4 *Drivers of Change in Ecosystems and Their Services*

Executive Summary

- Understanding the factors that cause changes in ecosystems and ecosystem services is essential to the design of interventions that enhance positive and minimize negative impacts.
- 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 and can therefore be identified and measured to differing degrees of accuracy. An indirect driver operates more diffusely, often by altering one or more direct drivers, and its influence is established by understanding its effect on direct drivers.
- Decision-makers influence some drivers and are influenced by other drivers. The first are the endogenous drivers and the latter are the exogenous ones. Conceptually, decisions are made at three organizational levels: by individuals and small groups at the local level who directly alter some part of the ecosystem; by public and private decision-makers at municipal, provincial, and national levels; and by public and private decision-makers at the international level. In reality, however, the distinction between these levels is often diffuse and difficult to define.
- The degree to which a driver is outside the influence of a decision-making process depends to some extent on the temporal scale. Some factors may be exogenous in the short run but subject to change by a decision-maker over longer periods.
- Local decision-makers can directly influence the choice of technology, changes in land use, and external inputs but have little control over prices and markets, property rights, technology development, or the local climate. National or regional decision-makers have more control over many indirect drivers, such as macroeconomic policy, technology development, property rights, trade barriers, prices, and markets.

- The indirect drivers of change are primarily demographic, economic, sociopolitical, scientific and technological, and cultural and religious. The interaction of several of these drivers in turn affects the overall level of resource consumption and disparities in consumption within and between countries. Clearly these drivers are changing: population and the global economy are growing, there are major advances in information technology and biotechnology, and the world is becoming more interconnected. Changes in these drivers are projected to increase the demand for food, fiber, clean water, and energy, which will in turn affect the direct drivers. The direct drivers are primarily physical, chemical, and biological, such as land cover change, climate change, air and water pollution, irrigation, use of fertilizers, harvesting, and the introduction of alien invasive species.
- Any decision can have consequences external to the decision framework. These are called externalities because they are not part of the decision-making calculus. Externalities can have positive or negative effects. The effect of an externality is seldom confined to the environs of the decision-maker. External effects extend to other parts of the ecosystem and even to other ecosystems. It is possible for individually unimportant external effects to have dramatic regional and global consequences when many local decision-makers simultaneously take decisions with similar unintended consequences.
- Multiple, interacting drivers cause changes in ecosystem services. There are functional interdependencies between and among the indirect and direct drivers of change, and, in turn, changes in ecological services lead to feedbacks on the drivers of changes in ecological services. Synergetic driver combinations are very common. The many processes of globalization are leading to new forms of interactions among drivers of changes in ecosystem services.

Introduction

A broad range of factors lead directly and indirectly to changes in ecosystems, ecosystem services, and human well-being. Many ecosystem changes are intended or unintended consequences of human decisions and the ensuing actions. The drivers of those changes may be well defined, such as grain prices or local rainfall, but they may also involve more complex and diffuse interactions arising from institutional or cultural influences. Understanding the factors that cause these changes in ecosystems and ecosystem services is essential to designing interventions that enhance positive and minimize negative impacts.

Here, as in many parts of the Millennium Ecosystem Assessment (MA), the first challenge is to find terms that mean the same thing to many different users. The term "driver," for example, is used widely in the ecological and other natural sciences but seldom used by economists. And even when the term is used, different meanings exist. The MA defines

BOX 4.1 Typologies of Drivers

Several typologies of drivers were considered for the Millennium Ecosystem Assessment conceptual framework—primary versus proximate, anthropogenic versus biophysical, dependent versus independent, primary versus secondary. The proximate and primary driver terminology, for example, is widely used in the land use change and climate change literature (e.g., Turner II et al. 1995; IPCC 2002). Proximate and primary drivers are conceptually similar to direct and indirect drivers respectively, but tend to be used when analyzing specific spatial processes in which the human intent (primary) is linked with actual physical actions (proximate). The explicit cross-scale linkages and inclusion of physical activities of this typology made it too complex, however, for characterizing the drivers in the Millennium Ecosystem Assessment conceptual framework. Other typologies have been developed for specific purposes and have their limitations. The distinction between direct and indirect drivers, in contrast, provides an opportunity to include highly diverse types of drivers and seemed acceptable to the broadest possible community.

driver in the broadest possible sense: any natural or human-induced factor that directly or indirectly causes a change in an ecosystem.

The approach adopted here is to distinguish between direct and indirect drivers. (See Box 4.1.) A direct driver unequivocally influences ecosystem processes and therefore can be identified and measured to differing degrees of accuracy. Indirect drivers operate more diffusely, from a distance, often by altering one or more direct drivers. An indirect driver can seldom be identified through direction observation of the ecosystem; its influence is established by understanding its effect on a direct driver.

A decision-maker can influence certain driving forces (the endogenous drivers) but not others (the exogenous drivers). Endogenous drivers are thus under the direct control of a decision-maker at a certain level, while exogenous drivers are not. The MA explicitly focuses on who controls specific drivers. This helps to explain the role of responses in describing, understanding, and projecting changes in ecosystems, ecosystem services, and human well-being.

