reliant on ecosystem functions and on the interactions between elements of biodiversity. (See Chapter 1.) It is also likely that more diverse systems are more resilient, resistant, and adaptable to changes in drivers. (See Chapter 11.) Among the most important factors identified is the degree of functional redundancy found between species within an ecosystem. For example, in many ecosystems there are several species that fix nitrogen. If the loss of any one of them is compensated for by the growth of others and there is no overall loss in nitrogen fixation, then the impacts of the loss of the species are reduced, in terms of the system's capacity to fix nitrogen.

There may, of course, be other consequences of the loss of these species. The possibility of significant losses of function increases as more species, and variability within species, are lost and as redundancy is reduced—that is, there is an asymptotic relationship between biodiversity and ecosystem functioning. Greater functional redundancy represents greater insurance that an ecosystem will continue to provide both higher and more predictable levels of services. (See Chapter 11.)

Although there have been significant benefits derived from the commercial exploration of biodiversity across a range of industrial sectors, and particularly from pharmaceutical bioprospecting, the consequences of losses of genetic and species diversity on bioprospecting potential remains largely speculative, especially in marine and coastal areas. (See Chapter 10.) Unlike some other services where there are minimum thresholds, however, overall declines in the amount of biodiversity proportionately reduce the resource base from which commercial exploration is possible.

There have been significant impacts of declining biodiversity on cultural services. Globally, many cultural values associated with the conservation of components of biodiversity, particularly relating to the amount and diversity of natural systems and of species and populations, continue to be affected directly through the current trends in declining biodiversity. (See Chapter 17.)

28.6 Is There Evidence That the Capacity of Ecosystems to Provide Services Is Reaching Critical Levels?

In addition to documenting the actual trade-offs that have been made while managing ecosystems for different services, the extent to which those trade-offs have resulted in a reduction in the capacity of ecosystems to provide services is also important to consider. If the underlying capacity of ecosystems to provide a range of services has been reduced, then there are obvious implications for the future not only of the ecosystems and services in question, but also for human well-being.

Of the services and systems examined in this report, it is clear that at a global level there are two issues where the capacity to continue to provide services has most clearly declined. One is marine and coastal capture fisheries, as described earlier in this chapter and in Chapter 18. It is now *well established* that the capacity of the oceans to provide fish for food has declined substantially and in some regions showing no sign of recovery. The other is the loss of biodiversity, in large part because the rates of loss (of species diversity) are so much more rapid than the creation of new diversity through evolutionary processes. (See earlier section and also Chapter 4.) The implications of this loss are less immediately clear than those of the decline of marine fisheries, but over the long run they are likely to be considerably more important. In addition, some systems have eroded their capacity to provide services on a regional basis, such as inland waters (Chapter 20), forests (Chapter 21), and drylands (Chapter 22). The implications of this regional reduction in capacity are explored more fully in the next section.

Understanding how the decline in the capacity of ecosystems to provide services has occurred is as important as documenting where the capacity has declined. A good deal of ecosystem change and corresponding decline in ecosystem services is gradual and occurs over long time frames. Such chronic loss of ecosystem services certainly affects human well-being but over decadal or intergenerational time frames. However, some ecosystem changes are nonlinear or abrupt and sometimes irreversible. The reasons for such nonlinearities include:

- intrinsic features of the ecology of certain ecosystems (that is, ecological thresholds),
- the magnitude and nature of the impact causing change (such as changes occurring in response to technological advances), and
- the features of the drivers of change (such as social and cultural ''ratchets'' that allow change in only one direction).

While each of these is described here separately, it should be noted that they are often present in tandem, particularly when large-scale ecosystem changes occur.

