Chapter 7

Drivers of Ecosystem Change

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

Main Messages

Drivers of ecosystem change act in distinct ways in different regions. Although similar drivers were present in different regions, the processes through which these interacting drivers cause ecosystem change differed among the sub-global assessments. For example, while the three regions of Latin America, Central Africa, and Southeast Asia in the Tropical Forest Margins assessment have the same set of drivers of land use change (deforestation, road construction, and pasture creation), the processes leading to change are different across these three regions. Deforestation driven by small-scale swidden agriculture is more widespread in upland and foothill zones of Southeast Asia than in the other regions of the tropics. In Latin America, state-sponsored road construction followed by colonizing migrant settlers, who in turn practice slash-and-burn agriculture, causes deforestation in lowland areas, especially in the Amazon Basin; large-scale pasture creation for cattle ranching causes deforestation almost exclusively in the humid lowland regions of mainland South America. The spontaneous expansion of smallholder agriculture and fuelwood extraction for domestic uses are important causes of deforestation in Africa.

The biophysical drivers of change mentioned most often across the sub-global assessments were land use change, climate change and variability, pollution, and invasive species. These drivers were seen to be only partially under the control of decision-makers at the particular scales assessed. Land use change comprises a whole range of processes, including urbanization (as in São Paolo or Portugal), encroachment on natural ecosystems by agriculture (as in Eastern Himalayas or Coastal British Columbia), and infrastructure works (as in Tropical Forest Margins or Caribbean Sea). A striking example of invasive species as a driver was found in the Caribbean Sea region, where dust blown from the Sahara across the Atlantic introduced new pathogenic bacteria which have been at least partially responsible for coral reef diseases in the last two decades.

Economic growth, structural change, and globalization were the most commonly identified indirect drivers of change. Their impacts on ecosystems were mediated by institutional and sociopolitical factors. Evidence from the sub-global assessments suggests that the impact of economic growth depends on a range of institutional settings and on the structure of growth itself. The economic changes of the 1990s introduced a market system in the Altai-Sayan ecoregion in Russia and Mongolia, for example, that resulted in a double impact: higher cashmere producer prices encouraged intensified herding at locations closer to marketplaces, causing overstocking in the surrounding areas. When Trinidad liberalized trade, local producer prices dropped, making local production of market crops unprofitable. The increases in transport that result from global trade are seen as a major indirect driver of increases in invasive species; the release of ballast water by ships in the Caribbean Sea, for example, introduced the Indo-Pacific green mussel *Perna veridis* to the region.

Drivers of change operate at different spatial scales and temporal rates of change, and there is no clear-cut relationship between a driver's spatial and temporal scales. Most drivers follow the general rule that the coarser the spatial scale over which the driver operates, the slower the process tends to be. However, the sub-global assessments identified a significant number of exceptions. For example, the São Paulo assessment mentions governance and legislation as a local, but slow driver. The same holds for soil degradation as a biophysical driver in Downstream Mekong. On the other hand, the assessment of San Pedro de Atacama, Chile, identified rapid worldwide changes of technology in the mining sector as an important driver. Argentine Pampas also identified fast technological change on the global, or at least the national, scale as an important driver.

Understanding drivers, their interactions, and the consequences for ecosystem services and human well-being is crucial for the design of effective responses. Although many responses target specific problems with ecosystem services, the nature of ecosystem change means that such responses can have unintended consequences in a system of multiple interacting drivers. Individual drivers may be difficult to influence without affecting other drivers; therefore intervening in the interactions among drivers is often a more direct way to achieve a desired outcome. This may also enable a more integrated and holistic approach to ecosystem management. The Kristianstad Wetlands assessment in Sweden found that this approach was adopted in the area through the implementation of adaptive management.

Drivers of ecosystem change often interact with one another in synergistic ways. Within the range of sub-global assessments, three major types of synergies between drivers were identified: processes that *trigger* each other, processes that *reinforce* each other, and processes that *constrain* each other. The introduction of EU policies in Portugal has triggered a high degree of dependency on decisions made at the European level, which might not be appropriate for local decision-making on the management of specific ecosystems and their services. Resettlement projects designed to release the pressures on the natural and social environment in the densely populated regions of coastal Southeast Asia have aggravated land use change (Tropical Forest Margins). The case when one driver constrains the action of another, might serve as a starting point for appropriate interventions. Institutional changes envisaged in the Stockholm Urban assessment in Sweden are seen as a possible action, as they are expected to constrain urban sprawl, which is a major driver of loss of green areas.

Drivers can be controlled to varying degrees by decision-makers. The degree of control is largely scale- and context-dependent. Factors such as legislation, international treaties, and governance structures can rapidly change and either mitigate or exacerbate the effects of drivers. In SAfMA Gariep, for example, the governance change that took place in South Africa in 1994 was rapid but affected a large area. Democratic governance had significant socioeconomic implications for the greater southern African region.

The effect of drivers can change over scales and over time. For example a driver, endogenous at a certain scale, can become exogenous when local decision-making becomes subordinated to the implementation of national or regional goals. For example, in the Stockholm Urban assessment, infrastructure and green area management were under the control of local municipal authorities, but local authorities were superseded when national infrastructure plans were implemented.

7.1 Introduction

This chapter relies on various sources of information on the drivers of ecosystem change considered in the sub-global assessments, in particular the state of the assessment reports. In addition, information was collected throughout the process, in particular through two questionnaires filled in by the sub-global assessment teams (Q1, Q2), the two knowledge markets (KM1, KM2), and personal communication with key individuals. Because the sub-global assessments and their focus on ecosystem services are user-driven, the results presented here cover only some of what can be found in the scientific literature on this topic (for example, with respect to land use and land cover change; see Lambin et al. 2003). Nevertheless, the chapter seeks to draw as many lessons as possible from comparison of drivers across the sub-global assessments. A complete presentation of all the individual drivers identified by each assessment can be found in the individual assessment reports available on the MA website (www.MAweb.org).

The chapter is organized as follows: The first section gives some background on the drivers of ecosystem change both within the MA global assessment and in the broader literature. The next section reports the findings on individual drivers in the sub-global assessments, their classification as direct or indirect and as exogenous or endogenous, and categories of drivers (economic, biophysical, etc.), giving particular emphasis to how drivers change across scales. The following two sections discuss driver interactions, first in terms of major processes of interaction and then with regard to non-linearity, thresholds, and crises. The final section explores the implications of these findings for ecosystem management, setting the stage for Chapter 9 on responses.

7.2 Background: Major Global Trends

The local and regional changes in ecosystems and their services in the various sub-global assessments operate against a background of global and regional-scale drivers. From the perspectives of most users of the sub-global assessments, these global and regional drivers are often considered exogenous, or beyond their control. This introductory overview is intended to outline major trends of those global drivers mentioned in the sub-global assessments, particularly climate change and economic globalization. It also seeks to elaborate on global trends of finer scale drivers discussed in the sub-global assessments, in order to frame the more detailed discussions of regional and local-scale drivers later in the chapter. This treatment is not meant to be comprehensive, and the reader is referred to MA *Scenarios,* Chapter 7, for a more detailed discussion.

Over the past two centuries, human activities have induced major changes in many ecosystems (for an overview, see Steffen et al. 2004; MA *Current State and Trends*). These changes have occurred at all scales, from local to global. Examples at the global level include perturbations of the world's climate system (Houghton et al. 2001), changes in stratospheric and tropospheric ozone concentrations, and changes in global patterns of transport of particles and pollutants (Hauglustaine and Brasseur 2001; Steffen et al. 2004). Changes at local scales are widespread and show a high degree of variability. Some of these local changes are reflected in the various sub-global assessments. We live on a human-dominated planet (Vitousek et al. 1997).

Population and economic growth, technological change, and changes in sociopolitical organization and institutions are key drivers of the massive increase in resource consumption. The nature of the interactions between these drivers (that is, how each of them dominates or is mediated by other factors, and the ability of natural systems to cope with pressures) varies across space and time. Nevertheless, these key changes constitute some major driving forces of environmental change.

Table 7.1 depicts changes in the world's population, production of food and energy, and economic output, between 1950 and 1993. Global population and global energy production have approximately doubled during this period, grain production has increased 2.7 times, world GDP has grown by a factor of 6, and global trade in merchandise by a factor of 20. Both per capita grain consumption and GDP per capita have increased in many places around the world, although significant exceptions exist. These global trends neglect regional differences in these factors, as well as differences in other factors and processes that may aggravate or attenuate them. Therefore, these gross increases give only a very general overview of the actual drivers of ecosystem change. Though efficiency improvements have been observed throughout history, the rate of economic growth has outpaced the rate of efficiency growth, thus leading to higher resource use and higher emissions of gases (carbon dioxide, nitrogen oxide, and to a lesser extent, sulfur dioxide) and increasing production of fluid and solid waste.

Table 7.1. Changes in Global Population, Food and Energy Production, and Economic Output, 1950–93 (Steffen et al. 2004 and MA *Scenarios,* Chapter 7)

	Grown by a factor of
Population (number of people)	2.2
Grain (total production in tons)	2.7
Energy (production)	2.0
Total world real GDP	6.0
Global trade in manufactured goods (volume, 1950–2001)	≈20
Consumption of N fertilizer (tons)	≈8

Human land use, agriculture in particular, is a key human activity altering ecosystems. Though grain production is still growing globally, the rate of growth is slowing. Meat production worldwide has grown at about 1.4% per annum over the last 40 years (FAOSTAT data 2004). Estimates of the expansion of cropland and pasture over the twentieth century range from 70% to 80% (Klein Goldewijk 2001). The sub-global assessment findings were consistent with these global observations.

Climate change is now considered by most scientists to be a significant driver of ecosystem change, and is expected to be an increasingly important driver in the future. According to the Intergovernmental Panel on Climate Change (2001), global mean temperature increased by between 0.4 and 0.8 degrees Celsius over the twentieth century. Although it is difficult to assign quantitative values to the contributions of the various factors influencing climate, it is now certain that anthropogenic interferences have contributed significantly to this rise in global mean temperature. Major reasons are the combustion of fossil fuels and land use change (particularly deforestation)—both of which add carbon dioxide to the atmosphere. Note that carbon storage is an important ecosystem service, which is assessed in a number of the sub-global assessments. (See Chapter 8.) The increase in global mean temperature plays out very differently in different regions of the world, and appears to be more pronounced in the northern high latitudes. In many regions of the world, this increase is accompanied by an increase in precipitation, though some tropical regions have also seen decreases in precipitation. There is evidence that recent climate change has already brought about some specific changes in ecosystems (for example, a shift in the latitudes at which certain plants and animals are found, and a trend toward earlier greening in the northern high latitudes (Lucht et al. 2002; IPCC 2001)).

Though discussions of the effects of human activities on ecosystems via atmospheric processes have focused largely on climate change, emissions of other gases and particulate production by the burning of fossil fuels and biomass represent another major impact on the atmosphere, and ultimately on ecosystems and their services. The emission of sulfur dioxide, for example, is responsible for most of the acidification trends observable in the 1970s and 1980s in Europe and North America, and now in large regions in Asia. Sulfates also are major constituents of small, aerosol particles, which have a distinct effect on climate. Aerosols also have a direct impact on air quality, photosynthetic active radiation, and particle deposition (Heintzenberg 2004). Estimates of sulfur dioxide emissions since 1850 indicate an almost continuous increase, reaching about 70 million tons per year in the early 1990s. The most pronounced growth has occurred since the 1950s, when emissions were about 30 million tons per year. Due to increased pollution control efforts (for example, flue gas desulfurization and switching from high to low-sulfur coal), these trends have slowed or even reversed. Other environmentally damaging emissions from human activities are nitrogen oxides (from fossil fuel combustion and agriculture), dust (which affects climate and nutrient cycling), and heavy metals (including toxic substances like mercury).

Global biogeochemical cycles (that is, the water, carbon, nitrogen, and phosphorus cycles) are increasingly connecting social-ecological systems around the world. The global hydrological cycle is a natural component of the earth system that has been increasingly modified by humans. The atmospheric processes outlined above; the development of infrastructure that modifies rivers, lakes, or other wetlands; and changes in land use are changing patterns and/or levels of precipitation, evaporation, runoff, and river discharge throughout the world. According to some estimates, about 40% of the global runoff to the oceans is now intercepted by large dams, and some major rivers like the Yellow River in China and the Colorado River in North America discharge only a small fraction of their overall volume of water into the ocean (Vörösmarty et al. 1997; MA *Current State and Trends,* Chapter 8).

In 1990, the total amount of reactive nitrogen created by human activities was about 141 teragrams per year, which represents a nine-fold increase over 1890. At present, biological nitrogen fixation occurring in cultivated crops, synthetic nitrogen production, and fossil fuel combustion have become major sources of reactive nitrogen. (See MA *Scenarios,* Chapter 7.) Together with an increased input of phosphorus, this has had the positive impact of increasing food production at affordable prices, but at the same time has also had negative consequences for some ecosystem services. Effects range from contributing to the greenhouse effect by nitrous oxide through modification of tropospheric chemistry, to water pollution by nitrates and phosphates. As the latter is often the limiting factor in lake and river ecosystems, increased input of phosphorus can induce eutrophication, thus affecting services such as the provisioning of fresh water and lake fisheries.

Growth in international merchandise and financial trade over the past five decades has consistently been larger than global GDP growth. In the 1990s, growth rates in merchandise trade were three times that of world GDP—6% versus 2%, respectively (WTO 2004). Similar trends also hold for financial flows. For example, gross foreign direct investment grew from 2.7% of global GDP in 1990 to 6.0% in 2002 (WTO 2004). This ''economic globalization'' comes along with a broader range of interconnectedness, in the way of improved information and communication technologies, and a homogenization—but also spreading plurality—of cultures. Different views on the effect of economic growth on ecosystem change exist, some claiming an increasing negative impact whereas others see an increase in environmental protection and decreases in impacts in the course of economic growth. (For a more thorough discussion, see MA *Scenarios,* Chapter 7.)

7.3 Individual Drivers

This section highlights some driver-related issues within the MA conceptual framework (MA 2003), reflects on the process of assessing individual drivers in the sub-global assessments, and then presents major findings from the sub-global assessments in terms of:

- types of drivers (demographic, economic, sociopolitical, etc.);
- relationships between the two driver classifications across different spatial scales (exogenous and endogenous drivers versus direct and indirect drivers); and
- relationships between the spatial and temporal scales of drivers. (See also MA *Scenarios,* Chapter 7, for findings on drivers from the MA global assessment.)

7.3.1 Drivers within the MA Conceptual Framework

The MA conceptual framework (MA 2003) distinguishes between different types of driving forces that influence changes in ecosystems, their services, and therefore human well-being: direct and indirect drivers, and exogenous and endogenous drivers.

According to the conceptual framework, a *direct* driver unequivocally influences ecosystem processes. An *indirect* driver operates more diffusely, by altering one or more direct drivers. There are demographic, economic, sociopolitical, science and technology, cultural and religious, and physical and biological drivers. Important direct physical and biological drivers include changes in climate, plant nutrient use, land use, fires, diseases, invasive species, floods and droughts, and landslides. Understanding drivers and their interactions, which cause changes in ecosystems and their services (for example, between land use and droughts) is essential to the design of interventions that enhance positive and minimize negative effects.