Consider, for example, the case of wheat production in Europe. A wheat farmer in southern France can vary the amount of nitrogenous fertilizer to apply but has no influence on the price received for the wheat. Policymakers in the European Union, however, can influence the price of wheat received by that farmer by imposing or eliminating wheat trade restrictions. As the time and space scales expand, more drivers become endogenous; that is, a different set of decision-makers has influence over the drivers. This distinction is especially important in identifying intervention points and strategies.

Another key point is that any decision can have consequences external to the decision framework. These consequences are called externalities because they are not part of the decision-making calculus. Externalities can have positive or negative effects. For example, a decision to plow a dry field for crop production might result in substantial particulate matter blowing into a nearby village, with negative health effects. But it is also possible to have positive externalities. A beekeeper might be motivated by the profits to be made from selling honey, for instance, but neighboring orchards could produce more apples because of enhanced pollination arising from the presence of the bees.

Previous Approaches on the Factors of Change

During the late 1960s and early 1970s, debates began about the factors that lead humans to have adverse effects on the biophysical environment. A number of "root" causes were asserted: religion (White 1967), common property institutions (McCay and Jentoft 1998), and capitalism and colonialism (O'Connor 1988). But none of these hypotheses of dominant cause could sustain empirical scrutiny. The IPAT formulation (Impacts = Population x Affluence x Technology) was an initial attempt to move beyond simple arguments about single causes by acknowledging:

- that there are multiple human drivers of environmental change,
- that their effects are multiplicative rather than additive,
- that increases in one driver can sometimes be mitigated by changes in another driver, and
- that assessing the effects of human drivers requires both theory and empirical evidence.

For a history of IPAT and related arguments about drivers, see Dietz and Rosa (1994).

IPAT continues to be used in discussions of the drivers of environmental change (e.g., Waggoner and Ausubel 2002), and the IPAT accounting framework finds productive use in industrial ecology (Chertow 2001). However, formulations that build on IPAT are emerging. The impact of population growth and affluence on consumption continues to be examined. A variety of studies demonstrate that population size has an effect on impacts but sometimes is less important than other factors (e.g., Palloni

1994; Rudel and Roper 1997; York et al. 2003). A substantial literature examines the effects of affluence on environmental impact (reviewed in Stern 1998; Nordstrom and Vaughan 1999), including a number of analyses that suggest that such effects depend strongly on context (Roberts and Grimes 1997). Research on drivers deploys the full repertoire of available methodologies, including statistical analyses, case studies, and simulation, and the literature is growing in both size and sophistication.

Over the last decade, the approach has been further refined in many assessment models by adding such factors as specific sociopolitical, biophysical, and cultural drivers. But these top-down approaches to environmental change still rely heavily on highly aggregated drivers, the value of which has recently been questioned (e.g., Barbier 2000; Contreras-Hermosilla 2000; Barrett et al. 2001; Indian National Academy of Sciences et al. 2001; Lambin et al. 2001; Myers and Kent 2001; van Beers and de Moor 2001; Young 2002). For example, in a statistical analysis of the causes of deforestation, Geist and Lambin (2002) show that different local and regional drivers play an important role. But perhaps the most important recent advance in understanding is the elucidation of a broader variety of interacting drivers that become more important in the local context.

The individual importance of global drivers cannot be assessed in a simple way. There is no clear hierarchy of drivers that encompasses cause and effect. Individuals and societies try to influence their environment and fulfill their needs by evaluating expected outcomes. If undesired impacts are foreseen, mitigating decisions can be made. This approach is made operational most clearly in the Driver-Pressure-State-Impact-Response (DPSIR) scheme that was developed by the Organisation for Economic Co-operation and Development (OECD InterFutures Study Team 1979).

Many assessments have followed this approach, at least in part. For example, the Intergovernmental Panel for Climate Change structured its assessment along these lines—activities > emissions > concentration > climate change > impacts > mitigation and adaptation responses (IPCC 2002)—recognizing that responses in turn alter activities (mitigation) and impacts (adaptation). The conceptual framework is a closed loop and displays different interactions between drivers and components. In the MA, determining trade-offs and synergies between different decisions and other responses will be central. This requires that the assessment examines carefully the interactions of drivers at specific scale levels and over varying spatial, temporal, and organizational dimensions.

Recent advances in integrated assessment (e.g., Alcamo et al. 1998; Stafford-Smith and Reynolds 2002) and comprehensive analyses of environmental problems (e.g., Petschel-Held et al. 1999; Ostrom et al. 2002) have shown that analyzing causes of environmental change requires a multiscale and multidimensional assessment of major components of the system and their dynamics and interactions. An appreciation of the feedbacks, synergies, and trade-offs among these components in the past improves understanding of current conditions and enhances the ability to project future outcomes and intervention options.