Significant changes in ecosystem structure and function can occur when certain triggers result in changes in the dominant species. An excellent example of this is provided by coral reef ecosystems that undergo rather sudden shifts from coral-dominated to algal-dominated reefs. The trigger for such phase shifts, which are for all intents and purposes irreversible, is usually multifaceted and includes increased nutrient input leading to eutrophic conditions and the removal of herbivorous fishes that maintain the balance between corals and algae. (See Chapter 19.) Once the thresholds for the two ecological processes of nutrient loading and herbivory (one an upper threshold and one a lower threshold) are passed, the regime shift occurs within months, and the resulting ecosystem, though stable, is less productive and less diverse than before the transformation. Human well-being is affected not only by reductions in food supply and income from reef-related industries (such as diving and snorkeling, aquarium fish collecting), but also by increased costs accruing from the decreased ability of reefs to protect shorelines, as algal reefs are more prone to being broken up in storm events, leading to shoreline erosion and seawater breaches of land.

Nonlinear changes in ecosystem structure and function can also occur at the regional level, affecting, for example, regional climate. (See Chapter 13.) The vegetation in a region influences climate through albedo, transpiration, and the aerodynamic properties of the surface. In the Sahel region of North Africa, vegetation cover is almost completely controlled by rainfall. When vegetation is present, rainfall is quickly recycled, generally increasing precipitation and in turn leading to a denser vegetation canopy. Model results suggest that land degradation leads to a substantial reduction in water recycling and may have contributed to the observed trend in rainfall reduction in the region over the last 30 years. In tropical regions, deforestation generally leads to decreased rainfall. Since forest existence crucially depends on rainfall, the relationship between tropical forests and precipitation forms a positive feedback, which, under certain conditions, theoretically leads to the existence of two steady states: rainforest and savanna. Some models suggest only one stable climate-vegetation state in the Amazon.

Introduced invasive species can also act as a trigger for dramatic changes in ecosystem structure, function, and delivery of services. (See Chapters 3, 4, and 11.) In marine systems, species are commonly brought into new areas through ballast water discharges from ships, and they sometimes establish in new areas through outcompeting native species for food and space. One example is the rapid and irreversible change in the Black Sea, where the carnivorous ctenophore *Mnemiopsis leidyi* caused the loss of 26 major fisheries species and has been implicated (along with other factors) in subsequent growth of the anoxic ''dead zone.'' (See Chapter 19.)

Certain kinds of human activity can lead directly to largely irreversible changes—the most obvious being habitat loss from conversion to urban environments, tourist resorts, ports and harbors, reservoirs, and agricultural lands. Habitat loss results in loss of not only the ecosystem services provided by the affected habitat, but often also the services provided by associated habitats. For instance, development of a port in an estuary may prevent people from obtaining food from the estuary and at the same time affect nearby fisheries whose target species depend on the estuary for nursery habitat. Even minor losses in species or habitat extent may reduce the capacity of ecosystems for adjustment to changing environments, with consequences for ecosystem function, services, and human-well being. (See Chapter 11.)

Finally, technological advances and other changes in drivers can have nonlinear impacts. For instance, societies moving from subsistence harvesting to harvesting with improved technology can cause very sudden and large changes in the rate of resource exploitation. These jumps in exploitation rates often pass the threshold for sustainability and result in crashes of harvested populations, such as fish stocks. The changes in drivers are also, in effect, irreversible, since a return to previous, low-tech methods is unlikely.

Another driver with a potentially disproportionate effect on environmental degradation and loss in services is human migration. This outcome can occur when in-migrants originate from culturally or ethnically different groups than local residents and have neither the same vested interests in environmental protection nor societal self-regulatory mechanisms, as do local communities. Such effects of migration are often not captured in assessments of population impact on environment, since migration, and especially internal migration, is often difficult to monitor and rarely shows up in population census data.

28.7 Are There Parts of the World in Which Recent Declines or Stagnation in Human Well-being Can Be Attributed to Changes in Ecosystem Services?

This assessment shows that global environmental change is highly variable among the world's regions. Some trends and their impacts become apparent only when the scale of analysis shifts from the global to regional and local scales. This section details some of the major findings emerging from the assessment at these lower scales and illustrates the needs to look at ecosystem changes at multiple scales.