Decision-makers are agents of change, and their choices are influenced by a number of drivers. Their behavior in turn can lead to changes in these drivers. Drivers that cannot be altered by a decision-maker at a certain scale, but influence his/her decisions, are called *exogenous* drivers. *Endogenous* drivers, in contrast, are defined as the drivers that the decision-maker at a particular scale can influence (MA 2003). This distinction is important in order to understand who should take action in response to drivers, and how it should be done to generate the greatest effect. As will be discussed later in this section, findings from the sub-global assessments suggest that this distinction between exogenous and endogenous drivers is not always clear, as some drivers are under *partial* control of decision-makers.

Whether a driver is endogenous or exogenous depends in part on the spatial and temporal scales at which the decision-maker operates. At the local level, it is likely that more driving forces cannot be controlled by decision-makers, and are therefore exogenous. The MA conceptual framework states: ''As the time and space scales expand, more drivers become endogenous; that is, a different set of decision-makers has influence over the drivers'' (MA 2003; p. 87). For example, prices for a particular commodity are usually an exogenous factor that an individual farmer has little control over, while a national government can influence those same prices by regulating markets for the commodity. Drivers that are exogenous in the short run can also become endogenous over longer time periods. Population growth rate is a good example of this. Migration policies or measures to curb population growth rates can influence national population growth over a 20–50 year time horizon.

7.3.2 Individual Drivers in the Sub-global Assessments

A wide variety of methods was used to identify and assess the drivers of ecosystem change at sub-global scales. (See Table 7.2.) The choice of methods was influenced both by the different ecosystems and human systems assessed and by the different goals of each sub-global assessment. Some assessments followed the MA conceptual framework closely; examples include Southern Africa (Q1–SAfMA) and Portugal. Other sub-global assessments were already under way before joining the MA process (for example, Tropical Forest Margins, which emerged from a long-standing research initiative that had developed independently of the MA); these initiatives largely adopted the MA conceptual framework, but in some cases had to modify some components.

Not surprisingly, the most common method reported for identifying drivers was an analysis of published literature and data sources (KM1). More interesting was the importance of user engagement in the identification and assessment of drivers. The assessment methods can roughly be divided into three classes (information based on KM2):

- At one extreme, three assessments used local and traditional knowledge to identify and assess drivers. These three assessments were conducted at the local scale, where it is usually easier to identify the driving processes of change (Veldkamp and Lambin 2001), at least with respect to local-scale drivers or the local ''expression'' of coarser scale drivers.
- At the other extreme, six assessments relied mostly on reviews of scientific literature and/or data analyses to identify and assess drivers. Some of these assessments (for example, Altai-Sayan and Western China) involved large areas where detailed local knowledge would not have been appropriate given the coarse scale of assessment.
- The rest of the assessments tried to reach a balance between scientific and nonscientific information sources.

Table 7.3 presents a broad classification of the scientific perspective of 20 sub-global assessments analyzed.

A common thread in many sub-global assessments was the lack of information needed to identify drivers and evaluate conditions and trends in ecosystem services, independently of one another. (See also Chapter 8.) In seven state of the assessment reports, it is clearly stated that there was not enough information to adequately assess the drivers, conditions, and trends of selected ecosystem services and related aspects of human well-being. Some assessments (for example, Northern Range in Trinidad) worked mostly with qualitative data, mainly due to gaps in quantitative information (Keisha Garcia, personal communication). Many assessments (for example, India Local and Sinai) tried to fill the information gaps using traditional and local knowledge; in these cases, the integration of different knowledge systems became particularly important. (See Chapter 5.)

Most sub-global assessments did not find it difficult to distinguish between direct and indirect drivers. However, the categorization of exogenous and endogenous drivers was more novel to many (from KM2). Several sub-global assessments (Caribbean Sea, San Pedro de Atacama, Papua New Guinea, Portugal) that categorized the factors influencing ecosystem change in their area according to the degree of controllability were able to apply the concept without much difficulty. In general, their definitions of ''controllability'' were analogous to the concept of whether a driver is endogenous or exogenous, and therefore fit well with the MA conceptual framework. The assessment in Papua New Guinea even clearly distinguished the usefulness of the different driver categories as an analytical tool, stating that ''the distinction between direct and indirect drivers is made from the point of view of scientists, while the distinction between internal (endogenous) and external (exogenous) drivers is made from the point of view of the manager or decision-maker'' (PNG).

Nevertheless, not all sub-global assessments used the concept of controllability of drivers at different scales as a analytical tool to discuss policy options with their stakeholder groups. The degree to which a sub-global assessment's work had been completed made an enormous difference in the understanding of the drivers assessed. Assessments in the preliminary stages typically included a list of broad categories of drivers in their status reports that were heavily influenced by the availability of data, and may not therefore have represented the full scope of drivers and their relative importance. Some also found it difficult to

Table 7.2. Summary of Methods Used to Identify and Assess Drivers of Ecosystem Change in Sub-global Assessments

Sub-global Assessment	Methods of Driver Identification and Assessment
Altai-Sayan	mostly from analysis of existing literature and data sources
Tropical Forest Margins	meta-analysis of case studies reported in the literature using LUCC framework
San Pedro de Atacama	review of current conditions and main trends, recent environmental impact studies of projects in the region, development initiatives in the region; through direct enquiries with users
Caribbean Sea	literature review, sending questionnaires to experts, drawing causal diagrams during focus group discussions at workshops, and in a few cases, analysis of statistics (e.g., hurricane frequency, tourism) and GIS (e.g., fisheries).
Colombia	review of existing literature and data sources; GIS analysis
Bajo Chirripó	review of existing literature and data sources, workshops, interviews, and a strong emphasis on participatory methods
India Local	review of existing literature; workshops and group discussions at different scales; emphasis on participatory methods
India Western Ghats	formal and informal interviews with a variety of actors (politicians, civil society, private institutions, communities); when available, secondary data used to complement primary data
Vilcanota	early stages involved fieldwork to identify preliminary driving forces, and conditions and trends, which were discussed at workshops with community members to select the main drivers; strong emphasis on participatory methods
Papua New Guinea	expert review of existing literature and datasets at national and local scales, supplemented by some stakeholder interviews at the local scale
Laguna Lake Basin	used the IPCC approach, which relies mainly on the assessment of existing literature
Portugal	workshops involving the assessment team and users; expert judgment (these experts undertook a literature review independently)
SAfMA	diversity of methodologies, with each component assessment using different methods to identify drivers; strong emphasis on participatory methods at the community and basin levels (Gariep, Zambezi, and Gorongosa-Marromeu basins); as the scale of analysis became coarser, the identification of drivers relied more on the review of existing literature and data sources, as well as quantitative modeling
São Paulo	field experience and analysis of existing literature and data sources used to identify drivers; these preliminary findings were presented and discussed at workshops with stakeholders and scientists to select the most important drivers from the preliminary list; after the drivers were chosen, scientists wrote a three-page summary giving specific details of the chosen drivers
Sinai	field visits used most frequently to identify and assess drivers; complemented by literature review and consultations with local people, stakeholders, and scientists
Sweden KW	drivers identified using literature review, semi-structured interviews with different stakeholders, and documented land use patterns since the 19th century; strong emphasis on understanding the social context (e.g., social capacity, social networks)
Sweden SU	drivers identified through review of existing literature and data, GIS analysis, gap analysis modeling, statistical trends, natural resource inventories, field data, and interviews with stakeholder groups; emphasis on stakeholder participation
Northern Range	drivers identified and assessed through workshops and meetings of collaborators (Advisory Group, Steering Committee, Working Groups) based on studies where they exist (e.g., study of carrying capacity for tourism on the North Coast of the island of Trinidad) and on expert knowledge
Downstream Mekong	interviews, workshops, review of existing literature and data, and GIS analysis
Western China	review of existing literature and data sources; quantitative modeling

conceptualize the interactions among drivers using formal instruments like diagrams. As the assessment process advanced, the understanding of what the specific drivers were, how they change over time, and how they interact, became clearer for the assessment teams.

7.3.3 Driver Categories

The sub-global assessments examined the full range of drivers outlined in the MA conceptual framework and ranked them according to their importance within their particular context. Major groups of drivers are discussed in the following subsections. The absence of particular drivers (for example, there is almost no indication of religious drivers) does not necessarily imply that these drivers do not play a role in those areas.

Figure 7.1 in Appendix A depicts the broad indirect drivers identified by the sub-global assessments at regional and national scales, and reflects the range of different approaches to the assessment of drivers. The information in the map comes from questionnaires, knowledge markets, and state of the assessment reports. Some assessments focused on a single driver, while others assessed a broad range of drivers.

7.3.3.1 Demographic Drivers

Population growth is mentioned as the most dominant indirect driver in the Downstream Mekong, Colombia, Sinai,

Table 7.3. Emphasis of the Scientific Perspective on the Identification and Assessment of Drivers

Perspective	Examples of Sub-global Assessments
Strong emphasis on the user/community identification of drivers	Bajo Chirripó, India Local, Vilcanota
Balance between the user/community identification of drivers assessment drivers through data analysis or literature reviews	San Pedro de Atacama, Caribbean Sea, PNG, Portugal, SAfMA, São Paulo, Sinai, Sweden KW, Sweden SU, Northern Range
Strong emphasis on data analysis or literature review	Altai-Sayan, Tropical Forest Margins, Colombia, Laguna Lake Basin, Downstream Mekong, Western China

and Eastern Himalayas assessments. In these areas, population growth is seen as a major cause of increasing demand for food, fuelwood, fodder, and other ecosystem services. National statistics on population growth suggest relatively high annual population growth rates in these locations in comparison with those sub-global assessment areas where population growth is not considered a dominant indirect driver (for example, Portugal, Northern Range, and Coastal BC). Where population growth was assessed to be a key driver, people often faced additional challenges including low economic growth and limited means of income generation apart from the utilization of local ecosystem services. (See Figure 7.2.)

Urbanization is frequently mentioned as a major demographic driver (Caribbean Sea, Northern Range, Sinai, SAfMA, Portugal, São Paulo). In most of these regions, urbanization in coastal areas was identified as having a more significant impact on ecosystem change than in inland areas, suggesting that the global increase of urban regions in coastal areas is going to be a major driver of ecosystem change in the near future.

7.3.3.2 Economic Drivers

All sub-global assessments identified economic drivers as important, although in different ways. In some regions, the driver was simply *economic growth.* A more comprehensive picture emerges if one considers how developments in particular economic sectors have profound impacts on ecosystem change. Key examples from sub-global assessments include:

- *Exploitation of natural resources, in particular forestry, fishing and other inshore marine resources.* The Lihir assessment in Papua New Guinea (PNG–Lihir) mentions increasing fishing pressure as an important example. In this region and also in the Caribbean Sea, increased fishing by international trawlers is putting increased pressure on marine fisheries in addition to fishing by local or regional fishermen. In PNG–Lihir, the national policy component of a sectoral resource management regime (like the fisheries regime) appears as an external imposition or constraint to members of a coastal community; but resource management decisions taken by members of traditional communities within their own domains are barely subject to any control by national government agencies (PNG–Lihir).
- *Tourism.* In three assessments (Caribbean Sea, Portugal, and Sinai), tourism was seen as an opportunity for income generation. At the same time, local people must also bear the often negative environmental side-effects of tourism. The Caribbean Sea is a good example of where there are only limited benefits of tourism for the local people in terms of income opportunities.
- *Mining.* Besides having direct ecosystem impacts, for example, through land use change, water withdrawal, or release of pollutants, mining can also have positive impacts by providing income for the local population (São Paulo, San Pedro de Atacama).
- *Mega-projects.* Examples include agricultural projects that aim to produce cash crops and provide income and economic growth to the region (Sinai) and the building of large dams (Eastern Himalayas, Coastal BC). The benefits for local people are often rather limited when compared to the costs.
- *External events.* A crisis in the global coffee market resulted in a shift toward less sustainable activities such as cattle grazing in the coffee-growing region of Colombia.

Thus economic growth was seen as a two-edged sword: though it often brings benefits that improve human well-being, it may also have other consequences that outweigh the benefits if not accompanied by appropriate institutional developments with regard to environmental protection. The issue, however, is not about economic growth per se, but rather about having the right institutional frameworks so that growth might occur equitably and sustainably.

7.3.3.3 Sociopolitical Drivers

Governance and policy structure and change are mentioned throughout most of the sub-global assessments, although they refer to changes in a diverse set of institutional settings and circumstances. Governance and policy changes have consequences for ecosystem services in three major ways:

- *Introduction of new economic regimes, possibly related to changes in political systems.* For example, in southern Africa, a trend toward democratization and increased participation can be observed in some countries, yet opaque and corrupt governments remain in power in others (Scholes and Biggs 2004). The trend toward democratization is sometimes accompanied by moves toward more open, market-oriented economies (for example, SAfMA and Altai-Sayan). In Portugal, the introduction of EU policies has led to major changes in the agricultural production system.
- *Co-operation or competition among decision-makers over resource management, particularly in open access or common property regimes.* The Caribbean Sea provides a good example of this, where the pursuit by individual national governments of economic opportunities based on Caribbean Sea resources have had the effect of forcing down economic rents as well as standards for environmental protection (Keisha Garcia, personal communica-

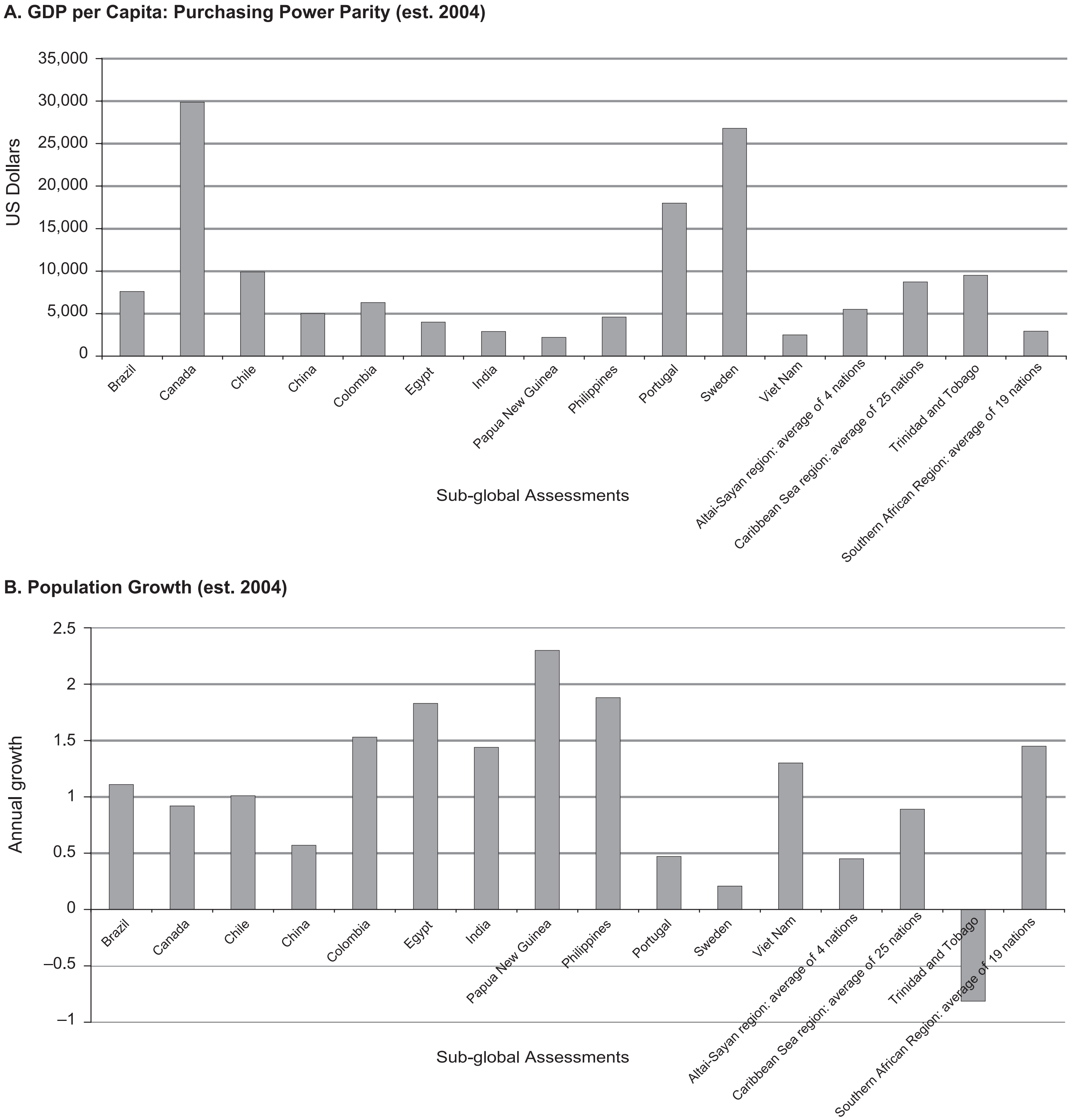

Figure 7.2. General Overview of Population Growth and Gross Domestic Product per Capita in Selected Countries with Sub-global Assessments (World Factbook 2004)

tion). This competition can also be observed at finer scales, as in the Stockholm urban assessment where individual municipalities compete with one another to secure construction investments and the establishment of enterprises (Sweden SU). This competition has often sub-optimal effects for regional green area management and for important ecosystem services (Jakob Lundberg, personal communication).