Drivers: An Overview

In the MA, key elements of drivers that are assessed include:

- an explicit recognition of the role of decision-makers at different levels who directly or indirectly affect ecosystems and their services;
- identification of drivers that influence these decision-makers;
- the specific temporal, spatial, and organizational scale dependencies of these drivers; and
- the specific linkages and interactions among drivers.

The MA approach assumes that decisions are made at three organizational levels:

- by individuals and small groups at the local level (such as fields and forest stands) who directly alter some part of the ecosystem;
- by public and private decision-makers at regional levels (the municipal, provincial, and national level); and
- by international conventions and multilateral agreements that operate at the global level.

For global drivers, we recognize that there is no explicit global governing body. The United Nations proceeds, for example, through consensus building between national governments. And in reality, of course, the distinction between these three levels is often diffuse and difficult to assess.

Today a fairly consistent, agreed-upon list of global or "big-picture" drivers that change ecosystems, ecosystem services, and human well-being has emerged. Many of these are used as inputs to models that project future energy and land use (e.g., Nakícenovíc et al. 2000). However, many of these models use global aggregates, and distinct local and regional patterns in these drivers are not captured. The major global driving forces used in many assessments, which the MA uses as a basis for analysis, are:

- demographic drivers;
- economic drivers;
- sociopolitical drivers;
- science and technology drivers;
- cultural and religious drivers; and
- physical, biological, and chemical drivers.

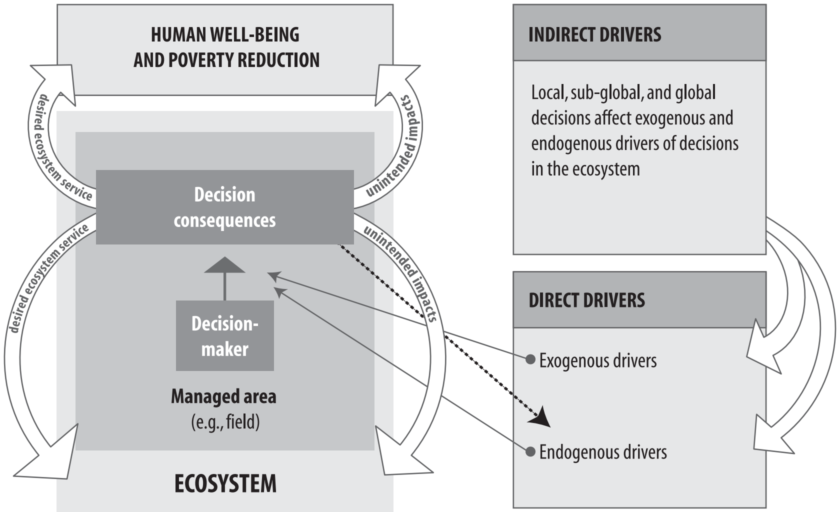
These globally aggregated drivers appear exogenous to decision-makers. Their current condition cannot be influenced effectively. Changes in these drivers are generally slow and are the cumulative effect of many diverse local and regional decisions. But viewed with a longer perspective, these drivers become subject to the influence of human decisions (that is, become endogenous). For example, today's population can be closely estimated and is truly exogenous. Today's decision-makers have no influence over the number of people in the world now. However, national rates of population growth (determined by birth and death rates adjusted for migration) could change substantially because of political decisions—that is, become endogenous—and could influence population half a century hence.

The Decision-maker within the Ecosystem

The influence of humans over ecosystems is most obvious at the local level. People living within an ecosystem undertake myriad activities that alter its condition and capacity to deliver useful services. We highlight important elements of this interaction in Figure 4.1, which is based on the MA conceptual framework diagram. (See Chapter 1.) In the lower left, the ecosystem is represented by the background rectangle. A typical ecosystem has many different decision-makers (farmers, fishers, households, local production communities) with control over some part of the system. We will refer to this unit as an agricultural field in this section for ease of exposition, but it could just as well be a lake, a forest district, or a marine region. The decisions made about the field, and the actions that follow, affect the condition of the ecosystem and the services it provides—both within the field and elsewhere.

The decision-making process is complex and multidimensional. The local decision-maker might be motivated by tradition (my family has farmed

FIGURE 4.1 Decision-making, Drivers, and Ecosystem Services at the Local Level



this land for centuries), by biophysical factors (this land and climate is the most productive throughout the year to grow flowers for the international market), by economic need (I sell crops at the local market to buy clothing and medicine), or by familial responsibilities (my children need education for a better future). The actual decision is based on a combination of many different motives and influences—some are observable, while others are not.

It is also important to realize that it is the actions arising from the decision that ultimately drive changes in the ecosystem. It is useful to distinguish here between the resulting physical drivers of ecosystem change (direct drivers) and the signals that motivate the decision-making process (indirect drivers). Furthermore, some drivers are under the control of the decision-maker (endogenous drivers) and some are not (exogenous drivers). (See Box 4.2.) These categories are indicated by the boxes on the right side of Figure 4.1 and the arrows between the drivers, the ecosystem, and the decision process.