Population growth rates are now declining nearly everywhere in the world, but with substantial regional differences. Substantial population growth is still expected in sub-Saharan Africa, South Asia, and the Middle East over the next few decades. The share of the global population represented by North America and Europe is expected to decline from 17% to 10%, while Africa's share is expected to increase from 13% to 23%. Urban populations are growing three times as fast as the population as a whole, creating ecological and socioeconomic problems in cities and surrounding hinterlands. Most of this growth will occur in developing countries. The most critical environmental effects, meanwhile, are local, such as unsafe water supply and indoor air pollution, where residents are also drawing down ecosystem services at ever-greater distances.

The trend toward an increasing proportion of urban dwellers can also most easily be seen on continental and regional scales. Over the past 50 years, there have been relatively modest increases in the proportion of the population living in urban areas in Europe (from 52% to 73%) and North America (64% to 77%). But both the absolute numbers and the percentages have increased dramatically in the developing regions of Africa (from 15% to 37%), Asia (17% to 38%), and Latin America and the Caribbean (42% to 75%). By the year 2000, Asia had 195 cities of more than a million inhabitants (up from 31 in 1990) out of a global total of 388 such cities. Asia also had 45 of the 100 largest cities in the world, while Europe had 15, North America 13, and Latin America 17. (See Chapter 27.)

Global agriculture has registered many successes for the provisioning of food from the world's ecosystems, but again a regional perspective reveals problems among generally favorable aggregate trends. Farmers in some of the world's poorest countries and other resource-poor regions have not shared in the yield increases over the past several decades. Per capita food output has actually declined in sub-Saharan Africa.

Meanwhile, policy distortions and market failures are important problems contributing to the highly variable pattern of food provisioning and food security. OECD countries provide extensive subsidies to their agricultural sectors and also protect them through tariffs, quotas, and export subsidies. The worldwide consequences of these institutional arrangements have been lower prices for internationally traded commodities, higher tax bills, and the overuse of agricultural inputs, such as fertilizers, with associated consequences on ecosystems. (See Chapters 12, 19, and 20.)

Despite widespread increases in the use of fertilizers in other parts of the world, sub-Saharan Africa stands out as a particular problem area where declining soil fertility is a principal constraint for sustaining food production and where soil nutrient stocks are being used unsustainably and fertilizer application remains low. (See Chapter 26.) Meanwhile, rising populations, declining use of fallow, the cultivation of fragile lands, and limited conservation investments are all apparent in many developing regions.

Although there is substantial reason to believe that the world in the coming decades can produce sufficient food to feed its growing population, important regional issues exist in the global pattern of cultivated land. Many regions have experienced declines in the area of cultivated lands over the last several decades, as described earlier. Due partly to increased competition for alternative land uses and to reduced availability of suitable land (particularly outside the tropics), there is declining potential for further expansion of agricultural lands; future increasing agricultural productivity in many parts of the world is likely to come largely from the intensification of the management of existing cultivated lands. (See Chapters 8 and 26.)

Access to sufficient clean fresh water is a problem at a global scale, but also one with a strong regional component. The essential functions of clean water are several: maintaining human and environmental health; supporting essential economic production, such as agriculture, energy, and industry; diluting and transporting wastes; and contributing to religious and cultural activities. (See Chapters 7, 15, 17, 20, and 26.) Despite their critical importance, these freshwater services are under threat throughout the world, and the world's poor people, concentrated in developing countries, are at particular risk. In the mid-1990s, some 80 countries with 40% of the world's population were already suffering from serious water shortages. North Africa and the Middle East, in particular, face great pressure and demand on already overstressed water resources. Azerbaijan, Egypt, and Libya, for example, were already using 55%, 110%, and 770%, respectively, of their sustainable water supplies in the early 1990s.