- *Failed centrally planned projects for improving the living conditions of local communities and people.* This was observed in India Local and appears to be particularly important for poor, rural areas. As noted in the literature (for example, McCully 1996), the benefits of these projects, even if they succeed, are often not fully received by the local people (see also discussion later in this chapter).

7.3.3.4 Science and Technology

Particularly important as a driver is the introduction of new technologies. Here, "new" does not necessarily imply an emergent or newly developed technology, but may simply mean a technology new to the region or locality being considered. The introduction of new technologies is closely related to economic drivers, as new industrial or economic activities in a region often bring new technologies. In other cases, it is the *substitution* or *extension* of existing technologies that induces ecosystem change (for example, the introduction of new cultivars in agriculture, new harvesting technologies, irrigation development, and genetically modified organisms).

The sub-global assessments suggest that technological change has both positive and negative effects: on the one hand it can increase human well-being by increasing the productivity or efficiency with which ecosystem services are obtained, on the other hand, it can increase pressure on ecosystems; examples include overfishing (Caribbean Sea, PNG–Lihir) or making new land available (housing in the steep hills of the Trinidad Northern Range). In some places, as in southern Africa, it is a lack of technology or infrastructure that induces pressure on ecosystems (Biggs et al. 2004).

7.3.3.5 Cultural and Religious Drivers

Cultural and religious drivers include changes in lifestyles (for example, from traditional to modern), values and norms (in particular with respect to the environment), and knowledge and education.

Changes in traditional systems and lifestyles were seen in the sub-global assessments to be a major driver of ecosystem change. For example, in the Mekong wetlands of Vietnam, increased demand for ecosystem services was found to be due to changes toward a more ''market-oriented lifestyle'' (Downstream Mekong). Changes in the Atacameños lifestyle in Chile, from traditional to more modern ways of living, and the effects on ecosystems, are illustrated by a comment from an inhabitant of the region:

> *''Now trickle irrigation is the fashion, so the agricultural engineer comes with a project and says: we need pvc, pvc trickler, engines, sulfates, etc., and estimates production over five years. Of course you get big fruit the first year, but by the fifth the soil is no good, it is exhausted. The engineer leaves after the five years are up.'' (San Pedro de Atacama, p.23)*

In two other assessments, the lack or loss of environmental awareness is mentioned as a driver of change (Northern Range, São Paulo). Northern Range mentions some improvements due to public education, but it is not yet widespread enough to alter human impacts on the Northern Range of Trinidad. There is a degree of stewardship and appreciation of sustainability issues among community and religious groups who are directly affected by the deterioration of the environment, and who are becoming more organized and articulate. Yet these trends have not yet reached a critical level of influence on society as a whole.

Examples can be found in the sub-global assessments where environmental awareness does lead to more sustainable behavior. In the Kristianstad Wetlands assessment in Sweden, a new generation of technicians with a worldview more open to nature conservation is working with urban planners to improve ecosystem health (Sweden KW). In the local community assessments in the Gariep basin in South Africa, it was found that religion serves as a starting point for responses, as it can serve as motivation for forming local institutions to deal with uncertainty (SAfMA Gariep).

7.3.3.6 Physical and Biological Drivers

One driver mentioned in a substantial number of sub-global assessments was the introduction and/or invasion of alien species. The Caribbean Sea assessment, for example, reports on research demonstrating that dust blown across the Atlantic Ocean from the Sahara brings along new microbes which directly affect coral reefs in the Caribbean—a particularly illuminating example of the effect of global processes on local environments. In other sub-global assessments, the introduction of alien species is mostly a by-product of increased national or international trade or the introduction of new technologies. The introduction of new cultivars has occasionally introduced new pests into the croplands of Papua New Guinea (PNG). In one of the sub-regions investigated in the Coastal British Columbia assessment, introduced deer have modified the forest more extensively than timber industry activities. Introduced raccoons and rats have destroyed seabird colonies. Beavers have reduced willow and wild apple populations and heavily modified lowland stream systems, altering stream courses and joining lakes that have been isolated since glaciation. The deer, raccoon, and beaver introductions were deliberate, for game and fur, while the rats came accidentally (Coastal BC).

Climate change and variability appear as a driver in the sub-global assessments in a variety of ways. Local climate change due to urbanization, resulting from the so-called urban heat island effect, has a measurable impact on ecosystems within the São Paolo urban region (São Paolo). In some instances, global climate change is reported to have directly caused recent ecosystem change (examples include Caribbean Sea and, to a lesser extent, SAfMA and Western China). Within the southern Africa region and throughout China, the recent trend of global warming is confirmed in many places. Nevertheless, a large degree of uncertainty still prevails with regard to both the causes and impacts of these changes in climate. In other assessments, the recent trends of climate change and the prospects of further warming in the future are seen as major drivers of future change, either directly or indirectly. In Papua New Guinea, for example, future climate change is seen as a major expected environmental problem, due to potentially increased frequencies and intensities of tropical cyclones, and the direct impacts of temperature increase and sea level rise (PNG). The Tropical Forest Margins assessment reports that climate change (present and future) has induced difficulties in crop planning. The prospect of future climate change has also elicited adaptive actions that have already had an impact on ecosystems, for example, in the Kristianstad wetlands where river embankments were raised (Sweden KW).

Several sub-global assessments identified the occurrence of climate-related extreme events as major direct drivers. Shifts in fire regimes were observed in Portugal and the forest ecosystems of the Altai-Sayan ecoregion. In the Caribbean Sea assessment, there is some indication that tropical cyclones are increasing in frequency, yet this increase is still within the natural range of variability of the last century. Given the difficulty of relating short-term trends in extreme events to climate change, it is not possible to attribute these drivers to anthropogenic climate change. Nevertheless, the increase in tropical cyclones in the region has induced a shift in yachting toward the south, which is correlated to infrastructure development on the north coast of Trinidad, with some implications for local ecosystems (Northern Range).

Overall, physical and biological drivers are mainly seen as increasing the pressures on ecosystems, resulting in decreases in the provisioning services of ecosystems.

7.3.4 Spatial Scales and Driver Classification

This section discusses the classification of drivers as being direct or indirect, and endogenous or exogenous—first in terms of particular spatial scales and then in terms of patterns across scales. In order to do this, the drivers found in individual assessments have been assigned to one or several of the following spatial scales: local, sub-national, national, regional, and global. There are, in principle, two aspects of scale to consider: the scale at which a driver operates and the scale at which the driver can be changed through human influence. Here, the focus is on the scale at which a driver can be changed. The information on scales has been obtained either from the state of the assessment reports, the knowledge markets, or answers to questionnaires. All data have been compiled into a single data file that can be downloaded from the MA website; the data served as a basis for the tables presented in this chapter and for the statistical analysis.

A total of 241 drivers were identified across all of the sub-global assessments. Of these, a classification of spatial scale was obtained for 213, and a classification of speed was obtained for 108. Many drivers were classified as belonging to more than one spatial scale. For 178 drivers, classification as direct/indirect and exogenous/endogenous was also done.

7.3.4.1 Drivers at the Local Scale

Local scale drivers found in the sub-global assessments are shown in Table 7.4, organized into a matrix of direct/indirect versus exogenous/endogenous. The most frequently mentioned direct driver was land use and land cover change, and it is in all instances classified as endogenous. In general, all endogenous drivers at the local scale appear to be related to management activities (that is, they can be controlled by changes in decision-makers' choices on how to manage local ecosystems and their services). An encouraging example is the South African initiative *Working for Water,* where local management decisions aimed to reduce the negative impact that the introduced Eucalyptus tree has had on the water table (Biggs et al. 2004).

As expected, exogenous drivers are more varied, ranging from natural phenomena (for example, climate) to economic policy and infrastructure development. In some instances, drivers are classified as being both endogenous and exogenous. This hints at the high degree of complexity when it comes to questions about control over drivers. Decision-makers at the local level may perceive some drivers as being under their *partial* control, as in the case of São Paulo, where urban growth and real estate speculation are seen as only partially controllable (São Paulo). This indicates that the concept of endogenous versus exogenous drivers introduced in the MA conceptual framework is sometimes not strictly applicable.

The table also shows that there are more endogenous than exogenous drivers identified at the local scale. This pattern also carries through coarser scales up to the national level. This is somewhat contrary to what is suggested in the MA conceptual framework (discussed further below in the context of emerging patterns).

In general, there are more direct than indirect drivers at the local scale. This probably relates to the perception that most drivers at this scale are unequivocally acting on ecosystems and causing change (MA 2003). Some anthropogenic drivers appear to be direct, and are mostly economic and technology-related. These drivers are also largely related to harvesting, management, and exploitation activities (for example, the intensification of harvesting activities in PNG–Lihir or the use of external inputs for agriculture in the Argentine Pampas).

7.3.4.2 Drivers at the Sub-national Scale

For drivers at the sub-national level, a picture somewhat similar to the one at the local scale emerges. (See Table 7.5.) Land use change, external input use, and harvesting are again seen as major direct drivers. However, there are more exogenous, indirect drivers than at the local scale, in particular in relation to endogenous, indirect drivers—perhaps because drivers that are exogenous at sub-national or local scales are actually perceived as homogenous across microregions and as not having a further variability across local scale communities. For example, economic growth as an indirect sub-national scale driver (for urban sprawl) relates more to growth in the entire Stockholm metropolitan region than to growth in the direct neighborhood of the Stockholm National Urban Park, the actual assessment area (Sweden SU).

7.3.4.3 Drivers at the National Scale

Most sub-global assessments dealt with national drivers and thus the largest number of drivers was assessed at this scale. (See Table 7.6.) Some drivers that were exogenous at the local scale became endogenous at the national scale. For example, in Viet Nam, legislation is an exogenous driver at the local scale but policies and regulatory management are endogenous at the national scale (Downstream Mekong). In Papua New Guinea, sectoral resource management is exogenous in the local-level assessment (PNG–Lihir) and endogenous in the national-level assessment (PNG).

Due to the strong link between the levels of decision-making and whether a driver is endogenous or exogenous, the classification of a driver as being exogenous or endogenous can actually change when the political or normative

Table 7.4. Drivers of Ecosystem Change at the Local Scale. Drivers are classified as being direct or indirect, and exogenous or endogenous. Note that there are some drivers which are classified as exogenous *and* endogenous at the same time (for example, loss of traditional knowledge in Bajo Chirripó).

<table>
<tr><th>EXOGENOUS</th><th>ENDOGENOUS</th></tr>
<tr><td colspan="2">DIRECT</td></tr>
<tr><td>Argentine Pampas: disease, pest, and weed outbreaks; climate
Laguna Lake Basin: lake water level; land cover change
PNG–Lihir: tectonic disturbances; freak weather events with localized impacts
São Paulo: air pollution; industrial deconcentration
India Local: legislation
SAfMA: climate
Sweden SU: invasive species
Downstream Mekong: legislation</td><td>Argentine Pampas: changes in land use/land cover; external input use; technology application
Laguna Lake Basin: land use change
PNG–Lihir: intensification of harvesting activities; deforestation for expansion of food-cropping; industrial exploitation of inshore marine resources; discharge of domestic waste material; deliberate introduction of exotic species or varieties
São Paulo: urban waste; mining
Bajo Chirripó: agrodiversity loss
Caribbean Sea: aquaculture
Eastern Himalayas: agricultural technology
San Pedro de Atacama: waste disposal
Sinai: ground water pollution; soil degradation
Western China: land use change; climate change; demography</td></tr>
<tr><td colspan="2">Bajo Chirripó: loss of traditional knowledge
India Local: NWFP ownership
Laguna Lake Basin: introduction of exotic species; technology introduction; pollution
São Paulo: urban growth and real estate speculation; infrastructure works; vegetation clearing and extraction</td></tr>
<tr><td colspan="2">INDIRECT</td></tr>
<tr><td>PNG–Lihir: sectoral resource management (national policy); price of commodity exports, imported food and fuel; scientific and technological change in agriculture, energy, and water supply
SAfMA: demography; regional integration
São Paulo: insufficient environmental awareness
India Local: economic demand (e.g., fish, trees); institutions (e.g., Forest Department)
Laguna Lake Basin: markets and consumption</td><td>PNG–-Lihir: volume of human migration across community domains; change in indigenous resource management regimes; devaluation of local customs and customary leadership; destabilisation of customary tenure systems; loss of agricultural knowledge
SAfMA: governance; growth rate, wealth distribution, foreign investment; sociocultural values; poverty; infrastructure
São Paulo: land regulation; governance limitations
Downstream Mekong: soil degradation
San Pedro de Atacama: Atacameños' lifestyle changes
Sinai: urbanization</td></tr>
<tr><td colspan="2">SAfMA: large-scale interventions</td></tr>
</table>

situation in a society changes. Before the end of apartheid, South African trade was largely limited by sanctions imposed by foreign governments; agricultural policy decisions were made at the national level and thus the driver was endogenous. With the end of apartheid, South Africa reentered world agricultural markets and its national agricultural policy is now influenced by international transactions (Bohensky et al. 2004).

7.3.4.4 Drivers at the Regional Scale

A smaller number of regional drivers were identified in the sub-global assessments than were identified at finer scales. (See Table 7.7.) This was probably due to the relatively small number of assessments at the regional scale. However, at this scale endogenous drivers are no longer dominant, at least in terms of numbers.

Anthropogenic direct drivers were mainly related to technologies and intensity of harvesting which appear to be, at least in the regions covered by the sub-global assessments, controllable at the national level or below, but not at regional or even global scales. In this respect, national governments are still seen as having the strongest role in decision-making when it comes to influencing the direct drivers of ecosystem change.