As discussed elsewhere in this chapter, the condition of an ecosystem is influenced by natural drivers, such as climate and biological processes, over which the decision-maker has no control. These direct drivers also condition the decisions made. The natural capacity of an ecosystem is a

BOX 4.2 Examples of Exogenous and Endogenous Drivers at the Local Level

Selected exogenous local drivers include:

- indirect drivers that influence the decision-making process
  - institutions (such as property rights, community organizations, or marketing regulations),
  - prices and markets, and
  - technology development.
- direct drivers that directly affect ecosystem condition and services
  - some ecosystem characteristics, and
  - local effects of regional and global environmental change (such as increased mean temperature from rising carbon dioxide concentrations or lower mean temperature from volcanic pollution).

Selected endogenous local drivers include:

- indirect drivers that influence the decision-making process
  - technology adaptation (such as fish location technology or precision agriculture).
- direct drivers that directly affect ecosystem condition and services
  - changes in local land use and land cover,
  - species introductions and removals, and external inputs (such as fertilizer use, pest control, or irrigation water).

function of abiotic (nonliving) and biotic (living) characteristics, including geomorphology, soil quality, weather conditions, and biodiversity. The natural capacity makes some potentially desirable ecosystem services biologically impossible (growing coffee in Canada, for instance) while others would require dramatic changes in the ecosystem. The natural capacity differs strongly between localities and regions. Coarse-scale patterns are largely determined by climate and parent material of the soil, while fine-scale patterns are defined by ecological, soil, and management processes and by land use history. The state of the natural capacity at the time a decision is taken sets the initial condition for the range, level, and quality of intended services that can be obtained. In addition, a potentially large number of local, sub-global, and global forces influence the decision process directly and therefore the drivers under control of the decision-maker.

The effect of an externality (indicated by the arrows to the right of the decision consequences in Figure 4.1) is seldom confined to the environs of the decision-maker. External effects extend to other parts of the ecosystem and even to other ecosystems. It is possible for individually unimportant external effects to have dramatic regional and global consequences when many local decision-makers simultaneously take decisions with similar unintended consequences.

Ecosystem Consequences of Decisions Outside an Ecosystem

The discussion thus far has focused on decision-making within an ecosystem and the decision-making process that directly affects the ecosystem and its services. But there are many decisions made to bring about outcomes that are not directed at a specific ecosystem or its services. What we call the regional level is intended to encompass all these other decision-makers.

One way to categorize these decision-makers is the distinction between private (entrepreneurs and business) and public (government and nongovernmental organizations [NGOs]). As a generalization (albeit with many exceptions), the private decision-maker has personal gain as a primary motive while public decision-makers are motivated by the well-being of the unit for which they are making decisions. Private decision-makers include individuals and communities that make collective decisions for local, national, and global businesses. Political decision-making takes place in units that include nations, sub-national units (county, district, municipal, province, or state), supra-national units (groups of nations such as the European Union that have some common legal, economic, and political institutions), and trading communities (such as the North American Free Trade Association or regional groupings such as the South Asian Association for Regional Cooperation).

Regardless of the motivation of these decision-makers, few if any of the units for which decisions are made are synonymous with an ecosystem. A county, state, or nation can encompass multiple ecosystems. Or a single ecosystem can cross multiple jurisdictional boundaries. As a result, efforts to mitigate negative externalities often require negotiations among multiple decision-makers with differing interests.

An almost limitless range of interactions is possible between the regional and the local levels. The ecosystem decision-maker at the local level uses inputs from the regional level in the process of enhancing provisioning and supporting ecosystem services. Ecosystem services from the local level, intended or unintended, are inputs into activities at the regional level. In turn, decisions made at the regional level can affect multiple ecosystems. Some regional decisions are intended to influence ecosystem conditions and services. Examples include land, water, and natural resource policies. Many other decisions taken at this level with no intent to affect an ecosystem nonetheless have consequences for it. The intent of these decisions is to influence activities in the domains over which they have some control—a political, business, or community unit—that does not necessarily correspond with an ecosystem or biome.

A wide range of factors influences decisions at the regional level. Unlike local ecosystem decisions, however, many more factors at this level are endogenous. The number of exogenous factors depends in part on the relationship among the various units involved. Although we refer to the region as a single level, it actually encompasses many nested and overlapping levels of control and decision-making. For example, most nations have sub-national political units (states or provinces), and these units are often further divided into counties, districts, and municipalities.

The sub-national, national, international structure provides a natural hierarchy of endogenity for drivers. Decision-making at higher levels influences factors that are exogenous to decision-makers at lower levels. For example, international grain markets collectively determine world wheat prices; national governments can influence prices that farmers receive with trade and production taxes and subsidies, but farmers treat those prices as exogenous. Or a national government can set air pollution standards that affect sulfur dioxide emissions from individual power plants. For the plant manager, the regulation is exogenous, and for the forest managers downwind, the reduction in acid rain is exogenous.