Water pollution is exacerbating local water scarcity in many parts of the world and is expected to accelerate in coming decades. In developing countries, 90% of sewage continues to be discharged into rivers, lakes, and coastal areas. In Africa, where such problems are particularly intense, major pollution sources include fecal contamination and toxic pollution from cities, industrial centers, and mining sites. (See Chapters 7 and 15.) It is clear, meanwhile, that environmental water is often the loser worldwide, for water needs also to be left in rivers and lakes to maintain the health of ecosystems and fisheries, which are already under heavy pressure from population and economic growth. (See Chapter 20.)

Differential vulnerability to environmental change and poverty also reveal strong regional and local variability. (See Chapter 6.) In the face of general global food availability and the progress in reducing the incidence of famine, many developing countries are experiencing declines in agricultural production and food security, especially among small-scale farmers, isolated rural populations, and those living on marginal lands. The global trends in natural disasters reveal that Asia is disproportionately affected, with more than 70% of all lives lost from natural disasters occurring there. (See Chapters 6 and 16.) In China alone, floods affect more than 100 million people on average annually.

Sea level rise from climate change poses risks for low-lying coastal areas throughout the world (see Chapters 19 and 23), but particularly vulnerable are the small islands of the Pacific, coral reefs, and the deltas of such areas as Egypt and Bangladesh. And the Intergovernmental Panel on Climate Change has concluded that the adverse impacts of ongoing and future climate change will occur largely in the developing countries already beset by poor sanitation, water stresses, financial pressures for needed development programs, and poor health and inadequate medical services.

28.8 What Are the Most Critical Gaps in Knowledge and the Most Crucial Research Needs?

There are many limitations on the scientific community's ability to provide a comprehensive judgment about the conditions and trends in ecosystems and the services they provide. Although it is certain that human well-being is affected by changes in the provision of ecosystem services, the details of that relationship remain difficult to untangle except in the simplest cases, such as the ability of ecosystems to provide food to increasing numbers of people. This section categorizes the main types of uncertainties that limit the ability to synthesize the results presented in the individual chapters on systems and services. Two major needs are focused on: data and information, and processes and understanding.

28.8.1 Data and Information

The most basic limitation is that there are many important features of today's world for which no information is available, much less the high quality, well-documented, and comparable information that is necessary to understand crucial problems. For example, we have relatively little replicable data on forest extent that can be tracked over time. Methods of measuring forest extent vary from country to country, and in spite of large efforts by international agencies to harmonize the information, the ability to document changes in this is surprisingly poor for much of the world.

A similar situation exists for cropland, where methodological issues and significant data gaps cloud the picture of cropland conversion and the use of cropland over time in most regions. The global distribution of wetlands remains unknown, as does the actual current distributions of many important plant and animal species, much less their changes over time.

All these gaps in information result in significant constraints on documenting the trade-offs between provisioning and non-provisioning services. While there is high certainty in some cases relating to large-scale trends such as climate change, species losses, and land degradation, the weakness in documentation and information on regional trends remains a serious handicap. Interestingly, local data and information can in turn be of extremely high quality, in part because the scales of measurement are more amenable to traditional sampling technologies and methods. However, the ability to generalize from local information to regional and global information is limited.

28.8.2 Processes and Understanding

The ability to provide a clear picture of the trade-offs among ecosystem services, and therefore information that is relevant to the continued management of ecosystems for human well-being, is also constrained by limits in understanding of the relevant processes and underlying relationships. For example, while it has become much clearer over the past decade that biodiversity is important for ecosystem functioning, there is limited understanding of the ways in which biodiversity regulates ecosystem functioning at local and regional scales, and there is intrinsic difficulty in predicting unexpected, accelerated, and some times irreversible changes triggered by alterations of local and regional biodiversity. The response of ecosystems to changes in the availability of important nutrients, including carbon, especially through increasing atmospheric pathways is not broadly understood and cannot be deduced strictly through model simulations.