7.3.4.5 Drivers at the Global Scale

Few sub-global assessments addressed global drivers, as might be expected given the focus of the sub-global assessments on

Table 7.5. Drivers of Ecosystem Change at the Sub-national Scale. Drivers are classified as being direct or indirect, and exogenous or endogenous.

<table>
<tr><th>EXOGENOUS</th><th>ENDOGENOUS</th></tr>
<tr><td colspan="2">DIRECT</td></tr>
<tr><td>Argentine Pampas: climate
Altai-Sayan: climate warming
São Paulo: industrial deconcentration
Sinai: external inputs
India Local: legislation
SAfMA: climate
Downstream Mekong: legislation</td><td>Argentine Pampas: external input use; technology application
Altai-Sayan: fire; recreation; forestry; water use; waste discharge
São Paulo: urban waste; mining
Sinai: land use pattern
Laguna Lake Basin: wetland rice cultivation; pollution; deforestation
San Pedro de Atacama: changes in land use patterns
Sweden KW: land use changes; increased flooding; eutrophication; urban sprawl
Sweden SU: green area loss
Tropical Forest Margins: agricultural expansion; infrastructure development; wood extraction</td></tr>
<tr><td colspan="2">Argentine Pampas: disease, pest, and weed outbreaks
San Pedro de Atacama: water consumption
India Local: NWFP ownership
São Paulo: urban growth and real estate speculation; infrastructure works; air pollution; vegetation clearing and extraction</td></tr>
<tr><td colspan="2">INDIRECT</td></tr>
<tr><td>SAfMA: demography
São Paulo: insufficient environmental awareness
Sinai: economic factors
Sweden KW: EU Common Agricultural Policy influence on land use changes; competition between municipalities; intensive agriculture
Sweden SU: economic growth
Altai-Sayan: economic transition and policy
Laguna Lake Basin: industrialization; population change and settlements
San Pedro de Atacama: economic growth
Tropical Forest Margins: economic policy and institutions; technology; culture; demography</td><td>SAfMA: governance; economic growth, wealth distribution, foreign investment; sociocultural values; poverty; infrastructure
São Paulo: land regulation; governance limitations
Sinai: population growth
Sweden KW: social capacity for ecosystem management; changes in forestry management
Sweden SU: population growth; lack of inter-municipal coordination
Western China: economic policy</td></tr>
<tr><td colspan="2">SAfMA: large-scale interventions</td></tr>
</table>

sub-global scales. Moreover, global scale drivers were seen to be exogenous by most of the sub-global assessments given that they were largely beyond the control of individual decision-makers at sub-global scales. (See Table 7.8.)

7.3.4.6 Emerging Patterns

Based on Tables 7.4 through 7.8 and some cross-cutting analysis, some conclusions on the directness of drivers, and whether they are exogenous or endogenous, can be drawn, depending on the scale of the drivers. Overall, the number of direct drivers assessed was slightly higher than the number of indirect drivers (53% versus 47%). Most of the direct drivers were biophysical (66%), with economic drivers (24%) dominating the remainder. The fact that a significant number of anthropogenic drivers were classified as direct is somewhat contrary to the MA conceptual framework, where biophysical drivers are seen as being dominant among direct drivers. Direct economic drivers mostly relate to harvesting activities; examples include deforestation (Laguna Lake Basin) and fishing (Caribbean Sea, PNG).

Anthropogenic drivers were predominant among the indirect drivers. In particular, economic drivers (35%) and sociopolitical drivers (27%) were mentioned. A number of biophysical drivers were also identified (9%). The Northern Range assessment in Trinidad reveals an interesting example of how changes in weather patterns on the scale of the entire Caribbean Sea constitute an indirect driver. Due to an increase in the frequency of tropical cyclones (the indirect driver) in the 1990s, the insurance rates for owning a yacht in one of the northern islands in the region increased. This led to increased demand for marinas on the northern coast of Trinidad, which is still seen as relatively protected from

Table 7.6. Drivers of Ecosystem Change at the National Scale. Drivers are classified as being direct or indirect, and exogenous or endogenous.

<table>
<tr><th>EXOGENOUS</th><th>ENDOGENOUS</th></tr>
<tr><td colspan="2">DIRECT</td></tr>
<tr><td>Altai-Sayan: climate warming
Caribbean Sea: Ship-borne species introduction
PNG: global warming and periodic droughts; accidental introduction or invasion of exotic species; land use or resource management by traditional communities
Downstream Mekong: legislation
India Local: legislation
SAfMA: climate</td><td>Altai-Sayan: fire; recreation; forestry; water use; waste discharge
Caribbean Sea: changes in coastal land and sea use; land-based pollution; marine pollution
PNG: discharge of waste by industry; industrial exploitation of inshore marine resources
Downstream Mekong: infrastructure and urban development
San Pedro de Atacama: changes in land use patterns
Laguna Lake Basin: pollution
Portugal: land use changes; exotic species
Northern Range: land conversion
Tropical Forest Margins: agricultural expansion; infrastructure development; wood extraction</td></tr>
<tr><td colspan="2">San Pedro de Atacama: water consumption
Portugal: fire regime
Downstream Mekong: land use change</td></tr>
<tr><td colspan="2">INDIRECT</td></tr>
<tr><td>PNG: sectoral resource management (global policy); world market prices for exports and imports; technical innovations in agriculture, energy, and water supply; natural population increase
SAfMA: demography
Northern Range: changing weather pattern; culture and behavior
Downstream Mekong: population change; technological development; war
Western China: population change; economic development; labor change; environmental policies
Altai-Sayan: economic transition and policy
Argentine Pampas: socioeconomic policies; public and private trade strategies; market fluctuations; demographic patterns; technology supply
Bajo Chirripó: political corruption
Laguna Lake Basin: industrialization; population change and settlements
San Pedro de Atacama: economic growth
Tropical Forest Margins: economics; policy and institutions; technology; culture; demography</td><td>PNG: macroeconomic and economic development policies; sectoral resource management (national policy); general decline in government services to rural areas; industrial exploitation of resources outside the coastal zone
SAfMA: governance; economic growth, wealth distribution, foreign investment; sociocultural values; infrastructure
Northern Range: economic forces; governance; urbanization; demand for recreation
Downstream Mekong: economic pressure; policies and regulatory management
Western China: economic policy
Portugal: land tenure</td></tr>
<tr><td colspan="2">Portugal: tourism; economic growth; population distribution and migration; environmental legislation and attitudes
SAfMA: large-scale interventions
Downstream Mekong: tourism</td></tr>
</table>

cyclones. The development of the corresponding infrastructure (the direct driver) brought about ecosystem changes in the region (Northern Range).

In an analysis across the scales of drivers, some general patterns emerge, in particular with regard to the relationship between direct and indirect drivers on the one hand, and exogenous and endogenous drivers on the other. (See Figure 7.3.) The overall number of direct drivers decreases as scales get coarser, that is, drivers act in the clearest ways at finer scales. This is in line with the observation that most direct drivers are related either to biophysical impacts or to management activities that take place at the scale of the ecosystem itself. With regard to indirect drivers, the number of drivers is highest at the national scale, because drivers that act diffusely are not seen as directly related to the scale of the ecosystem, but more related to the scale of adminis-

Table 7.7. Drivers of Ecosystem Change at the Regional Scale. Drivers are classified as being direct or indirect, and exogenous or endogenous.

	EXOGENOUS	ENDOGENOUS
DIRECT	**Caribbean Sea:** climate change: hurricanes; alien species from Amazon/ Orinoco **SAfMA:** climate	**Caribbean Sea:** fish harvesting technology **India Local:** dependence on one single product
INDIRECT	**Caribbean Sea:** trade: international shipping **SAfMA:** demography **Argentine Pampas:** socioeconomic policies; public and private trade strategies; market fluctuations; demographic patterns; technology supply **Northern Range:** changing weather pattern	**Caribbean Sea:** population growth; coastal urbanization; trade; regional coordination and governance **SAfMA:** governance; economic growth, wealth distribution, foreign investment; sociocultural values; infrastructure; regional integration
INDIRECT (exogenous and endogenous)	**Portugal:** environmental legislation and attitudes; EU Common Agricultural Policy and global markets **SAfMA:** large-scale interventions; science and technology	

Table 7.8. Drivers of Ecosystem Change at the Global Scale. Drivers are classified as being direct or indirect, and exogenous or endogenous.

	EXOGENOUS	ENDOGENOUS
DIRECT	**Caribbean Sea:** climate change: sea temperature; species introduction: Sahara dust	
INDIRECT	**SAfMA**: economic growth, wealth distribution, foreign investment **Argentine Pampas:** socioeconomic policies; public and private trade strategies; market fluctuations; demographic patterns; technology supply **San Pedro de Atacama:** technological changes in mining **Northern Range**: changing weather patterns **Downstream Mekong**: climate change	**SAfMA**: international trade regime

trative organization. This is supported by the fact that, by far, most indirect drivers are anthropogenic.

Most identified direct drivers—from local to national scales—are endogenous. At finer scales, many identified drivers are perceived as being at least partially controllable. At coarser scales, the perception of controllability fades. The limited controllability of regional resource management policies in the Caribbean is a good example of this.

Most indirect drivers at the national scale are exogenous, whereas at other scales indirect drivers are more evenly exogenous or endogenous. This is related to the fact that many decision-makers involved in ecosystem management at different scales perceive drivers at the national scale to be outside of their control. For example, the structure and development of the economy might well be under the control of national decision-makers, but may not be perceived in this light by an individual official inside the agriculture ministry. Unfortunately, no good example to support this hypothesis can be found among the sub-global assessments.

A number of sub-global assessments identified specific drivers as being exogenous *and* endogenous at the same time (for example, the loss of traditional knowledge on the local scale in Bajo Chirripó). In being assigned to both categories, it appears that *some* control over the driver is attributed to the decision-maker at the specific scale, although it is not seen as under the decision-maker's *total* control. The specification of drivers as exogenous or endogenous also depends on the political and institutional structures of a given society.

7.3.5 Driver Scale and Dynamics

This section focuses on the relationship between the spatial and temporal scales of drivers analyzed in the sub-global assessments, distinguishing between two aspects of a driver's temporal scale: the speed at which the driver operates and the speed at which the driver can change. A similar distinction is made between these two aspects of a driver's spatial scale. Though not many assessment teams distinguished be-

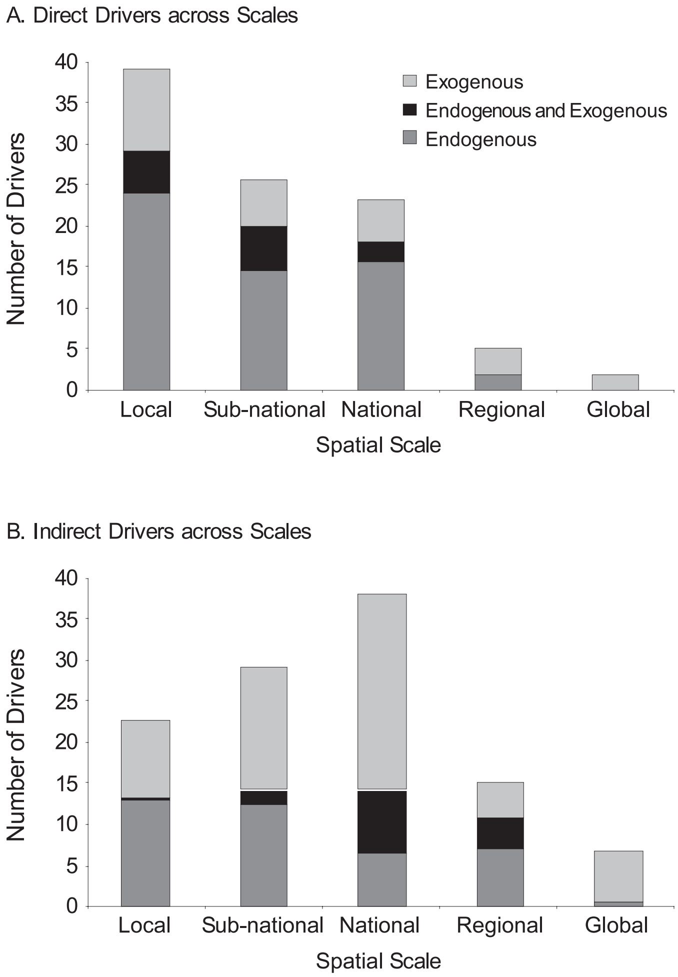

Figure 7.3. Direct and Indirect Drivers across Scales and Their Classifications as Exogenous or Endogenous

tween these two different scale features of drivers in their assessments, it was possible to make this distinction retrospectively in interviews with the assessment teams, especially during the knowledge markets (KM-1, KM-2). The distinction is helpful when assessing the controllability of drivers: a decision-maker often has more ability to control drivers that operate or change at the temporal and spatial scale at which the decision-maker is situated.

For driver speed, the following categorization was used: fast (F), medium (M), slow (S), and very slow (VS). A few drivers were classified in intermediate categories of medium-fast and medium-slow. The classification of driver speeds was determined through interviews with assessment teams and was based on the characteristic time scale of a driver's effects (that is, how long it takes for the driver to have a significant effect). The results are presented in Table 7.9.

Within the overall set of drivers in the sub-global assessments, 103 were categorized according to the spatial and temporal scales at which they operate. To analyze the relationship between spatial scale and speed, some aggregation was necessary. Drivers in the medium-slow and medium-fast categories were considered to be medium. Very slow drivers were considered to be slow. This left only three speed categories: fast, medium, and slow. When a driver was indicated as covering more than one spatial scale, it was split among those spatial scales. For example, if a driver was indicated as covering spatial scales ranging from local to national, it counted as one third for the local scale, one third for the sub-national, and one third for the national.

The five spatial scale categories (local, sub-national, national, regional, global) were aggregated into three categories: local and sub-national, national, and regional and global. Since the sampling on the spatial scales was biased due to the spatial scales of the sub-global assessments themselves, we normalized the number of drivers for each spatial scale. The final result is presented in Figure 7.4, resembling a similar figure in the MA conceptual framework (MA 2003, Figure 5.2), which presented the relationship between spatial and temporal scales conceptually.

It is often hypothesized that small scale processes are fast. For a large number of drivers identified in the sub-global assessments, the hypothesis holds that the coarser the spatial scale, the slower the process of change. However, a significant number of exceptions were observed. For example, the São Paulo assessment mentions governance and legislation as a local, but slow driver; similarly Downstream Mekong

Table 7.9. Classification of Drivers by Temporal Scale. This classification of driver "speeds" was based on the characteristic time scale of a driver's effects, that is, how long it takes for a driver to have a significant effect.