But this hierarchy is by no means exclusive. Some drivers are endogenous at the local level but exogenous at the regional level. For example, land use management rules such as zoning regulations are frequently a local decision over which the state or national government has no control. Furthermore, the degree to which a driver is outside the influence of a decision-making process depends to some extent on the temporal scale. Some factors may be exogenous in the short run but subject to change by a decision-maker over longer periods.

At the regional level, then, the endogenous drivers of decision-making often include:

- institutions (such as property rights or trade barriers),
- service and commodity prices and markets,
- technology development, and
- macroeconomic policy.

The exogenous drivers include:

- changes in land use and cover patterns,
- developments in basic science, and
- ecosystem characteristics.

Drivers of Ecosystem Change

The most important sets of drivers that the MA will use play out at all levels (global, regional, and local), but in differing time frames and combinations.

Demographic Drivers

The demographic variables that have implications for ecological systems include population size and rate of change over time (birth and death rates), age and gender structure of a population, household distribution by size and composition, spatial distribution (urban versus rural and by country and ecosystem), migration patterns, and level of educational attainment.

The interactions among population and ecosystems are complex. Population size and other demographic variables influence the use of food, fiber, clean water, energy, shelter, transport, and a wide range of ecosystem services. Increases in population decrease the per capita availability of both renewable and nonrenewable resources. When coupled with growing income and other factors such as urbanization and market development, population growth increases the demand for food and energy.

Demographic projections suggest that future population growth rates will not be uniform throughout the world. At least 95 percent of the additional 3 billion or so people likely to inhabit the planet in the next 50 years will live in developing countries, and most will be in the tropics and sub-tropics. The U.S. Census Bureau projects a world population of 9.1 billion by 2050 (U.S. Census Bureau 2002), while the median projection of the United Nations Population Bureau for 2050 is 8.9 billion (UN Population Division 2001). Other projections, however, cite both higher and lower numbers. In 1985, 75 percent of the world lived in developing countries; this increased to 78 percent by 2000 and is projected to reach 86 percent by 2050 (UN Population Division 2001). Estimates are that the 49 lowest-income countries, which are mainly in the tropics and subtropics, will almost triple their population—from 668 million to 1.86 billion—by 2050 (UN Population Division 2001).

The location of the increases in population has important consequences for ecosystems at the local, regional, and global level. In the past 50 years, for example, on average 90 percent of food was produced in the country of consumption (FAO 2003). If there is no significant change in this ratio, and if the expected population growth in the tropics and sub-tropics materializes, tropical and sub-tropical ecosystems will need to provide significantly more food in addition to the services they already provide. A further complication is that agricultural productivity in the tropics and sub-tropics is projected to suffer from human-induced climate change. Hence these ecosystems will be under considerable pressure in the coming decades. It should also be noted that nearly 50 percent of the current human population live in the 12 megadiversity countries; where the population growth rate is expected to exceed that of the global average, these unique ecosystems will be under significant pressure (Secretariat of the Convention on Biological Diversity 2001).

In contrast to the tropics and sub-tropics, the population of some regions, such as Eastern Europe, is projected to decrease over the next 50 years (U.S. Census Bureau 2002). The implications of negative population growth on economic performance and ecological systems are uncertain.

During the past 30 years, there has been a rapid increase in the percentage of people living in urban centers, a trend that is expected to continue over the next 30 years. In the period 2000–2030, world population is expected to increase by 2.2 billion people, of which 2.1 billion will be urban dwellers. In 1950, 30 percent of the population lived in urban areas; by 2000, the urban population increased to 47 percent, and it is projected to reach 60 percent by 2030 (UN Population Division 2002). In 1975, there were five megacities (with 10 million or more residents)—two in industrial countries and three in developing countries. By 2000, there were 19 megacities, of which 15 were in developing countries. And, by 2015, it is projected there will be 23 megacities, of which 19 will be in developing countries (UNFPA 2002).

Another important demographic dimension is the interaction between population growth and the distribution of income across individuals, countries, and regions. A combination of extreme poverty for many, low national income growth, and weak property rights can, in some instances, greatly increase pressure on fragile, marginal ecosystems. On the other hand, wealthier societies are associated with high consumption patterns of energy and biological resources, which has its own implications for the demand for ecosystem services.

Age, gender, and levels of education are also important demographic variables. Persons with different educational levels tend to vary in their impacts on the environment and in their vulnerability to environmental change. The number and distribution of households by size and composition is important as well. Greenhouse gas emissions, and hence human-induced climate change, can be assumed to depend on the number of households, not just the number of individuals (Roberts and Grimes 1997).

The most crucial population variable in the long run is the rate of change both locally and globally, which is the nexus of birth, death, and migration rates. While the most hopeful dimension of the population equation is that the global growth rate is falling as families around the world choose to have fewer children, a less hopeful sign is that life expectancy has declined dramatically in the Russian Federation due to changes in economic condition and in many sub-Saharan African countries due to HIV/AIDS.