One of the most critical needs for further information is an improved understanding of the factors governing the capacity of ecosystems to provide services. Documenting threshold changes in ecosystems and understanding the structural and dynamic characteristics of systems that lead to threshold and irreversible changes is clearly important in this respect and is currently not well understood. Equally important is the development of both conceptual and quantitative models that can begin to give both scientific and policy communities advance warning of when the capacity of systems is beginning to be eroded or thresholds are likely to be reached, so that action may be taken before significant adverse trade-offs have occurred.

Table 28.2 on page 838 synthesizes some of the main recommendations for data and information on particular ecosystems and services that are the most important ones for building the capacity to forecast changes in ecosystem services. The table identifies a selection of the critical issues to be resolved by further research, why those issues are important, and what processes or questions are important to understand in terms of those issues. Finally, the minimum data and information that will be required to address the issues raised are identified.

References

Lepers, E., E.F. Lambin, A.C. Janetos, R. DeFries, F. Achard, N. Ramankutty, and R.J. Scholes, 2005: A synthesis of rapid land-cover change information for the 1981–2000 period. *BioScience,* **55 (2),** 19–26.

Loh, J. and M. Wackernagel (eds.) 2004: *The Living Planet Report 2004.* Gland, Switzerland, and Cambridge, UK: World Wide Fund for Nature and United Nations Environment Programme World Conservation Monitoring Centre.

United Nations, 2003: World Population Prospects: The 2002 Revision Population Database. New York.

Table 28.2. Critical Issues Requiring Research and Data Collection to Forecast Significant Impacts of Ecosystem Change on Human Well-being. This list is intended to highlight the most critical issues and does not identify many other important research and data needs.

Which ecosystems and services most critically require research and data collection to forecast significant impacts on human well-being?	Why is the issue critical?	What do we need to know?	What types of data are required?
Drylands in all semiarid areas	direct dependence of poor on ecosystem services and coping capacity during times of stress; intensifying use for rangeland and cropland	Where is productivity of drylands declining from intensifying use? What are the feedbacks from intensifying rangeland and cropland on soil fertility, climate regulation, and access to water? Where and how is human well-being changing in response to changes in productivity?	indicators of land productivity; indicators of human well-being attributable to changes in land productivity
Coastal and marine systems in all parts of the world	recipient of nutrients from food production systems; importance for fisheries	Where is nutrient input and overharvesting affecting fisheries? Where are declining fisheries affecting access to protein?	nutrient inputs; trends in fish populations
Tropical forests	most significant repository of biodiversity, with high cultural value and potential implications for ecosystem function; rapid conversions expected to continue; non-timber forest products can be major contributor to household food, medicine, traditional livelihoods	Where is habitat loss causing declines in biodiversity? What are the effects of habitat loss on species and populations over what time scales?	indicators of habitat extent and quality, indicators of biodiversity
Boreal forest	acceleration of natural disturbances (e.g., pests and fire)	What drivers are most important for accelerating disturbance regimes? What are anticipated responses to climatic changes?	information on interaction of disturbance regimes and global change
Inland waters	water is basic societal and biological need; human health and economic development issue; direct provision of food	What are contemporary and historical patterns of water infrastructure, use, and supply? What is the access of humans to surface and groundwater sources? Sustainability of fisheries?	basic surface hydrography and well-log data from around the world; extent of fisheries; water quality data
Polar systems	most sensitive to climate change; potentially significant feedbacks to climate regulation; importance of traditional livelihoods	How are polar systems responding to climate change? How does the climate regulation function of polar systems change in response to climate change?	species composition; changes in hydrology and trace gas fluxes' rate and extent of change in permafrost and peat
Food and cultivated systems	cultivated systems occupy a large global area; food provision critical for human well-being; large changes in ecosystem states and services due to provision of food	What are the trade-offs in other services inherent in different management practices? What is the overall sustainability of current fisheries management?	contemporary simultaneous data on outputs and other services from different cultivation and grazing systems
Emergence of disease related to ecosystem change	potentially large implications for human health	Which types of ecosystem changes trigger the emergence of disease? Which types of diseases and which ecosystems are potentially the most significant?	occurrences of diseases related to ecosystem change