Chapter 3

Drivers of Ecosystem Change: Summary Chapter

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Main Messages

This chapter provides a summary of the assessment of global drivers of ecosystem change that appears as Chapter 7 of the MA *Scenarios* volume. A driver is any natural or human-induced factor that directly or indirectly causes a change in an ecosystem. A direct driver unequivocally influences ecosystem processes. An indirect driver operates more diffusely, by altering one or more direct drivers.

The MA categories of indirect drivers of change are demographic, economic, sociopolitical, scientific and technological, and cultural and religious. Important direct drivers include climate change, nutrient pollution, land conversion leading to habitat change, overexploitation, and invasive species and diseases.

Changes in ecosystem services are almost always caused by multiple, interacting drivers that work over time and over level of organization and that happen intermittently. Changes in ecosystem services can feed back to alter drivers.

3.1 Introduction

This chapter provides a summary of the assessment of global drivers of ecosystem change that appears as Chapter 7 of the MA *Scenarios* volume (with references included). The chapter examines the two right boxes in the MA conceptual framework: indirect and direct drivers. (See Chapter 1 for the diagram and description of the conceptual framework.) It is important to recognize that neither this discussion nor the chapter in the *Scenarios* volume covers the remaining two boxes for the framework—the mechanisms by which drivers interact with specific ecosystems to alter their condition and ability to deliver services. Those topics are left to the individual condition and service chapters in this volume and to later chapters in the *Scenarios* report.

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3.2 Changes in Key Indirect Drivers

3.2.1. Demographic

Global population doubled in the past 40 years and increased by 2 billion people in the last 25 years, reaching 6 billion in 2000. Developing countries have accounted for most population growth in the past quarter-century, but there is now an unprecedented diversity of demographic patterns across regions and countries. Some high-income countries such as the United States are still experiencing high rates of population growth, while some developing countries such as China, Thailand, North Korea, and South Korea have very low rates.

Urban areas now contain about half the world's population yet cover less than 3% of the terrestrial surface. Regional rates of urbanization vary widely. High-income countries typically have populations that are 70–80% urban. Some developing-country regions, such as parts of Asia, are still largely rural, while Latin America, at 75% urban, is indistinguishable from high-income countries in this regard.

World population will likely peak before the end of the twenty-first century at less than 10 billion. The global population growth rate peaked at 2.1% a year in the late 1960s and fell to 1.35% a year by 2000, when global population reached 6 billion. Population growth over the next several decades is expected to be concentrated in the poorest, urban communities in sub-Saharan Africa, South Asia, and the Middle East. Populations in all parts of the world are expected to experience substantial aging during the next century. While industrial countries will have the oldest populations, the rate of aging could be extremely fast in some developing countries.

3.2.2 Economic

Global economic activity increased nearly sevenfold between 1950 and 2000. Despite the population growth just described, average income per person almost doubled during this period. However, dramatic regional variations in per capita income growth existed. As per capita income grows, the structure of consumption changes, with wide-ranging potential for effects on ecosystem condition and services. With rising per capita incomes, the share of additional income spent on food declines and the consumption of industrial goods and services rises. The composition of people's diets changes, with less consumption of starchy staples (rice, wheat, potatoes) and more of fat, meat, fish, fruits, and vegetables.

Energy and materials intensity (the energy use per unit of economic output) tend to decline with rising levels of GDP per capita. In other words, energy and material productivity—the inverse of energy intensity—improve in line with overall macroeconomic productivity. However, growth in productivity has historically been outpaced by economic output growth. Hence, materials and energy use have risen in absolute terms over time.

Domestic policy distortions such as taxes and subsidies can have serious economic and environmental consequences, both in the country where they are implemented and elsewhere. Subsidies to conventional energy are estimated to have been $250–300 billion a year in the mid-1990s. The 2001–03 average subsidies paid to the agricultural sectors of OECD countries were over $300 billion annually. OECD protectionism and subsidies cost developing countries more than $20 billion a year in lost agricultural income.

Policies that distort international trade flows also have negative economic consequences. Nations with lower trade barriers, more open economies, and transparent government processes tend to have higher per capita income growth rates. International trade is an important source of economic gains, as it enables comparative advantage to be exploited and it accelerates the diffusion of more-efficient technologies and practices.

3.2.3 Sociopolitical

Sociopolitical drivers encompass the forces influencing decision-making and include the quantity of public participation in decision-making, the makeup of participants in public decision-making, the mechanisms of dispute resolution, the role of the state relative to the private sector, and levels of education and knowledge. Over the past 50 years, there have been significant changes in sociopolitical drivers. There is a declining trend in centralized authoritarian governments and a rise in elected democracies. The role of women is changing in many countries, average levels of formal education are increasing, and there has been a rise in civil society (such as increased involvement of NGOs and grassroots organizations in decision-making processes). The trend toward democratic institutions has helped empower local communities, women, and resource-poor households. There has been an increase in multilateral environmental agreements. The importance of the state relative to the private sector—as a supplier of goods and services, as a source of employment, and as a source of innovation—is declining.