The bottom line is that demographic variables are critical drivers of the demand for ecosystem services and the capacity of the global ecosystem to provide them. Barring major dislocations, such as world war or pandemics, the number of people alive in 2050 and their geographic distribution is an endogenous variable. Decisions made at national and subnational levels can have a dramatic effect on population growth rates through their impact on sociopolitical and cultural factors—in particular, in opportunities for education and the advancement of women and in urban-rural distribution. Decisions at the supra-national level can influence migration across national boundaries.

Economic Drivers

Economic and social well-being are clearly affected by global economic growth and its distribution by country, sector, and individual. How growth is distributed determines the character of demand for ecosystem services. Global economic performance is more than simple changes in national economic activity. International trade, capital flows, and technology are crucial elements in global growth and its consequences for the world's ecosystems. Moreover, the unprecedented rate of global interconnection is leading to dramatic changes in lifestyles and consumption patterns; the consequences of this for global ecosystems are not yet clear.

Global economic trends that began in the last century will likely persist and probably strengthen as the twenty-first century unfolds. First, growth in international trade flows continues to exceed growth in global production, and the differential may be growing. Between 1990 and 1998, for example, the 12 fastest-growing developing countries saw their exports of goods and services increase 14 percent and their output 8 percent (World Bank 2002a). However, not all trade flows are equal in their effects on growth. Dollar and Collier (2001) found that the countries experiencing the most rapid trade-driven economic growth were trading a large share of high technology products. Therefore changes in the volume, value, direction, and composition of trade must be carefully evaluated, along with the degree of restrictions on flows. New and expanded regional and global trade agreements and institutions, such as the World Trade Organization, will likely increase the importance of international trade in global economic performance.

Financial flows and policies affecting international capital movements are also critical. The trend of the late twentieth century toward more open economies led to greater uniformity in macroeconomic (monetary, fiscal, and exchange rate) policies across the world. This trend is manifested in increasing capital mobility and flexible exchange rate regimes, encouraged by institutions such as the International Monetary Fund, the World Bank, and regional development banks. But not all developing countries participated equally. For instance, the vast majority of private-sector capital flows is concentrated in the 10 largest developing countries (World Bank 2002b).

Identifying the key interactions among the rate of growth of an economy, the degree of inequality in the ownership of resources, and trade and capital flows is crucial to understanding their impacts on land use patterns, resource extraction, water diversion and pollution, biodiversity losses, and the landscape. Equally important is understanding the impact of sector-specific subsidies and taxes (on agriculture, energy, and so on), particularly in industrial countries, on local and global ecosystems.

There is some controversy about whether the outcomes of global economic growth are sustainable. There is little question that some of the world's ecosystems have experienced unsustainable pressure. However, the evidence on which this statement is based could be improved considerably. There is a need for a systematic assessment of the potential negative impacts of growth on the resource base in both industrial and developing countries. There is also evidence that the structure of economic growth has an impact on the extent of ecosystem pressure. Demand for services (as opposed to manufacturing), which tend to have fewer negative externalities, rises with income. In addition, as per capita incomes rise, there is greater willingness to pay for mitigation and remediation.

Sociopolitical Drivers

"Sociopolitical" is a word that attempts to capture all the forces that lie in the large conceptual space between economics and culture that affect decision-making at all levels. Indeed, the distinction between sociopolitical and cultural factors blurs as the time scale is extended (Young 2002). Sociopolitical driving forces have been important in the past (e.g., Redman 1999; de Vries and Goudsblom 2002) and should be explicitly included in the MA.

Four categories of sociopolitical forces appear to be undergoing major changes at the beginning of the twenty-first century:

- The general role of the public in decision-making appears to be expanding, as evidenced by the extent of democratization. Despite some backsliding, there is a declining trend in centralized, authoritarian governments and a rise of elected democracies. As well, there is some evidence of improving governance across the developing world.
- The voices that are heard and how they are expressed has changed, as evidenced in the changing role of women and the rise of civil society. Democratic institutions have also encouraged decentralized decision-making, with the intended beneficiaries having a greater say in the decisions made. This trend has helped empower local communities, especially rural women and resource-poor households. Decentralization trends have also had an impact on decisions made by regional and international institutions, with the increasing involvement of NGOs and grassroots organizations, such as traditional peoples groups.
- The mechanisms by which nations solve their disputes, peaceful and otherwise, are changing. Although the cold war has ended, the persistence of regional and civil wars and other international conflicts in some parts of the world continues to be a matter of concern. There is an urgent need to understand the driving forces behind such conflicts and their impact on sustainable livelihoods and the natural resource base.
- The declining 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 evident. The future functions of the state in provisioning public goods, security, and regulation are still evolving, particularly in the developing world. In both the developing and the industrial world, the implications of privatization trends on the sustainable management of the local and global resource base are still not clear.

Scientific and Technological Drivers

The development and diffusion of scientific knowledge and technologies can have significant implications for ecological systems and human well-being. Rates of investment in research and development, rates of adoption of new technologies, changes in the productivity and extractive capabilities of new technologies, and the access to and dissemination of information through new technologies all have profound implications.