	Fast	Medium	Slow	Very Slow
Local scale	$<$ 1 year	1–5 years	$>$ 5 years	
Sub-national to global scales	$<$ 2 years	2–10 years	$>$ 10 years	$>$ 20 years

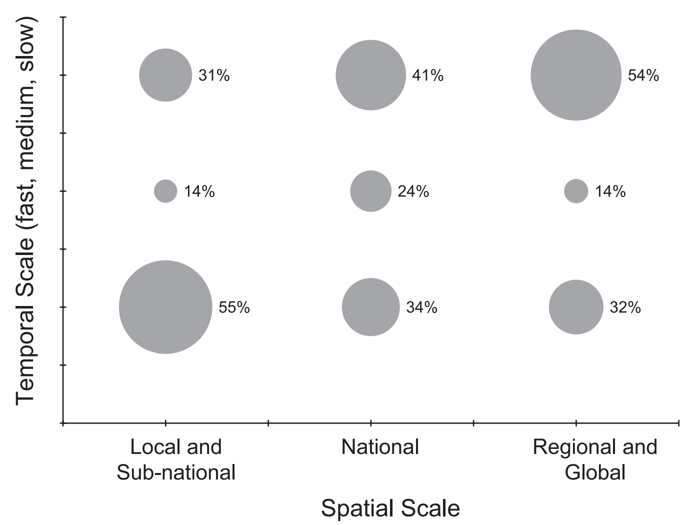

Figure 7.4. Relationship between Spatial and Temporal Scale of all Drivers Considered in the Sub-global Assessments. The size of the circles represents the proportion of drivers at a certain spatial scale which had a certain speed (e.g., of all the drivers mentioned on local and sub-national scales, 55% were fast). The general pattern is that fine spatial scale (local and sub-national) processes tend to be fast, while coarse spatial scale (regional and global) processes tend to be slow. Notable exceptions are discussed more thoroughly in the text (see also Figure 5.2 in the MA conceptual framework).

considers soil degradation a slow local biophysical driver. On the other hand, in San Pedro de Atacama, the rapid change of technology in the mining sector taking place worldwide is an important driver. This character of technology (that is, fast change on the global or at least national scale) also holds for the Argentine Pampas.

Table 7.10 summarizes the 103 drivers according to speed and directness in relation to the MA driver categories. Biophysical drivers have been further subdivided into land use change, species introductions, pollution, climate change, and others.

Among indirect drivers, demographic, sociopolitical, and cultural and religious drivers are generally slow, while science and technology is fast. Among direct drivers, it appears that biophysical drivers split into two groups: fast drivers related to pollution, land use change, and ''others''; slow drivers related to climate and species introductions. Economic drivers do not have a well-defined behavior according to this classification.

7.4 Integrating Drivers

7.4.1 Assessment Process

For the sub-global assessments, analyzing the interactions among the multitude of drivers was not surprisingly more difficult than the assessment of individual drivers. This was often due to a lack of quantitative data or to the availability of these data only late in the assessment processes. Extensive statistical work to assess the interplay of drivers was not feasible for most assessments. The SAfMA Zambezi Basin component assessment was unique in that it was able to draw on previous work to capture the interactions among drivers (SAfMA Zambezi).

Most of the assessments used qualitative methods to assess interactions among drivers. These methods differed in the degree to which stakeholders and users were involved, and whether literature and theoretical knowledge was used. In general, it appears that pragmatic considerations dominated when choosing the assessment methods. Factors influencing the choice of methods were:

- the degree to which contacts with potential users of the assessment had been established before the launch of the assessment. Existing contacts made it easier to involve users, and thus led to a stronger user-driven assessment; and
- the disciplinary composition of assessment team members as well as their experience with the assessment area. The Zambezi Basin assessment within SAfMA illustrates the benefits of longer work within the region, as various tools such as models already existed when the local assessment began (KM2).

Table 7.10. Relationship between Speed and Directness of Drivers. The main categories of drivers were classified as being fast or slow, and direct or indirect. There was no general pattern for economic drivers (that is, they were as often slow as fast).

	Fast	Slow
Direct	biophysical—pollution biophysical—land use change biophysical—others	biophysical—climate biophysical—species introductions
Indirect	science and technology	demographic sociopolitical cultural and religious

The following discussion of interactions among drivers should be read in the context of the limitations in assessment methods and the often preliminary character of the information found within the individual sub-global assessments.

7.4.2 Cross-scale Impacts of Drivers

Identifying drivers at the global scale does not provide a complete picture of their effects at national and sub-global scales. For example, changes in trade flows brought about by increased economic openness trickle down to the local level and can alter the demand for ecosystem services. In Viet Nam, export demand for shrimp, triggered by integration into the world market, resulted in the conversion of mangroves for shrimp farming. In addition to the positive service of increased shrimp production, there were negative environmental effects such as the intrusion of brackish water into freshwater ecosystems, the destruction of coastal ecosystems, and coastal erosion (Downstream Mekong).

In the sub-global assessments, three general modes by which global and national drivers ''trickle down'' to the local scale were observed. Trade drivers can be used to illustrate these modes. In the first mode, global and national scale drivers jointly influence ecosystem change at the local scale. (See Figure 7.5.) For example, in the Laguna Lake Basin in the Philippines, land conversion from agriculture to industrial zones is driven by demand for and trade of products such as cars and semiconductors at *both* the global and national scales. To produce these products, transnational companies are enticed by the national government to invest in industrial parks within the basin. These industrial parks are built on rich alluvial plains that were formerly prime agricultural areas. They have major impacts on the lake ecosystem by reducing water quality through pollution, and reducing the lake's bioproductivity (Laguna Lake Basin).

In the second mode, global (or sometimes regional) drivers directly influence change in ecosystems at the local scale, with little mediation from national or regional scale drivers. This is illustrated in the case of the Kristianstad wetlands, where increased precipitation, probably due to large scale shifts in weather patterns throughout Europe (Werner et al. 2000) has induced increased flooding with impacts on local ecosystems (Sweden KW). Another example is in India, where global demand for areca nut has caused a shift in land use from paddy fields to areca plantations (India Local).

In the third mode, local ecosystem change is largely driven by national drivers independently of global or regional drivers. For example, in Sinai, demand for agricul-

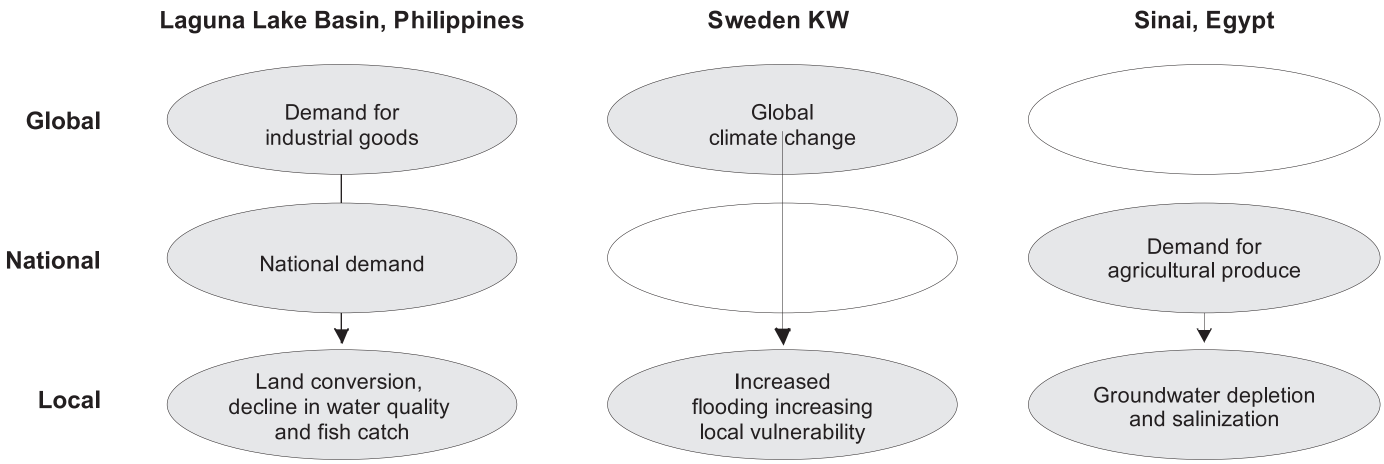

Figure 7.5. Three Modes by which Global and National Drivers "Trickle-down" to the Local Scale

tural products at the national scale caused intensification of agricultural cultivation that led to groundwater depletion, increased soil salinity, and eventual replacement of native species with introduced species.

From the preceding discussion, three related lessons emerge:

- Global drivers can reinforce national drivers to enhance their effect on ecosystem change at the local scale. In this case, global-scale drivers might actually be partially endogenous for national decision-makers.
- Global drivers can cause changes in ecosystems directly at the local scale, without interacting with national or regional drivers. In this case, controllability might be difficult.
- National scale drivers can influence ecosystem change at the local scale apart from global drivers. Here, controllability is purely at the national scale.

7.4.3 Interactions among Drivers and their Impacts

No individual driver could be identified as key across all the sub-global assessments, nor did any single driver appear to be of equal relevance across the assessments. It appears that drivers act in very distinct ways in different places, and though a similar driver (for example land use change) might be identified throughout many assessments, the actual processes by which this driver operates can be very different (see Tropical Forest Margins example discussed below). The drivers in each location do interact, and these interactions are key elements of the social-ecological system in that location. The uniqueness of these interactions is a major reason for carrying out independent sub-global assessments.

Despite the uniqueness of driver interactions, certain patterns of interactions are evident. For example, 12 out of the 20 assessments analyzed identified drivers concerning smallholder agriculture (Argentine Pampas, Altai-Sayan, San Pedro de Atacama, Tropical Forest Margins, India Local, PNG, Portugal, SAfMA, Northern Range, Downstream Mekong, Eastern Himalayas, Sinai). Although differing in detail, there is a degree of similarity in the processes by which smallholder farming has an impact on ecosystems. It should be noted, however, that there are differences even within individual assessments. For example, the different SAfMA local assessments depict variations in the drivers of change in smallholder agriculture. Thus the idea of interaction patterns should only be seen as a rough aggregation scheme to systematize the complexity of the socioecological systems assessed. Besides the processes behind changes affecting smallholder agriculture, interactions of drivers in the following areas were also considered:

- commercial resource exploitation (in 7 sub-global assessments);
- economic development strategies (in 8 assessments);
- processes of urban change (in 5 assessments);
- tourism (in 8 assessments); and
- natural extreme events (in 6 assessments).

7.4.3.1 Smallholder Agriculture

In smallholder agriculture, a number of indirect drivers induce changes in agricultural production. (See Figure 7.6.) The following three indirect drivers are mentioned in various sub-global assessments:

- *Fluctuating market prices and changes in market access.* In Altai-Sayan, the increase in market prices for cashmere resulted in the intensification of herding. Herders and their livestock moved closer to towns to have better market access. This increased the pressure on grasslands in these areas with degradation of soils and vegetation, reducing the provisioning of fodder. In the Northern Range of Trinidad, the liberalization of trade and the resulting competition forced down local produce prices, which made local production of market crops uneconomical. In Portugal, the decrease of agricultural producer prices also led to a decrease in productivity; the people's efforts to balance the potential income losses brought about three types of change: intensification in ecologically more productive regions, extensification on less productive land, and abandonment in cases where more attractive income opportunities were available. Lack of knowledge was also mentioned in Western China and Altai-Sayan as contributing to increased pressure on ecosystems by smallholder agriculture.
- *Population pressure creating increased need for agricultural produce from smallholdings.* The Downstream Mekong assess-

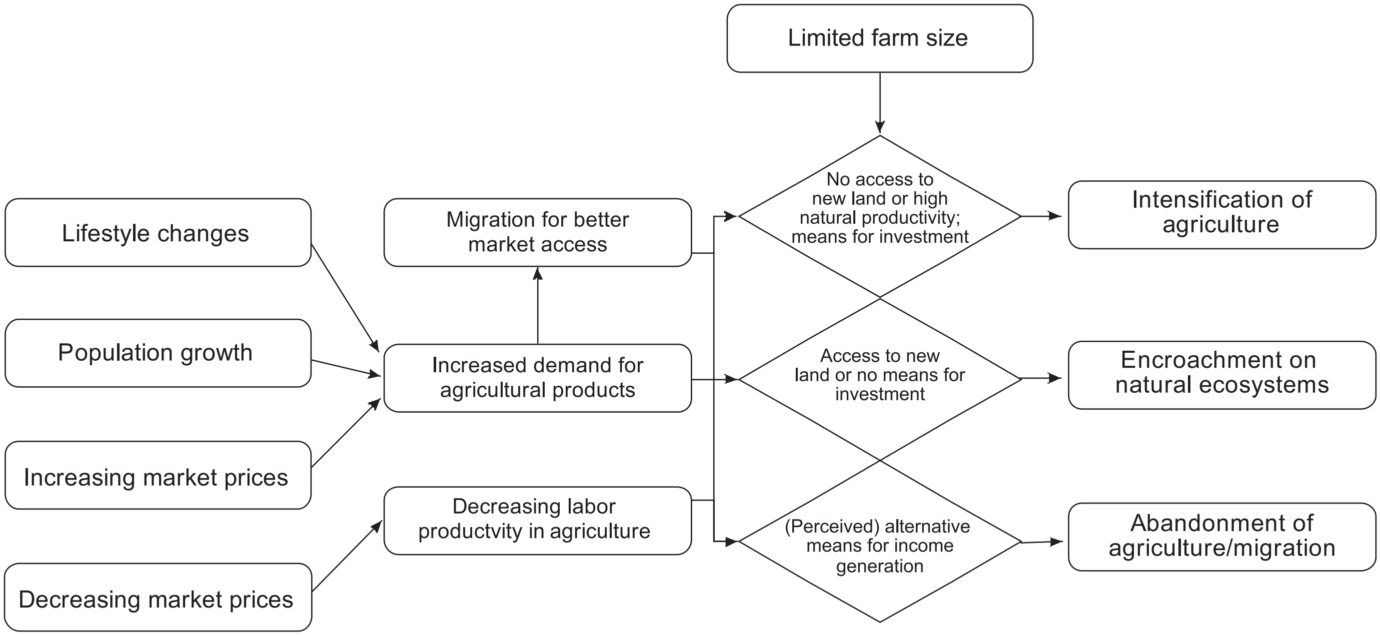

Figure 7.6. Interactions among Drivers, and Their Impacts, in Smallholder Agriculture

ment states that the pressure depends "on the state's socioeconomic development policies, the local human awareness and the actual conditions of the locality" (Downstream Mekong, p. 36). Eastern Himalayas refers to population growth as a major driver.

- *Growing aspirations and changes in lifestyle.* Both Downstream Mekong and San Pedro de Atacama called these important drivers, and indirect evidence of their role can be found in other sub-global assessments. The impact is via increasing demand for ecosystem services. "From late 80s to present, local livelihoods have basically changed, shifting from self-supporting to market-oriented, the latter being ruled by free market economic principles. More profits gained in the open economy have led to increases in individual incomes, leading to higher demands for ecosystem services, especially those related to land, water and forest products." (Downstream Mekong, p. 38).

These main indirect drivers are mediated by two other major indirect drivers: the size of holdings often related to land tenure and outmigration to seek improved living conditions. Depending on the actual pressure and the availability of land, three major outcomes can be observed:

- *Intensification.* With respect to land tenure, evidence from the general literature (Kates and Haarman, 1992) and also from the sub-global assessments indicates that problems relating to intensification arise if landholdings are too small (India Local, Portugal). This may happen for different reasons, such as division of land among siblings or land reform acts (India Local). The limitations of land induce an intensification of production beyond the limits of ecological capacity of the land. Within the sub-global assessments, intensification is reflected in increased application of fertilizers and pesticides (India Local, Eastern Himalayas, Sinai) or increased grazing (Altai-Sayan, Argentine Pampas). The sub-global assessments also reveal that intensification occurs in the whole range of farming strategies, from commercial (Portugal) to subsistence (SAfMA).
- *Encroachment on natural ecosystems, in particular forests.* Increasing needs for agricultural production, either for subsistence or for income, lead to continued clearing of forests (Eastern Himalayas, PNG). For example, in the Darjeeling Hills of the Eastern Himalayas, people now have to collect softwood rather than the preferred hardwood in the public forests either for their own fuelwood needs or for selling in the markets, as hardwood has disappeared due to unsustainable cutting in the past. To satisfy the demand for wood, an even larger area has to be harvested, because of the lower energy density of softwood.