3.2.4 Cultural and Religious

To understand culture as a driver of ecosystem change, it is most useful to think of culture as the values, beliefs, and norms that a group of people share. In this sense, culture conditions individuals' perceptions of the world, influences what they consider important, and suggests courses of action that are appropriate and inappropriate. Broad comparisons of whole cultures have not proved useful because they ignore vast variations in values, beliefs, and norms within cultures. Nevertheless, cultural differences clearly have important impacts on direct drivers. Cultural factors, for example, can influence consumption behavior (what and how much people consume) and may be a particularly important driver of environmental change.

3.2.5 Science and Technology

The development and diffusion of scientific knowledge and technologies that exploit that knowledge have profound implications for ecological systems and human well-being. The twentieth century saw tremendous advances in the understanding of how the world works physically, chemically, biologically, and socially and in the applications of that knowledge to human endeavors. Productivity improvements from application of science and technology are estimated to have accounted for more than one third of total GDP growth in the United States from 1929 to the early 1980s, and for between one third and two thirds of GDP growth in OECD countries over the period 1947 to 1973.

The impact of science and technology on ecosystem services is most evident in the case of food production. Much of the increase in agricultural output over the past 40 years has come from an increase in yields per hectare rather than an expansion of area under cultivation. For instance, wheat yields rose 208%, rice yields rose 109%, and maize yields rose 157% in the past 40 years in developing countries. At the same time, unintended effects of technological advances can lead to the degradation of ecosystem services. For example, eutrophication of freshwater systems and hypoxia in coastal marine ecosystems result from excess application of inorganic fertilizers. Advances in fishing technologies have contributed significantly to the depletion of marine fish stocks.

3.3 Changes in Key Direct Drivers

For terrestrial ecosystems, the most important direct drivers of change in ecosystem services in the past 50 years, in the aggregate, have been land cover change (in particular, conversion to cropland) and the application of new technologies, which have contributed significantly to the increased supply of services such as food, timber, and fiber.

Deforestation and forest degradation affect 8.5% of the world's remaining forests, nearly half of which are in South America. Deforestation and forest degradation have been more extensive in the tropics over the past few decades than in the rest of the world, although data on boreal forests are especially limited, and the extent of the loss in this region is less well known. Approximately 10% of the drylands and hyper-arid zones of the world are considered degraded, with the majority of these areas in Asia. Cropped areas currently cover approximately 30% of Earth's surface.

For marine ecosystems and their services, the most important direct driver of change in the past 50 years, in the aggregate, has been fishing. Improved marine fishing technology has made it possible to extract considerable fish biomass from the marine system. In fact, humankind has probably reached the maximum (and in some places has exceeded) levels of fish biomass removal before significant ecosystem changes are induced. In the Gulf of Thailand, for example, higher-trophic animals are no longer present and the system is dominated by lower-trophic species with a high biomass turnover. Research in West Africa and the North Atlantic indicates similar changes. FAO estimates that about half of the wild marine fish stocks for which information is available are fully exploited and offer no scope for increased catches.

For freshwater ecosystems and their services, depending on the region, the most important direct drivers of change in the past 50 years include modification of water regimes, invasive species, and pollution, particularly high levels of nutrient loading. The introduction of non-native invasive species is one of the major causes of species extinction in freshwater systems. For example, marine and estuarine waters in North America are heavily invaded, mainly by crustaceans and mollusks in a pattern corresponding to trade routes.

Over the past four decades, excessive nutrient loading has emerged as one of the most important direct drivers of ecosystem change in terrestrial, freshwater, and marine ecosystems. Synthetic production of nitrogen fertilizer has been the key driver for the remarkable increase in food production that has occurred during the past 50 years. Nitrogen application has increased fivefold since 1960, but as much as 50% of the nitrogen fertilizer applied is lost to the environment, depending on how well the application is managed. Since excessive nutrient loading is largely the result of applying more nutrients than crops can use, it harms both farm incomes and the environment.

Excessive nitrogen loading can cause algal blooms, decreased drinking water, eutrophication of freshwater ecosystems (a process whereby excessive plant growth depletes oxygen in the water), hypoxia in coastal marine ecosystems (substantial depletion of oxygen resulting in die-offs of fish and other aquatic animals), nitrous oxide emissions contributing to global climate change, and air pollution by nitrogen oxides in urban areas. Improvements in nitrogen use efficiency require more investment in technologies that achieve greater congruence between crop nitrogen demand and nitrogen supply from all sources and that do not reduce farmer income.