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. From the introduction of the automobile in the early years to commercialization of genetically modified crops and widespread use of information technology in the later years, many new products drew both praise and damnation regarding their effects on ecosystems. The twenty-first century is likely to see continued breathtaking advances in applications of materials science, molecular biology, and the information revolution—with real potential to improve human well-being around the planet. But these developments have uncertain consequences for ecosystems.

Humans have been extremely successful in institutionalizing the process of scientific and technical change. The organizational structures that encourage researchers to make breakthroughs and use them to develop potentially valuable products—such as research universities, publicly funded research centers, public-private collaborations for research and development, regulatory institutions, and international agreements that collectively determine intellectual property rules—are either in place or being implemented in the industrial world. However, they are not in place in most developing countries. Furthermore, institutions to facilitate use of, and compensation for, indigenous knowledge are not well developed.

Society's ability to manage the process of product dissemination—identifying the potential for adverse consequences and finding ways to minimize them—has not always kept pace. This disparity became especially obvious as the introduction of genetically modified crops met widespread opposition in many parts of the world. The protests in part resulted from the speed of advancement, as the rate of commercial adoptions of the first products of this new technology was unprecedented in a number of countries. At least 30 years passed between the development and widespread use of hybrid maize in industrial countries. For semi-dwarf rice and wheat in developing countries, a similar rate of use was reached only 15 years after development began (Babinard 2001). But use of genetically modified soybeans reached similar levels of use after only 5 years in Argentina and the United States. The use of the Internet accelerated worldwide communication and the organization of protests.

The state of scientific and technical knowledge at any given point in time depends on the accumulation of knowledge over time. Decision-makers can, however, affect the rate of change in scientific and technical knowledge through setting research priorities and changing levels of funding. Domestic government funding for science and technology is driven by objectives such as scientific education, technology development, export markets, commercialization and privatization, and military power. International donors strongly influence science and technology in developing countries, primarily through the type of research they are willing to fund. The private sector responds to the perceived future for their products, looking for those that will be the most acceptable and profitable.

Drivers Determined by Cultural and Religious Values

The word "culture" has many definitions in both the social sciences and in ordinary language. To understand culture as a driver of ecosystem change, it may be 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. And while culture is most often thought of as a characteristic of national or ethnic groups, this definition also acknowledges the emergence of cultures within professions and organizations, along with the possibility that an individual may be able to draw upon or reconcile more than one culture.

There is a substantial literature examining the role of culture in shaping human environmental behavior. It focuses primarily on variations within a nation rather than across nations, in part because it is extremely difficult to establish causal effects of a variable as broad in conceptualization as culture. Two central concerns of the literature are the degree to which the environmentally salient parts of a culture are amenable to change and the degree to which culture actually influences behavior with regard to the environment. There is considerable debate about the first concern. Again, broad generalizations are not warranted, but it is clear that some aspects of culture can change with great rapidity while other elements are inherently conservative.

A substantial body of literature provides lessons on how policies and programs can most effectively produce cultural change around environmental behavior (Dietz and Stern 2002). Obviously, the relationship between culture and behavior is context-specific. Indeed, one important lesson of research on this topic is that overarching generalizations are seldom correct, that the ability of culture to shape behavior depends on the constraints faced by individuals, and that the effects of changing constraints on behavior depend on the culture of the individuals encountering the changes (Gardner and Stern 1995; Guagnano et al. 1995).

At least since it was argued by White (1967) that environmental disruption is a result of some elements of Judeo-Christian culture, there has been special interest in the role of religion in shaping environmental behavior. Arguments that major world religions have led to national or regional differences in environmental impact have not been sustained. However, there is a growing body of scholarship that examines how variations in religious beliefs within a society are related to environmental beliefs and values (Eckberg and Blocker 1989; Kempton et al. 1995; Eckberg and Blocker 1996). In addition, theologians have begun exploring in detail the teachings of the major world religious traditions with regard to the environment. Finally, religious precepts that prescribe acceptable and unacceptable consumption patterns might have a significant impact on the demand for ecosystem services as population grows.

Physical, Biological, and Chemical Drivers

There are natural and human-induced physical, chemical, and biological drivers of change. Natural drivers include solar radiation, climate variability and extreme weather events (such as droughts, floods, hurricanes, and cyclones), fires, volcanic eruptions, earthquakes, pest and disease outbreaks, and natural biological evolution. The primary human-induced drivers include land use changes, climate change, air and water pollution, acid deposition, soil erosion, soil salinization and fertility changes, irrigation, fertilizer use, harvesting, the use of persistent organic chemicals, and the introduction of non-native species.

Key physical and biological characteristics include the living (plants, animals, and microorganisms) and nonliving (atmospheric composition, climate, soil, terrain, rivers, lakes, and oceans) components of the Earth system that sustain ecosystems and human life. Earth has evolved over millions of years through the interactions between living organisms and their environment. These interactions facilitated new life forms and landscapes, and the current conditions of a life-supporting atmosphere.

