Chapter 8

Condition and Trends of Ecosystem Services and Biodiversity

Coordinating Lead Authors: Henrique M. Pereira, Belinda Reyers, Masataka Watanabe
Lead Authors: Erin Bohensky, Simon Foale, Cheryl Palm
Contributing Authors: Maria Victoria Espaldon, Dolors Armenteras, Maricel Tapia, Alexander Rincón, Marcus J. Lee, Ankur Patwardhan, Inês Gomes
Review Editors: Jan Plesnik, Valery Neronov, Bernadette O'Regan

BOXES

FIGURES

TABLES

*These appear in Appendix A at the end of this volume.

Main Messages

The sub-global assessments show that several ecosystem services are in fair to poor condition and declining. Despite some gains in the provisioning of food, water, and wood, the capacity of ecosystems to continue to provide these services is at risk in several locations; problems with provisioning services include deterioration of water quality, deterioration of agricultural soils, and incapacity of supply to meet demand. Some threats affecting regulating services are loss of forest cover, rangeland degradation by overgrazing (particularly in drylands), loss of wetlands to urban development and agriculture, and change in fire frequency. Problems with cultural services include loss of cultural identity and negative impacts from tourism. Biodiversity is decreasing due to the loss of habitats and the reduction of species population sizes. Species declining particularly fast include species with large body size, species occupying high trophic levels, and species that are harvested by humans.

In general, the assessments found the condition of water provisioning and biodiversity at global and sub-global scales to be congruent. However, in some cases, the sub-global assessments reported a poorer or better condition than the global findings for that region. Differences were due to the effects of drivers that were not picked up at the global scale, or to fine-scale heterogeneities missed in coarser-scale analyses at the global scale. There were more mismatches for biodiversity than for water provisioning because the concepts and measures of biodiversity were more diverse in the sub-global assessments.

Land use change is the most important driver for provisioning, supporting, and regulating services and for biodiversity. Some direct drivers of ecosystem change were also indicators of the condition of the service (for example, harvest pressure is an indicator of biodiversity). Indirect drivers control the patterns of demand for provisioning and cultural services, thus inducing changes in ecosystems. Tourism was found to have a negative impact on biodiversity in the Northern Range, SAfMA, Portugal, and Caribbean Sea assessments. While human controlled drivers play a major role in determining the condition of ecosystem services, local biophysical constraints such as climate and soils also limit the production of ecosystem services.

Clear trade-offs exist among ecosystem services. For example, a potential trade-off situation exists at one site in the southeastern part of the Gariep Basin, where biodiversity is totally irreplaceable and protein and caloric production are highly irreplaceable. The sub-global assessments, like the MA global assessment, found that an increase in provisioning services generally occurs at the expense of regulating services, supporting services, and biodiversity, or at the expense of the capacity of ecosystems to provide services to future generations. Trade-offs also occur among provisioning services such as between irrigated agriculture and freshwater provisioning.

Trade-offs among ecosystem services can be minimized. The studies of the Tropical Forest Margin assessment in Indonesia and Cameroon showed that a "middle path" of development involving smallholder agroforestry and community forest management for timber and other products is feasible. Such a path could deliver an attractive balance between environmental benefits and equitable economic growth.

New approaches were developed to demonstrate, communicate, and discuss these trade-offs with policy-makers. One was the Alternative to Slash-and-Burn matrix, where natural forest and alternate land use systems were scored against criteria reflecting the objectives of different interest groups in the Tropical Forest Margins assessment. Another was the use of a decision support tool, the Podium Model, to assess options for cereal-based food security and water availability in the Gariep Basin of southern Africa; this showed that expanding irrigated area alone, at large costs to water provisioning services, is unlikely to improve food security.

The sub-global assessments improved understanding of how human well-being depends on ecosystems, in several ways. Examples include inventories of ecosystem services (for example, 64 plant species used to extract biochemical substances were identified in Downstream Mekong); calculations of trade-offs among services (for example, between water conservation and food production in SAfMA); economic valuations of ecosystem services such as tourism, soil protection, run-off regulation, and carbon sequestration (Portugal), and lessons about the importance of cultural landscapes and biodiversity for local livelihoods (Bajo Chirripó and India Local).

The sub-global assessments used numerous and varied methods to assess the current condition and trends in ecosystem services. These methods included geographic information systems, remote sensing, inventories, indicators, economic valuation, and participatory approaches. Participatory approaches were useful in incorporating both scientific and local knowledge into the assessments. Because the sub-global assessments used different definitions and methods of assessing condition, the findings were not always comparable across assessments.

The different approaches used to assess the condition of ecosystem services reflected different interpretations of what is meant by the condition of an ecosystem service. Some assessments emphasized the ecological capacity of the system to provide the service (for example, Portugal) while other assessments emphasized the production and the demand for the service (for example, SAfMA) or equity of access to the service (for example, Sinai). Differing emphases were partially related to the socioeconomic development of the region being assessed: issues of equity and production versus demand were not the main focus of industrial-country assessments (Portugal, Sweden, Norway).