Phosphorus application has increased threefold since 1960, with a steady increase until 1990 followed by leveling off at a level approximately equal to 1980's applications. These changes are mirrored by phosphorus accumulation in soils, which maintains high levels of phosphorus runoff that can cause eutrophication of freshwaters and coastal waters.

Many ecosystem services are reduced when inland waters and coastal ecosystems become eutrophic. Water from lakes that experience algal blooms is more expensive to purify for drinking or other industrial uses. Eutrophication can reduce or eliminate fish populations. Possibly the most striking change is the loss of many of the cultural services provided by lakes. Foul odors of rotting algae, slime-covered lakes, and toxic chemicals produced by some blue-green algae during blooms keep people from swimming, boating, and otherwise enjoying the aesthetic value of lakes.

Climate change in the past century has already had a measurable impact on ecosystems. Earth's climate system has changed since the preindustrial era, in part due to human activities, and is projected to continue to change throughout the twenty-first century. During the last 100 years, the global mean surface temperature has increased by about 0.6 Celsius, precipitation patterns have changed spatially and temporally, and global average sea level rose between 0.1 and 0.2 meters. The global mean surface temperature is projected to increase from 1990 to 2100 by 1.4–5.8 Celsius, accompanied by more heat waves. Precipitation patterns are projected to change, with most arid and semiarid areas becoming drier and with an increase in heavy precipitation events, leading to an increased incidence in floods and drought. The MA scenarios project a sea level rise of 9–88 centimeters.

Observed changes in climate, especially warmer regional temperatures, have already affected biological systems in many parts of the world. There have been changes in species distributions, population sizes, and the timing of reproduction or migration events, as well as an increase in the frequency of pest and disease outbreaks, especially in forested systems.

Biological invasions are a global phenomenon, affecting ecosystems in most biomes. Human-driven movement of organisms, deliberate or accidental, has caused a massive alteration of species ranges, overwhelming the changes that occurred after the retreat of the last Ice Age. In some ecosystems, invasions by alien organisms and diseases have resulted in extinction of native species or a huge loss in ecosystem services. In the United States, for example, invasions of non-native plants, animals, and microbes are thought to be responsible for 42% of the decline of native species now listed as endangered or threatened.

The threats that biological invasions pose to biodiversity and to ecosystem-level processes translate directly into economic consequences such as losses in crops, fisheries, forestry, and grazing capacity. Mismanagement of semiarid grasslands, for instance, combined with climatic changes has caused woody plant invasion by native bushes and loss of grazing lands in North and South America. However, introductions of alien species can also be beneficial in terms of human population; most food is produced from introduced plants and animals.

3.4 Driver Interactions

Changes in ecosystem services are almost always caused by multiple, interacting drivers that work over time (such as population and income growth interacting with technological advances that lead to climate change) and over level of organization (such as local zoning laws versus international environmental treaties) and that happen intermittently (such as droughts, wars, and economic crises).

Changes in ecosystem services can feed back to alter drivers. For example, changes in ecosystems create new opportunities for and constraints on land use, induce institutional changes in response to perceived and anticipated resource degradation, and give rise to social effects such as changes in income inequality.

No single conceptual framework captures the broad range of case study evidence. This chapter ends with a few selected examples of driver interactions and ecosystem consequences.

In all regions of the humid tropics, deforestation is primarily the result of a combination of commercial wood extraction, permanent cultivation, livestock development, and the extension of overland transport infrastructure. However, many regional variations on this general pattern are found. Deforestation driven by swidden agriculture is more widespread in upland and foothill zones of Southeast Asia than in other regions. Road construction by the state followed by colonizing migrant settlers, who in turn practice slash-and-burn agriculture, is most frequent in lowland areas of Latin America, especially in the Amazon Basin. Pasture creation for cattle ranching is causing deforestation almost exclusively in the humid lowland regions of mainland South America. Expansion of smallholder agriculture and fuelwood extraction for domestic uses are important causes of deforestation in Africa. These regional differences mostly come from varying mixes of economic, institutional, technological, cultural, and demographic factors underlying the direct causes of deforestation.

Agricultural intensification is usually defined as substantial use of purchased inputs, especially fertilizer, in combination with new plant varieties that respond well to the increased inputs. Globally, intensification has been a major contributor to the doubling of food production over the last 40 years. Drivers of intensification include new crop and fertilizer production technologies, development of markets and transportation infrastructure, and changes in credit and price policies.

Urbanization provides another illustration of interactions. Though only about 2% of Earth's land surface is covered by built-up area, the effect of urban systems on ecosystems extends well beyond urban boundaries. Three processes of urban change appear to be of relevance for ecosystem change: the growth of urban population (urbanization), the growth of built-up area (urban growth), and the spreading of urban functions into the urban hinterland connected with a decrease in the urban-rural gradient in population density, land prices, and so on (urban sprawl).