Human societies have for centuries affected the local environment through land use practices, domestication of plants and animals, and the introduction of exotic species to an area, but the cumulative effect of their activities are now for the first time dominating many regional and global processes—biodiversity, global biogeochemical cycles, and climate (IPCC 2002)—in part driven by increasing demand for food, fiber, clean water, energy, minerals, and transport. Understanding how human activity affects the basic geology and biology of the planet is crucial to assessing the future capacity of the global ecosystem.

Many of these drivers are changing and are projected to continue to change in the coming decades in many parts of the world, as indicated by these examples:

- conversion and fragmentation of ecosystems in many parts of the world, as illustrated by an annual rate of tropical deforestation of about 0.7 percent (Houghton et al. 2001);
- climate change, with the expectation of warmer temperatures, changes in precipitation, and increases in extreme weather events such as heat waves, floods, and droughts and associated fires and pest outbreaks (Houghton et al. 2001; McCarthy et al. 2001);
- a global rise in sea level (Houghton et al. 2001; McCarthy et al. 2001);
- degradation of air, water, and land, especially in many developing countries (Stafford-Smith and Reynolds 2002); and
- planned and inadvertent introductions of nonnative species (Heywood and Watson 1995; Dukes and Mooney 1999).

Interactions among Drivers

Changes in ecosystem services are always caused by multiple, interacting drivers originating from different levels of organization of the coupled human-environment systems. For example, many changes are driven by a combination of drivers that work over time (such as population growth and climate change) and drivers that happen intermittently (droughts, wars, or economic crises, for example). There are functional interdependencies between the drivers of changes in ecosystem services, both at each organizational level (horizontal interplay) and between levels of organization (vertical interplay) (Young 2002).

Moreover, the changes in ecosystem services lead to feedbacks on the drivers of changes. For example, changes in ecosystems create new opportunities and constraints for land use, induce institutional changes from local to global levels in response to perceived and anticipated resource degradation, and give rise to social changes in the form of income differentiation (as there are winners and losers in environmental change).

The drivers of change may follow different modes of interactions:

- One cause may temporarily dominate other drivers in a certain period. For example, local changes in ecosystems are caused not by climate change but by habitat loss. This fact has been used by non-biologists to argue that climate change is of little importance to ecosystems. This approach, however, effectively ignores small, systematic trends in drivers that may become important in the longer term (Parmesan and Yohe 2003).
- Factors driving changes in ecosystem services can be connected as causal chains—that is, interconnected in a way that one or more variables (indirect drivers, mainly) drive one or more other variables (direct drivers).
- Different factors can intervene at the same time—for instance, independent but synchronous operation of individual factors can lead to land change.
- Different factors may also intervene in synergetic factor combinations—that is, several mutually interacting variables drive changes in ecosystem services over time.

Reviews of case studies reveal that the most common type of interaction is synergetic factor combinations (Geist and Lambin 2002). This implies combined action of multiple drivers that produces an enhanced or increased effect due to reciprocal action and feedbacks between drivers.

The complexity in the interactions among drivers of changes in ecosystem services can be greatly reduced by recognizing that there are a limited number of ways in which these drivers are actually combined. For any given human-environment system, a restricted set of drivers is essential in order to predict the general trend in the ecosystem. This makes the problem tractable. This idea is the basis, for example, of the syndrome approach (Petschel-Held et al. 1999), for the analyses of trajectories of environmental criticality (Kasperson et al. 1995), of major spirals of household impoverishment and environmental degradation (Kates and Haarmann 1992), of pathways of land use change (Lambin et al. 2001), and of spatial economic models of land use change (Nelson and Geoghegan 2002).

Models have captured some of the generalizable patterns of change that result from recurrent interactions among driving forces. For example, the environmental Kuznets curve describes the relationship between environmental degradation and economic growth, which holds true for a range of ecological issues—those at the local scale, which affect a population in the short term (Kuznets 1979). Case studies also identify specific sequences of events leading to changes in ecosystem services. Tropical deforestation sometimes results from a sequence of extraction of timber plus initial colonization, for instance, followed by the establishment of colonists with greater access to capital. Competition for access to land takes place and leads to increasing land holdings for the winners, while the losers are pushed to expand the agricultural frontier further. If cattle provide the largest economic rewards for the winners, given market conditions and government subsidies, large-scale land conversion to pasture follows. This, in turn, drives up land prices, leading to further land consolidation (Lambin et al. 2001). In other cases, macroeconomic decline generates large numbers of unemployed people who move into forest areas that are effectively open access. They survive by clearing forest patches of subsistence crops and converting wood to charcoal for sale (Cruz and Repetto 1992). Even though these sequences may play out differently at the detailed level in specific situations, their identification may confer some predictive power by analogy with similar pathways in comparable regional and historical contexts.

The many processes of globalization lead to new forms of interactions among people and between drivers of changes in ecosystem services; they amplify or attenuate the driving forces by removing regional barriers, weakening national connections, and increasing the interdependency among people and between nations. Globalization can either accelerate or buffer the impact of sectoral drivers on ecosystems, but it always gives rise to a greater level of functional interdependencies among drivers between local, national, regional, and global levels.