Several sub-global assessments applied novel approaches to the assessment of biodiversity. These include measures such as the Biodiversity Intactness Index (SAfMA), the Reef Condition Index (PNG), and the Ecological Integrity Index (Coastal BC). Each of these measures integrated indicators of different aspects of biodiversity condition into a single index, that could then be used to enhance the dialog on biodiversity with policy-makers and the public.

There is a need for long-term monitoring of the condition of all types of ecosystem services using comparable indicators. Limited data were available to assess the condition of regulating and supporting services. There is an overwhelming lack of historical data on the state of biodiversity in the sub-global assessments. In many locations, sub-global assessments collected data on the condition of ecosystem services for the first time; these data can serve as a baseline for future assessments. The lack of data and the spatial heterogeneity of the condition of ecosystem services led to uncertainty in the assessment of condition and trends of ecosystem services. The development of fine-tuned responses to the deteriorating conditions of ecosystem services will require a concerted effort at data collection and analysis at all scales.

8.1 Introduction

This chapter assesses the current state and recent trends in ecosystems and their services in the MA sub-global assessments. As of January 2005, 24 sub-global assessments had produced information on the condition and trends of ecosystem services. Of these, 16 were still on-going (Argentine Pampas, Bajo Chirripó, Caribbean Sea, Colombia, Downstream Mekong, India Local, Laguna Lake Basin, Northern Range, Portugal, PNG, San Pedro de Atacama, Sweden KW, Sweden SU, Tropical Forest Margins, Vilcanota, Western China). Three were completed (Coastal BC, SAfMA, and the pilot assessment in Norway), and five had only preliminary findings from pilot activities (Altai-Sayan, Eastern Himalayas, India Urban, São Paulo, Sinai). The chapter draws heavily on the state of assessment reports and final reports of the sub-global assessments, with additional information gathered through personal communication with the sub-global assessment teams.

The chapter is structured into four major sections. The first section provides a general overview of the methods and data sources used by sub-global assessments for assessing current condition and trends of ecosystem services, and looks at the complexity of undertaking such analyses. The second section collates robust findings from the sub-global assessments and identifies key uncertainties; it links the findings to condition indicators and drivers of change. The third section summarizes the sub-global findings on trade-offs and linkages between ecosystem services and biodiversity, and the final section integrates and analyzes the main results of the first three sections.

8.2 Condition and Trends of Ecosystem Services and Biodiversity: A Complex Issue

The MA conceptual framework (MA 2003) states that people perceive the condition of an ecosystem in relation to its ability to provide the services desired. This definition implies that different cultures may well have different perceptions of the condition of ecosystem services. Furthermore, the MA focuses not only on the production or ''flow'' of ecosystem services, but also on the sustainability of the use of these services, which can be thought of as maintaining the ''stock'' of natural assets. These concepts are simpler to apply to marketed services (Perman et al. 2003), which are mostly provisioning services, than to non-marketed services such as supporting or regulating services.

Current approaches for assessing condition and trends use a combination of methods and tools (Carpenter et al. 1998; Foster et al. 1998; Fuller et al. 1999). This section starts by illustrating the range of methods and data sources used by the sub-global assessments and then examines issues associated with synthesizing and comparing results across assessments.

8.2.1 Approaches Used in Assessing Condition and Trends

In order to understand changes in the maintenance of critical functions and the provision of essential services, assessments can use integrated historical and spatial reconstruction of ecosystems, such as historical records and databases, paleo studies, remote sensing, models, and expert knowledge. Briefly introduced here, these data sources and approaches are discussed at greater length in Chapter 2 of MA *Current State and Trends*.

8.2.1.1 Remote Sensing

Remote sensing data are usually obtained from satellite sensors and can be used to monitor Earth's surface and atmosphere on a regional and global scale (Burrough 1994; Peuquet and Marble 1990). Remote sensing allows for the assessment of large areas in a consistent fashion, something which is seldom possible through ground-based surveys, although ground-truthing is an essential component of the classification of remotely sensed images. The images generated through remote sensing can be used to derive data on land cover, land use, wetland distribution, land degradation, primary productivity, and other attributes of the land. Repeated observations of the same area are possible and allow for the assessment of trends in the above-mentioned attributes. Many sub-global assessments made use of remotely sensed data (Tropical Forest Margins, Western China, Downstream Mekong, Portugal, PNG, São Paulo, SAfMA, Norway, and Colombia). Western China was one of the few assessments to extract land cover and primary productivity data directly from satellite images; most assessments relied on already-classified land cover maps.