According to the Tropical Forest Margins assessment, slash-and-burn agriculture is not the only, or even the key, driver of deforestation. Other important drivers include commercial wood extraction, (permanent) cultivation, livestock development, and the extension of overland transport infrastructure. Deforestation driven by swidden agriculture is more widespread in the upland and foothill zones of Southeast Asia than in other tropical regions of the world. Road construction by the state followed by colonizing migrant settlers, who initially practice slash-and-burn agriculture, is most frequent in lowland areas of Latin America, and especially in the Amazon Basin. In addition, pasture creation for cattle ranching is a cause of deforestation that occurs almost exclusively in these regions. In Africa, the spontaneous expansion of smallholder agriculture and fuelwood extraction for domestic use are important causes of deforestation.

- *Abandonment.* In less productive areas of Portugal, people are leaving the agriculture sector for more attractive jobs (for example, within the tourism sector), leading to abandonment and afforestation of formerly agricultural lands. In more productive areas, intensification of agriculture is taking place (for example, with increased use of inorganic fertilizers and pesticides which reduce ground water quality).

Interestingly, none of the sub-global assessments considered the effects of large-scale agriculture in detail.

7.4.3.2 Extraction of Natural Resources

This section focuses on the direct, for-profit or subsistence-oriented extraction of wood from forests or of fish. Note that impacts on forests can also be induced by other processes (for example, extension of smallholder agriculture on new land or fires, discussed below). With regard to the direct extraction of wood or fish from natural ecosystems, the following four direct drivers appear in various assessments:

- *Commercial logging.* The selective logging activities of Malaysian companies in Papua New Guinea have extended towards the western border with Indonesia (KM2–PNG). This is not seen as a major source of degradation by local people, as it is perceived as something which has been going on in the past anyway. There is an issue, however, relating to who receives the benefits. In India, the current system of offering time-bound leases for forest exploitation has led to overexploitation (India Local).
- *Fuelwood extraction.* Local people, especially women, have to spend more time and effort to gather increasingly diminishing supplies of fuelwood (India Local). The overexploitation of high-yielding fuelwood (hardwood species) is one of the main factors that has contributed to destruction of forest ecosystems (Eastern Himalayas). One backload of Buk (*Quercus lamellosa*) wood provides two hours burn time. The same quantity of other species like Kharaney (*Symplocus theifolia*) gives only 30 minutes burn time and therefore needs to be harvested in higher quantities.
- *Unsustainable extraction of other resources.* In São Paulo, for example, this includes palm heart, bromeliads, orchids, and wild animals; in the Eastern Himalayas, it includes mosses and medicinal and aromatic plants; in Papua New Guinea: hunting of wild animals and birds and gathering of wild plants and fruits. Another aspect is the illicit grazing of cattle and lopping trees for fodder (Eastern Himalayas).
- *Fishing.* Overfishing by outside trawlers is an important issue in Bada village, India, where local people interviewed during the assessment reported that fish resources were declining. Fishing during the breeding season has resulted in the loss of local fish availability. Fishery resources are now neither abundant nor diverse. The destructive fishing methods such as the use of dynamite and poisons have led to the depletion of fish, which are now estimated to be around 25% of the levels experienced by older people in the village (India Local). In Papua New Guinea, dynamite fishing is cited as a problem. From the literature it is known that dynamite fishing can have serious impacts on coral reefs, and might even induce a phase shift to soft-coral colonization as hard corals have difficulties recovering on the rubble zones caused by dynamite fishing (Fox et al. 2003). Yet, for the time being, such phase shifts have not been observed in the coastal areas of Papua New Guinea (PNG). In the coastal areas of British Columbia (Canada) fishing has either caused declines of fish populations or exacerbated the effects of habitat degradation, with competitive pressure exerted by foreign and domestic fleets and—within the domestic fleet—commercial, recreational, and aboriginal components (Coastal BC).

Two feedback loops (see Figure 7.7) at different scales were only briefly mentioned in sub-global assessments, but can also be found in the literature (Geist and Lambin 2002; Cassel-Gintz and Petschel-Held 2000).

- *Local loop.* The indirect driver of increasing demand for fuelwood creates a local loop through the direct driver of wood harvesting. With the overuse of traditional collection grounds, people shift to harvesting wood from formerly untouched forests, or they harvest types of wood they have not used before. This causes local encroachment on forests that can be expected to continue, and thus might lead to self-reinforcing encroachment.
- *Global loop.* The overexploitation of forests and fisheries creates a global loop, where commercial companies shift from overexploited areas to new areas that have similar patters of resource extraction (the direct driver) to meet global market demand (the indirect driver).

7.4.3.3 Development Strategies and Plans

Economic development programs implemented by national governments, in some cases with assistance from international development agencies, can help poor rural people improve their well-being, but can also have unintended negative effects on ecosystems. The sub-global assessments contain a number of examples. The generalized structure of the underlying mechanisms is depicted in Figure 7.8.

- *Macroeconomic policy reform.* The introduction of market-oriented macroeconomic policies is often promoted by external actors like the World Bank or the International Monetary Fund. In many countries in southern Africa, these policies included the withdrawal of government subsidies, facilitation of privatization, and removal of pan-territorial pricing (SAfMA). The performance of aggregate agricultural production under structural adjustment was disappointing, as production growth did not keep pace with population growth between 1990 and 1997. At the livelihoods level, market liberalization, and particularly the way in which it was applied, has removed some of the institutional support that provided a safety net for the food insecure, and smallholder farmers have become more vulnerable to livelihood shocks, particularly in times of market failure (Scholes and Biggs 2004).
- *Population resettlement.* Sometimes governments seek to relieve population pressure—and thus to a certain extent also the pressure on the environment—by promoting major development efforts in more remote regions. The Egyptian government, for example, seeks to develop the

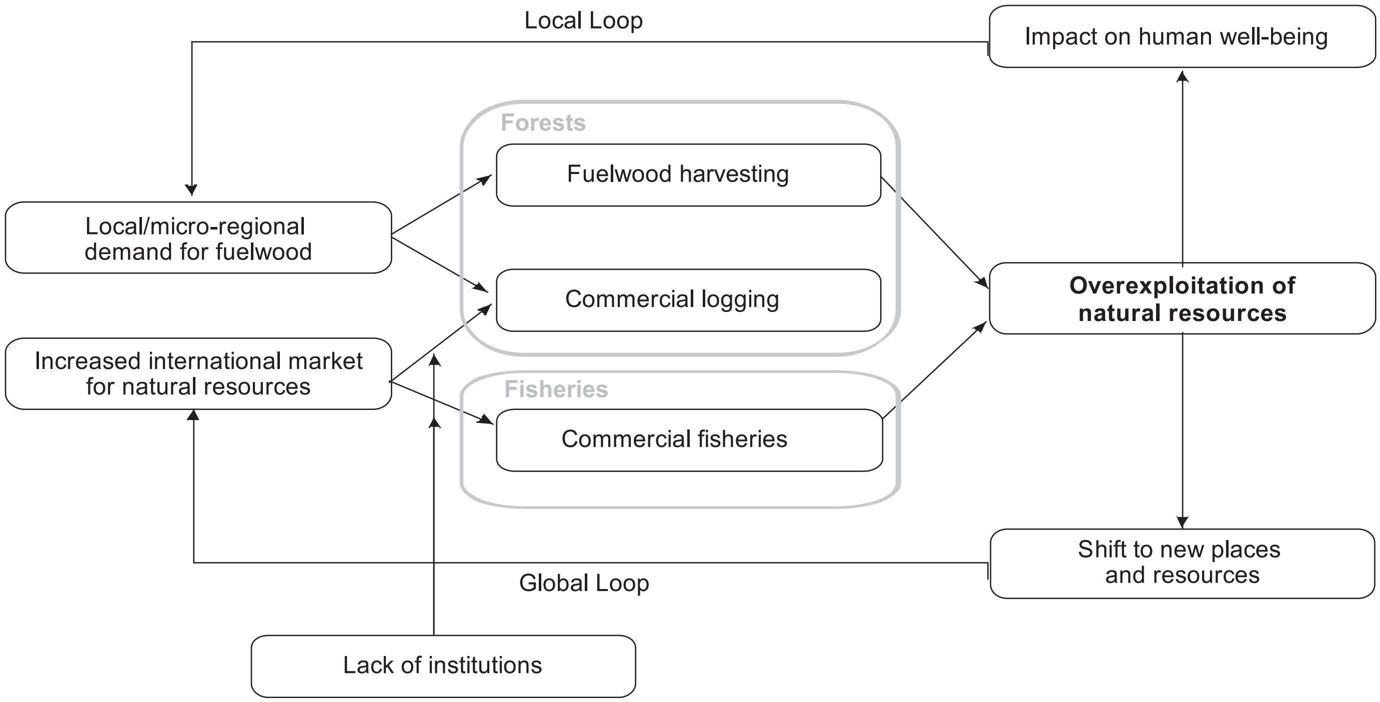

Figure 7.7. Interactions among Drivers, and Their Impacts, in the Extraction of Natural Resources

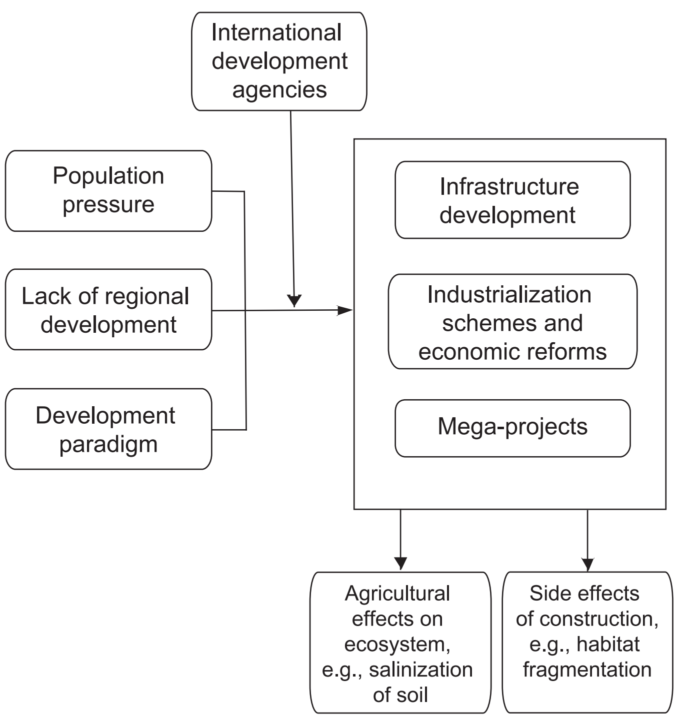

Figure 7.8. Interactions among Drivers, and Their Impacts, Arising from Economic Development Strategies

northern part of the Sinai peninsula for a total of 6 million people in order to reduce the high population density in the Nile valley. This will include the development of heavy industries, export processing zones, and agricultural projects with potentially significant impact on ecosystems such as pollution and salinization of soils (Q2–Sinai).

- *Infrastructure development.* Infrastructure development in remote areas or in areas close to cities where it might induce urban sprawl or growth is often a development strategy. In the metropolitan area of São Paulo and Santos, for example, infrastructure investments are targeted at providing opportunities for the secondary sector. The resulting urban growth fragments habitat or causes increases in pollution levels (see below). In more remote areas like the Amazon Basin, infrastructure development triggers streams of incoming settlers, who in turn practice slash-and-burn agriculture leading to decreased soil fertility in the long run (Tropical Forest Margins). In the Darjeeling region in the Eastern Himalayas a total of 85 dams are proposed mainly for electricity production, which will have impacts on ecosystems through the fragmentation of habitats of flora and fauna (Eastern Himalayas).

These drivers raise a major evaluation problem as it is often not easy to compare their benefits for human well-being, in terms of new income opportunities or improved infrastructure, with the negative consequences on human well-being via ecosystem change. For more details on the lack of evaluation tools for dealing with these types of trade-offs, see also MA *Current State and Trends.*

7.4.3.4 Urban Processes

Sometime in the first decade of the twenty-first century, the threshold of 50% of the global population living in urban areas will be crossed (MA *Scenarios,* Chapter 7). This figure differs widely between industrial and developing countries, with some 80% of the population of industrial countries in urban areas, and 40% in developing countries. For assessing ecosystem changes, the effects of conversion of land to urban use needs to be distinguished from the effects of change within existing urban areas. Whereas the expansion of urban areas basically represents a form of land use change, existing urban areas cause pollution, waste generation, and resource use with effects that can be felt far from the urban area itself. Both aspects of urban change are addressed within the São Paulo sub-global assessment (São Paulo). The process of urban growth and/or sprawl is addressed in a few other assessments (Sweden SU, Sweden KW, Caribbean Sea, Northern Range). The impacts of urban lifestyles are discussed in Coastal BC. These two types of urban process (that is, expansion in urban areas and growing urban populations) have somewhat different impacts on ecosystems, as indicated in Figure 7.9.

The case of the huge metropolitan region of São Paulo illustrates the dimensions of material flows induced by a population of around 18 million people. The metropolitan area produces 20,000 tons per day of domestic waste and 60,000 tons per month of civil engineering rubble in the municipal district. The resulting problems are amplified by the dual character of the area, comprising a *formal city* that receives most of the public investments and an *informal city* that is growing exponentially (and illegally), exacerbating social and environmental dissimilarities. These problems are exacerbated by the prevailing growth of the metropolitan area, both in terms of area and to a lesser extent in terms of population. Between 1980 and 1991, the population grew by 22.9%. An additional 15.7% growth occurred between 1991 and 2000. The large population in the Metropolitan Region of São Paulo and the related problems of overpopulation and housing tend to drive people toward the surrounding zones, consuming important natural resources (São Paulo).

In contrast, urban areas in industrial countries are dominated by urban sprawl. Both within the urban area of Stockholm and in the Kristianstad wetlands, urban sprawl is a major driver of ecosystem change (Sweden SU, Sweden KW). In the Kristianstad wetlands, extension of sealed urban land leads to increased flooding. In Stockholm, ecologically valuable land is converted, thus destroying corridors for species migration and leading to a loss in genetic diversity.

7.4.3.5 Tourism

For the sub-global assessments that found tourism a driver of ecosystem change, the effects were mainly due to the construction of buildings and other infrastructure, mainly on the coastal strips of islands (Caribbean Sea) or in coastal mainland areas (Portugal, Sinai). Figure 7.10 illustrates how tourism affects ecosystems. The sub-global assessments provide a number of examples of how tourism might in the future undermine its own basis, that is, damaging those amenities that originally drew tourists.

Tourism has been increasing steadily in the coastal areas of Portugal—in the Algarve and the coast of Lisbon and now in the coast of Alentejo—where it damages estuaries by excessive water consumption and/or pollution. The pressure of tourism comes to an extent from international tourism markets, but is mostly domestic, through internal demand for holiday houses and the economic interests of the construction sector (Portugal).

The tourism industry is the major source of investment in the Sinai. Its negative effects on ecosystems and their services include reduced biodiversity and damage to coral reefs in the Red Sea off the coast of the Sinai peninsula in Egypt. The coral damage eventually prompted government intervention to enforce protection measures and rehabilitate coral reefs. Massive amounts of solid waste and wastewater from hotels and other new establishments are newly emerging problems in Sinai (Sinai, KM2–Sinai).

In the San Pedro Basin in Chile, tourism is seen as competing with mining for limited water resources. Mining makes tourism unattractive, yet the assessment has evaluated tourism as a major cause of land use change (San Pedro de Atacama).

In some cases, massive investment in tourism (for hotels, roads, marinas) effectively creates an economic monoculture, which is the case in almost all the islands of the Caribbean (reaching 99% of GDP in the Bahamas). The main exception is Trinidad, which receives about 70% of its GDP from the petroleum sector. Investments in the tourism sector (in many cases foreign) often lead to land use changes on flat coastal land or land that has been reclaimed from the sea. This impacts coral reefs, seagrass, and mangrove swamps (Caribbean Sea). Cruise ships, which bring in a major portion of the tourists in the region, often dispose their used water into the sea, which leads to increased nutrient input and thus affects marine ecosystems.

In southern Africa, nature-based tourism is one of the fastest-growing sectors. According to the southern African

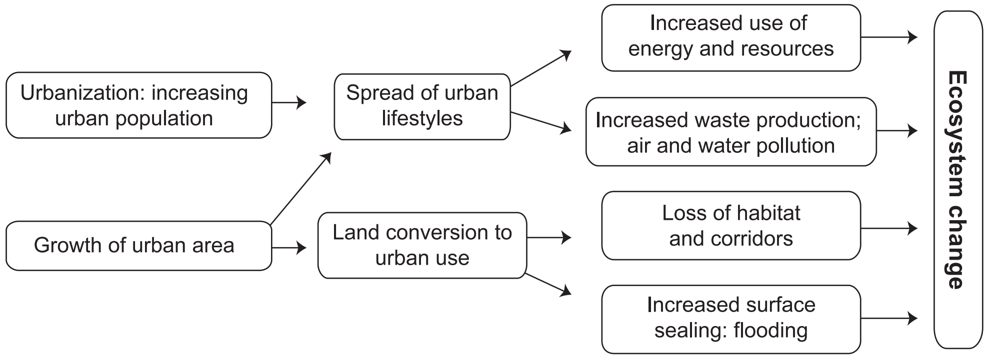

Figure 7.9. Interactions among Drivers, and Their Impacts, from the Growth and Expansion of Urban Areas

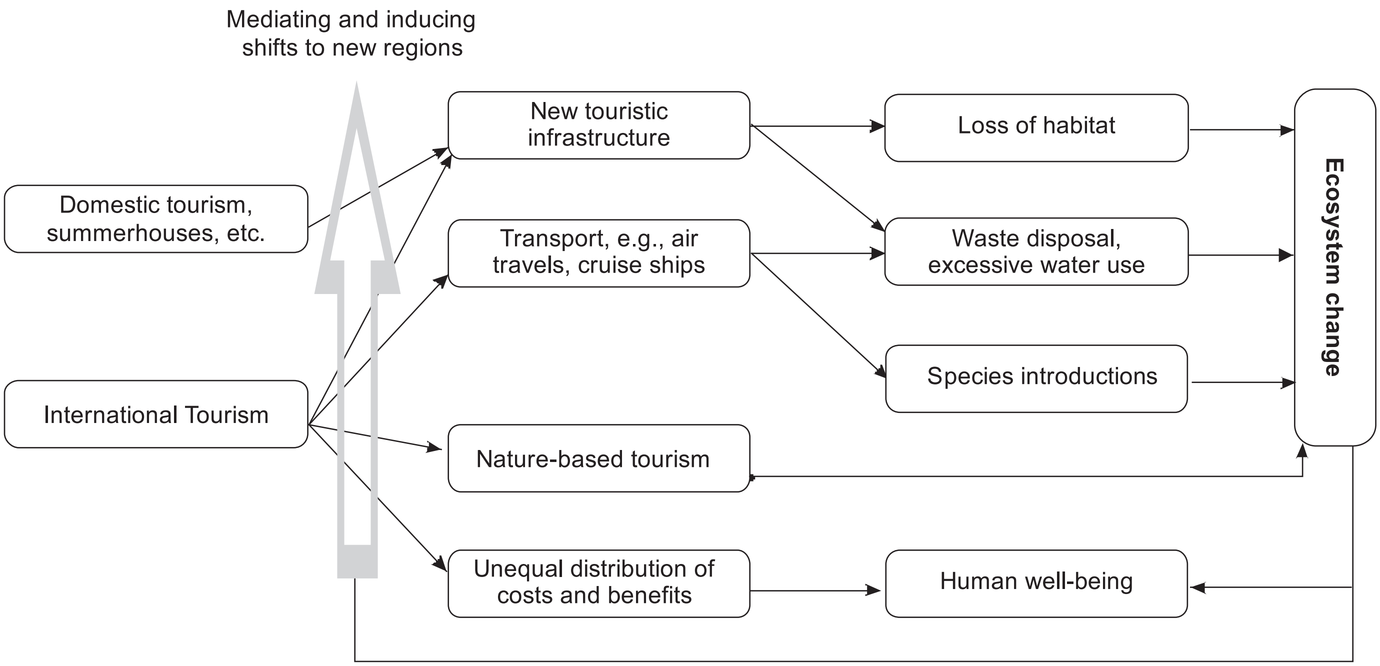

Figure 7.10. Interactions among Drivers, and Their Impacts, Related to Tourism. Note that there is a strong option for mediating the negative consequences by development of sound tourism concepts. Furthermore, a feedback loop exists due to ecosystem change that reduces landscape amenity, thus inducing a potential shift of tourism to new regions.

regional assessment (Scholes and Biggs 2004), the attraction of the region for nature tourism is mainly related to some elements of structural biodiversity, particularly the "big five" of lion, elephant, rhinoceros, buffalo, and leopard. A major problem related to nature tourism in the region is the distribution of costs and benefits. According to some studies in the region, the fraction of the sector turnover that accrues to local people can be as low as a few percent, whereas the negative impacts at the local level are considerable due to the inappropriate treatment of sewage and other wastes and from "visual pollution" due to badly designed and poorly sited developments (Scholes and Biggs 2004).

7.4.3.6 Natural Disasters and Extreme Events

Natural disasters have always been important drivers of ecosystem change. Until the second half of the twentieth century, global climate has changed independently of human activities (IPCC 2001). Fire has always been an important element of the successional cycles of ecosystems, and tectonic activities like volcanic eruptions, earthquakes, and tsunamis have had major consequences for ecosystems and human well-being. Yet more recently, there is increasing evidence that human activities are having an effect on the frequency and intensity of extreme events. The sub-global assessments add evidence with respect to changes in fire regimes and to a lesser extent also to climate. Figure 7.11 sketches the general structure of these effects.

The Altai-Sayan and Portugal assessments report that fire is a major driver of change in their assessment areas. In Altai-Sayan, differences in the fire regime across the region are due to natural climatic conditions; there is as yet no indication that climate change has had an impact on changes in the fire regime or on shifts of treelines in the region

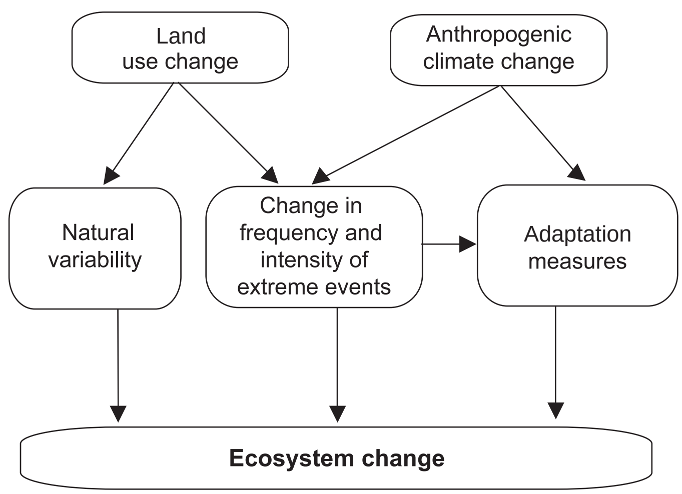

Figure 7.11. Interactions among Drivers, and Their Impacts, Related to Extreme Events. It has become increasingly evident that these changes mostly relate to increases in frequencies or intensities, or both.

(Altai-Sayan). In Portugal, the fire regime has become more pronounced over time. For example, in 2003, 5% of the area of Portugal burned, which was the largest area affected by fire in the country's recent history (Portugal).

In Kristianstad, normal annual flooding is a natural dynamic of the ecosystem, which had always had a high buffering capacity to regulate flooding in the watershed, limiting the damages to humans. Yet the extreme annual flooding events in the recent past (caused by very high precipitation) hint at a possible reduction of this buffering capacity. This loss is possibly due to direct drivers such as land use change, watercourse simplification, and the building of drainage ditches. Beyond the direct effects of the observed extreme floods, biodiversity loss may be an additional consequence (Sweden KW).

Tropical cyclones are seen as a major driver of ecosystem change in the Caribbean Sea. During the 1990s, the frequency of tropical cyclones increased compared to earlier decades. General public opinion interprets this as an effect of climate change, but analysis of the time series for several decades shows that there has as yet only been a small increase in recent occurrences. It remains unclear whether the increase is within the range of natural climate variability, or whether climate change is responsible for the change. The impacts of tropical cyclones on coastal areas are exacerbated by heavy economic investments in coastal areas and also by some recent coral diseases, among others due to the import of bacteria by Saharan dust (Caribbean Sea).

In Papua New Guinea, periodic droughts, as part of climatic variability, have always been a problem. However, there is evidence that climate change is making these droughts more frequent. Also in Papua New Guinea, volcanic activity and extreme weather events have a significant effect at the local scale. Coastal ecosystems are also vulnerable to damage by tectonic activities and tsunamis (PNG).

7.4.4 Patterns of Interaction

Given the interactions and impacts described, it is possible to evaluate these together to check for patterns across all the sub-global assessments. Table 7.11 provides an overview of the different sub-global assessments and the processes of driver interactions.

In only two assessments, Western China and Sweden SU, ecosystem change appears to be driven by a single major process. Although in both cases, the process indicated is indeed dominant, this does not necessarily imply that other processes are not taking place or that these might come to play a more important role in the future. In Sweden SU, for example, processes of learning and institutional change are emerging, which is an indicator of hope for better future planning and land management strategies (Jakob Lundberg, personal communication).

The other assessments show that several processes of ecosystem change are interwoven. In many cases the interactions between these processes do not just add up, but can trigger, reinforce, or sometimes also constrain one another. Table 7.12 shows the three major modes of interaction; it is based on results from the various sub-global assessments as well as from other sources:

- *Triggering*. Deforestation provides an example of how one process of ecosystem change can trigger others. Particularly in Latin America, the commercial exploitation of forests clears space for settlers to move into the forests and cause further ecosystem change through cultivation (Tropical Forest Margins). Impoverishment and induced migration within smallholder systems can themselves trigger processes of urbanization (rural–urban migration as in São Paulo) or economic development strategies to alleviate underdevelopment (Eastern Himalayas). It can also aggravate the effects of natural disasters due to a lack of adaptive capacity (for example, the decreased resilience of coastal ecosystems to tropical cyclone impacts in the Caribbean Sea).
- *Reinforcing*. Processes can also enhance the effects or intensities of others. Resettlement projects designed to release the pressures on the natural and social environment in the densely populated regions of coastal Southeast Asia has intensified land use change in the rural inland areas due to swidden agriculture in the forest margins (Tropical Forest Margins).
- *Constraining*. In some cases, processes can be constrained by others. Natural disasters and resource exploitation can easily reduce the attractiveness of a region for tourism. More generally, however, ecosystem change reduces the recreational value of ecosystems (for example, Portugal).

The complex interactions among drivers can make efficient responses to ecosystem change difficult. Influencing individual drivers is seldom sufficient, as any given driver is almost always embedded in a system of interactions like those assessed in this section. Before examining possible responses, however, it is necessary to look into the implications of potentially nonlinear interactions between drivers.

7.5 Drivers and Thresholds

Changes in drivers are often nonlinear; thus an abrupt or extreme change in a driver is not always possible to anticipate, and seemingly small incremental changes can have massive effects. Problems may arise when a driver or an interaction changes in such a way that a critical threshold is exceeded, beyond which ecosystem service delivery or associated human well-being is compromised. How drivers change and interact can determine if and when critical system thresholds are passed.

Unfortunately, there are only hints found in the sub-global assessments that the interactions between drivers operating or changing at different temporal and spatial scales can play a role in pushing social-ecological systems past critical thresholds. In some cases, the interaction is between climate, which tends to change slowly, and changes in land use, policies, or markets, which change more quickly. In the Argentine Pampas assessment, the interaction between climatic conditions that were more favorable for farming, and the aggressive intervention of commercial firms between 1970 and 2000, has driven a westward expansion of the annual-crop boundary onto rangelands and grasslands. This interaction has boosted agricultural productivity and rural incomes in the short-term, but has had a negative effect on soil stability in the long-term. However, the accumulated degradation of soils has triggered a feedback mechanism in some areas that has prevented further expansion of annual crops (Argentine Pampas).

In British Columbia, climate events—notably the El Niño–La Niña cycle—are cited as a major driver of ecosystem change, along with other less predictable influences, possibly linked to global warming. Against this background, the main drivers of environmental change are harvest pres-

Table 7.11. Major Processes of Driver Interaction across the Sub-global Assessments

Sub-global Assessment	Smallholder Agriculture	Resource Extraction	Economic Development	Urban Growth	Tourism	Natural Disasters	Number of processes
Altai-Sayan	■					■	2
ASB	■	■					2
Coastal BC		■					1
Caribbean Sea					■	■	2
Darjeeling Valley	■		■				2
India Western Ghats	■	■	■				3
Sweden KW				■	■	■	3
Downstream Mekong	■	■	■				3
Papua New Guinea	■	■				■	3
Portugal	■				■		2
SAfMA Gariep	■		■		■		3
SAfMA Regional	■		■		■	■	4
Sinai	■		■	■	■		4
San Pedro de Atacama	■				■		2
Sweden SU				■			1
Laguna Lake Basin		■	■				2
Northern Range	■			■	■		3
Western China		■	■	■		■	4
Number of assessments		12	7	8	5	8	6

Table 7.12. Modes of Interaction among Processes. Key: T = Trigger; R = Reinforce; C = Constrain.

Interactions: ↓ acts on →	Smallholder Agriculture	Resource Extraction	Economic Development	Urban Change	Tourism	Natural Disasters
Smallholder agriculture			T	T		R
Resource extraction	T				C	R
Economic development	T	T			T	
Urban change	R	T				
Natural disasters	T,R				C	

sure and introduced species. The timber sector has the most extensive effect on land ecosystems through conversion to roads and modification by logging. Logging has caused declines of the most sought-after timber populations. Thus in the case of British Columbia, a global driver (climate change) interacts with national, regional, and local drivers (Coastal BC).

Portugal reports a particular web of interactions between policy and biophysical drivers operating and changing at different scales. Economic growth in the 1960s and the integration of Portugal into the European Union in the 1980s and 1990s spurred growth in the industrial and services sectors. This has resulted in increased labor costs in agriculture (in the form of hired labor costs for agricultural companies or opportunity costs for farmers exploiting their farms directly). At the same time, entry into the EU Common Market and the reform of world trade agreements has led to lower agricultural prices, only partially compensated by subsidies. Hence, maintaining economic viability requires an increase in labor productivity, through either extensification or intensification. One outcome has been the conversion of some agricultural land to fast-growing forest plantations (eucalyptus or pines), which has contributed to increased fire frequency. Fire often leads to abandonment, both by itself and through increased soil erosion. The abandonment of agriculture facilitates the establishment of shrubs as land becomes increasingly degraded, affecting fauna and flora, and creating conditions for the development of frequent and severe fire cycles and loss of soil, and diminishing the system's capacity to recover. This invasion of shrubs in the sub-cover after abandonment of agriculture activities is particularly well known in the holm oak *montado* (Portugal).

Many sub-global assessments have not specifically pinpointed the location of critical thresholds. These thresholds are not commonly identified until they are reached, simply because the information is lacking, or signs that they are being approached may be ignored or masked through technological or political mechanisms. Nevertheless, many ecosystems assessed by the sub-global assessments exhibit the characteristics that tend to result in such situations. Crises in social-ecological systems often occur at the intersection of large-scale processes and changing local variability, as local problems cascade up to higher levels (Gunderson et al. 2002). They also seem to emerge when people respond to drivers at one scale but ignore those occurring at others.

While crises may result from changes in drivers, crises can also trigger further change, as several sub-global assessments indicate, underscoring the importance of analyzing drivers within a broader systems perspective. (See Box 7.1.) Understanding where the critical thresholds lie is therefore essential to anticipating when a response is likely to be needed, which response options are likely to be available, and which response options are most likely to succeed. As noted in the Argentine Pampas assessment, climate is not completely controllable, but a sensible land use policy that limits the abrupt conversion of lands for short-term gains might avoid undesirable interactions between climate and land use change.

7.6 Implications for Interventions

This section discusses some of the implications of the findings on drivers for designing responses to ''undesired'' ecosystem change. While Chapter 9 discusses responses in much more detail, issues discussed in this chapter suggest some relevant conclusions when it comes to the design of good responses.

7.6.1 The Problem of Multiple Effects of Interventions

In assessing the effect of interventions on an endogenous driver, it is necessary to take into account the various interactions the driver experiences with other drivers. For example, improved market accessibility, often seen as both a response and a driver (see Biggs et al. 2004), has at least two counteracting effects. On the one hand, it can increase the income of smallholders. On the other hand, it can induce an increase in aspirations of wealth, or increase vulnerability of smallholders to livelihood shocks, thus putting greater pressure on ecosystems. Its net effect, however, depends on how other drivers, like cultural or institutional change, interact with improved market accessibility.

In principle, changing a single driver can bring about effects by all modes of interactions discussed earlier, that is, triggering, reinforcing, and constraining other drivers, sometimes as unintended side effects called ''externalities'' within the economic literature.

7.6.1.1 Triggering

The introduction of market mechanisms as a means of improving human-well being has often triggered other drivers of change (for example, in southern Africa and Altai-Sayan). Smallholders now depend more heavily on commodity prices, and thus on the world market, than before; in this way, market prices have become a (potential) driver for ecosystem change. The introduction of EU policies in Portugal has led to a high degree of dependence on decisions made at the European level, which may not in all cases lead to policies that are appropriate for managing ecosystems and their services effectively at the local level. Unintended effects of responses/drivers might eventually counteract the intended positive effects of the changes.

Both market integration and shifts in decision-making involve changes in a driver that is exogenous to local decision-makers (farmers, smallholders). The effect, however, is not restricted to changes in exogenous drivers made by decision-makers external to the specific scale of the assessment. The dependence on European-level decisions, for example, is also present at the national level in Portugal and it was indeed a national decision to adopt these regulations.

7.6.1.2 Reinforcement

The Tropical Forest Margins assessment revealed that the resettlement projects designed to release the pressures on the natural and social environment in the densely populated regions of coastal Southeast Asia aggravated land use change due to swidden agriculture, which is a main driver in the processes of deforestation in the tropical forest margins in this region. The same assessment also showed that in lowland Latin America infrastructure development by the state—motivated by an attempt to improve human well-being at the national scale—has also contributed to slash-and-burn agriculture in the lowlands and to pasture creation for cattle ranching by incoming largeholders.

7.6.1.3 Constraining

Changes in a driver can also constrain the effects of other drivers. If the constrained drivers were causing problematic changes in ecosystems and their services, this constraining side effect is positive, as it further counteracts a negative driver of change. Developing institutional changes to constrain urban sprawl is an example of this type of interaction (Sweden SU).

However, if the action in question is constraining the effects of a ''positive'' driver (that is, a factor that induces changes of ecosystems for the better) or releasing the constraints on ''negative'' drivers, the side effect counteracts the effects envisaged by the original action. Examples of this type of interaction were found in some community assessments, where changes in ecosystems sometimes developed due to constraints in the practice of traditional agriculture, often seen as being more sustainable than modern agriculture. Strategies to foster economic development in Western China seek to regulate local activities, thus constraining the application of traditional knowledge and techniques in the region.

BOX 7.1
Crises in Ecosystems

A crisis is a devastating event or syndrome, often considered surprising, that typically follows a prolonged phase of inappropriate action or inaction, possibly due to a lack of awareness of the underlying drivers of the problem at hand. Crises can drive change by serving as triggers for action once an ecological or social threshold is passed. Often, the ecosystem has reached such a compromised state that the range of possible interventions is limited. Depending on how the crisis affects stakeholders and decision-makers, a crisis can be very effective in sending a message that action needs to be taken to solve a problem. A crisis can provide a "clean slate" that allows a system to reorganize, or decision-makers or managers to operate amid a context of renewal, and possibly learn from their past actions. However, a crisis that is not well-managed can trigger further crises (that is, have a domino effect). In still other situations, crises, even when severe, do not result in learning.

A crisis may be a management or policy failure. In Stockholm, Sweden, pressure groups have used their social networks to preserve areas in danger of being exploited (Sweden SU). These groups provide an example of how self-organization arises in a time of a crisis. When a crisis occurs, space is created for renewal, reorganization, and novelty. The crisis may be changes in property rights, acidification of soils, resource failures, rigid paradigms of resource management, new legislation, or governmental policies that do not take into account local contexts (Folke et al. 2003).

In the district of Toco in the northeastern section of Trinidad's Northern Range, communities perceived a crisis in government plans to develop a port facility, which they considered would have been disruptive to their way of life without necessarily contributing appreciably to improving their well-being. As they were not consulted in the process and could not give input, the experience motivated the communities to formulate their alternative vision and plan for the district, to unite themselves in a community-based organization encompassing all the communities of the district, and to successfully resist the government plans.

A crisis may be a natural or environmental disaster. In Trinidad, more frequent and intensive floods in the city in recent years, including the suburbs which previously were not thought to be vulnerable, have led to an increasing emphasis on reforestation with rapid initiatives being taken. Recent discovery of sewage pollution in a water treatment plant has led to relevant agencies coming together to collaborate in taking remedial action (Northern Range).

A crisis may not always inspire a change in management. While certain individuals or groups may view a situation as a crisis, those who have the ultimate authority may be unaware of it or choose to ignore it, or take inappropriate or superficial measures to address it. Droughts in southern Africa in the 1990s that led to water shortages in the urban and relatively affluent Gauteng Province of South Africa were collectively considered a "crisis" that motivated the government to impose restrictions on water use, causing a reduction in the domestic consumption of water; the government even considered shutting off certain supplies (SAfMA Gariep). This represented a huge opportunity to change behavior and attitudes toward water use. However, when the rains came, the restrictions were lifted, allowing people to revert to their previous behavior. This is an example of a conditional crisis, brought about by changes in the apparent availability of an ecosystem service.

From these examples, it is evident that crises can serve as impetus for action. Sometimes this may lead to positive results, as in the case of Toco (positive from the point of view of the communities). Sometimes, the action may be hasty and not well grounded in an analysis of all the factors (for example, in the case of a decision to reforest without the proper analysis of where, why, with what species, etc.). While crises offer opportunities for action and for influencing action, the effectiveness of actions and the resulting winners and losers depend upon a range of factors.

While a crisis can create opportunity, much destruction and devastation may result before renewal can begin. Whether or not the ultimate effects of crises are positive, they can often be instructive for decision-making if they provide lessons on how and why crises occur. Scenarios can be a useful tool for improving understanding of events that lead to crises, because they help to identify a system's governing structures and processes. Changes in slow variables are most likely to catch communities and decision-makers off-guard because these variables may not be monitored or even carefully observed. While surprises are inevitable, a participatory scenario planning exercise can help decision-makers to understand the functioning of less well-known system components.

The examples illustrate that responses designed to affect a single driver can bring about a range of unintended side effects—either positive or negative with respect to ecosystem change. This produces trade-offs that have to be dealt with by a careful analysis of the system in order to assess the net effects of an intervention. (See Table 7.13 for a summary of how interacting drivers play out in the sub-global assessments.)

7.6.2 Intervening in Drivers: Multiscale Issues

All sub-global assessments distinguished between drivers that are under the control of the decision-maker addressed by the assessment (endogenous) and drivers that are not controllable (exogenous). As shown earlier, many drivers which were assessed as being exogenous at one scale are considered endogenous at another scale.

The multiscale property of endogenous versus exogenous characteristics of drivers suggests that in many cases a successful response needs to be coordinated across scales. Otherwise a situation can arise in which the incentives given at the local scale, for example to land users for resource conservation, are offset by other measures, such as prices or subsidies developed at the national scale, as was evident in some of the local assessments in southern Africa (Erin Bohensky, personal communication).

7.6.3 Adaptive Co-management of Social-ecological Systems

All ecosystems have a certain degree of resilience, which is the amount of change a system can withstand while retaining its structure and the variables and processes that control its behavior (Holling and Gunderson 2002). In other words, resilience refers to a system's capacity to be flexible (Redman and Kinzig 2003). Although originally developed for ecological systems alone, the concept is now also applied to social-ecological systems. The complex set of driver interactions is a substantial ingredient in the resilience of the overall system. For social-ecological systems, resilience

Table 7.13. Interventions in Interacting Drivers: Examples from Selected Sub-global Assessments

Sub-global Assessment	Interventions in Interacting Drivers
Altai-Sayan	The driver of environmental consciousness and behavior is public environmental education. Positive results may emerge in the next decade under a cooperative educational effort, particularly if the process is accompanied by successful small businesses in services and agriculture (where most local stakeholders are).
	Suggests that interventions must include stakeholder participation.
Tropical Forest Margins	For policy intervention, it will be important to evaluate all the consequences of turning around certain drivers. Some of the underlying causes of deforestation, such as economic development and technological change, cannot be attenuated without negatively affecting the potential to improve the well-being of the population living in forest environments. Rather than being suppressed, these forces should be channeled toward a more sustainable use of ecosystem services.
	Policies should focus on the feedback mechanisms built into pathways of ecosystem change (e.g., deforestation), with an aim of influencing positive and negative feedbacks. The goal should be to quickly turn around deforestation trends once they have started.
	Suggests that interventions should be designed to take account of naturally occurring feedbacks.
Caribbean Sea	Fish harvest technology adaptation and use, together with open access to the Caribbean Sea by international fishers, has led to overharvesting of fish stocks, which cannot be controlled because of the lack of a regional governance framework for fisheries.
	Suggests that it is difficult to intervene in interactions without effective governance.
India–Western Ghats and Eastern Himalayas	Interventions have been directed at land use patterns through integrated farming systems (farming, animal husbandry, and forestry). The change in farming systems has been fairly successful because this provides a holistic approach to conservation and livelihoods.
	Population growth has been successfully reduced, as users saw the personal and social benefits of minimizing family sizes, birth control technology became easily accessible everywhere, and options emerged to secure the benefits previously provided by having many children.
	Suggests that integrated interventions can be successful.
SAfMA	Regional scale initiatives such as the New Partnership for Africa's Development (NEPAD) are intended to enable more regional cooperation in the management of ecosystem services, through shared water agreements, regional food production, and trans-frontier conservation areas. However, the level of member states' participation in these initiatives, and their capacity to design and implement them, varies.
	Since democratic elections, legislation in South Africa has been aimed at achieving basic human needs and social equity, maintaining ecosystem services, and promoting economic growth. This requires interventions that are designed to address the interactions and synergies among these objectives.
	Suggests an emphasis on inclusive, multiscale, multi-objective interventions.
Sweden KW	Interventions include the EU Water Framework Directive (basin-scale water management, multi-layer management, and different knowledge systems). By allowing subsidies to be used for cattle to graze flooded meadows under the Common Agricultural Policy, agricultural and ecological objectives have merged.
	Suggests a multisectoral approach to interventions.
Sweden SU	The major direct driver of losses of ecosystem services is green area loss. Economic development, coupled with institutional mismatches for ecosystem management, and a lack of understanding of ecological support functions all indirectly drive green area loss. Interventions include (1) the Swedish strategy to achieve the targets of the CBD that places this responsibility on industry and society; (2) protected areas (natural and cultural); (3) stakeholder participation in policy-making; and (4) adaptive co-management of all areas, including buffer zones and weak links, not just the focal urban area.
	Suggests that a holistic approach to management that includes adjacent/supporting areas (buffer zones and links) is needed.

strongly depends on the degree to which a system is capable of self-organization, learning, and adaptation to change.

Because drivers are a major human component of any social-ecological system, they are a strong determinant of the system's self-organizing capability. This can be seen, for example, in Sweden KW: the assessment defined a social-ecological system to be comprised of four major elements:

- the function and dynamics of an ecosystem;
- the management practices of this ecosystem;
- the knowledge system behind this management; and
- the institutions underlying this management.

The latter three elements are usually directly related to endogenous drivers, and include social capacity to adopt an ecosystem management approach, to cope with urban sprawl, increased flooding, or eutrophication.

The study of social-ecological systems leads to the concept of adaptive co-management, which, according to the Kristianstad assessment:

> *focuses on creating functional feedback loops between social and ecological systems. It relies on collaboration among a set of stakeholders operating at different levels, often in networks,*

from local users to municipalities to regional and national or supranational organizations. Adaptive co-management systems have been defined as flexible community-based systems of resource management tailored to specific places and situations supported by, and working with, various organizations at different levels. (Sweden KW, p.8).

In order to address the complexity of interactions among drivers, and between drivers and ecosystems, interventions need to be focused on changing the system. Interactions should be changed to promote the resilience of the overall social-ecological system.

7.7 Conclusion

The sub-global assessments revealed a richness and complexity among drivers of ecosystem change that is not found in the MA global assessment. Yet the results presented in this chapter give only a limited perspective on the overall information found within the sub-global assessments. The meta-analyses on the relationship between drivers' directness and controllability as well as between spatial and temporal scales are unprecedented, and as such valuable and illuminating. Yet their general validity is not ensured, as the set of sub-global assessments is not representative of the plurality of social-ecological systems.

The attempt to shed light on the interactions among drivers has to be read with care. The generalizations made in attempts to give a general picture of the processes identified in these specific assessments neglect important details of the sub-global processes of ecosystem change and related implications for human well-being. However, generalizations are necessary in a multiscale, complex world, where decision-making takes place at multiple scales and in the context of complex social-ecological systems.

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