8.2.1.2 Geographic Information Systems

The analysis of disparate spatial data sets, comprising social, economic, and ecological data, is made possible through the use of geographic information systems. These disparate data sets can be combined in a GIS to generate spatially explicit results (in SAfMA, for example, GIS was used to examine where human demand for a particular ecosystem service exists and where that service is supplied). Sub-global assessments used GIS for tasks such as: integrating land cover information from different sources (for example, Tropical Forest Margins, Western China, Downstream Mekong, Portugal, PNG, SAfMA, Sweden SU, Norway, and Colombia); analyzing temporal changes in primary productivity (Western China) and land use (for example, Sweden SU); determining spatial characteristics such as distance, patch size, and shape (for example, Sweden, SAfMA); analyzing trade-offs between provisioning services and biodiversity (SAfMA Gariep); and providing a graphic interface with spatial models of ecosystem processes (Western China) and scenario outputs (SAfMA Regional).

8.2.1.3 Indicators

An indicator is a scientific construct that uses data to measure the condition of ecosystem services, drivers of change, or human well-being (MA 2003); it acts as a surrogate measure of more complex aspects of the reality being assessed. An indicator can simplify the multivariate nature of the attribute being measured into a single value, thus allowing for spatial and temporal comparisons between values. Indicators provide an effective means of communication with policy-makers. Caution should be exercised when interpreting indicators, as they are simplifications of complex reality and might thus not capture all elements of the condition being measured (Bossel 1999). A bias toward easily quantified indicators may ignore some of the more important elements of the condition of ecosystem services, and temporal and spatial scale mismatches are also potentially confusing. For instance, there is a potential disconnection between the production of a service and the sustainability of that production (as found in the Portugal assessment).

The sub-global assessments used a variety of indicators of the condition of ecosystem services. In general, these indicators can be divided into two types: indicators representing the current state of particular services, and indicators measuring the pressure from drivers that influence the condition of those services (discussed in greater detail later in this chapter). It was apparent from the sub-global assessments that there are far more data and indicators available for provisioning services and human well-being than for regulating, supporting, and cultural services.

8.2.1.4 Inventories

In the sub-global assessments, inventories can be broadly divided into biodiversity inventories, ecosystem service inventories, and natural resource inventories. (See Chapter 11 for a discussion of social inventories.)

The biodiversity inventory is usually composed of species lists, often including lists of endemic or threatened species, although some may include lists of habitats or vegetation types found in the ecosystem as well. These inventories do not reflect the entire biodiversity of a region and tend to focus on well-known species, flagship species or species of value within the ecosystem (Royal Society 2003). Information in these inventories is usually collected through field surveys.

Inventories of ecosystem services list all the types of services provided by given location, such as services extracted from a forest or all known regulating services provided by a wetland. (See Box 8.1.)

Biodiversity and ecosystem service inventories were widely used in the sub-global assessments and proved to be very useful in assessing the importance of various ecosystems, and their services, for human well-being. Some of these inventories were produced by the sub-global assessment teams; examples include Downstream Mekong, Tropical Forest Margins, and India Local (the latter produced biodiversity inventories collected by school children in the study area). Other sub-global assessments relied on existing inventories, such as those found in museum collections, atlas data, and the scientific literature (examples include SAfMA Gariep, Portugal, Sweden KW, and Norway).

A third type of inventory is a natural resource inventory. These inventories may include data on the locations and amounts of provisioning services such as water, timber, agricultural products, and fisheries. They are often conducted at a national scale and include national statistics on production; an example is the Global Forest Resources Assessment (FAO 2001). Not all sub-global assessments used this type of inventory; this could be due to the fact that the boundaries of the assessment areas and national boundaries often did not coincide. Sub-global assessments that used national or international natural resource inventories include SAfMA, Laguna Lake Basin, Colombia, and Portugal.

BOX 8.1

An Inventory of Ecosystem Services: Downstream Mekong Wetlands

Provisioning services

- Food: agricultural crops, livestock, wildlife, vegetables, fruit, honey, and spices.
- Provisioning of medicinal substances: 280 medical plant species have been identified, 150 of which are frequently harvested; some animals including reptiles and birds.
- Timber: timber for house frames, leaf stems for roofs and walls
- Fuelwood, resin, and fiber.
- Provisioning of bio-active substances: 16 plant species providing toxic products, 28 species providing color products, 21 species providing tannin.
- Fresh water.

Regulating services

- Alum soil regulation.
- Water purification and run-off regulation.
- Climate regulation.
- Disease regulation.

Cultural services

- Inspirational
- Birthplace of various traditional performances
- Ecotourism and recreation
- Cultural heritage

8.2.1.5 Ecological Models

Ecological models are simplified mathematical expressions that represent the complex interactions between physical, biological, and socioeconomic elements of ecosystems (Roughgarden 1998; MA 2003). A review of the types of models available can be found elsewhere (MA *Current State and Trends,* Chapter 2, and MA *Scenarios,* Chapter 4). To the extent that models are simplified representations of reality, they provide an important tool for filling gaps in existing data, quantifying the effects of management decisions on the condition of ecosystem services, projecting long-term effects of changes in ecosystem condition, and assessing the effects of individual drivers and scenarios on ecosystem condition and the supply of ecosystem services (MA 2003). They can also project the viability of specific species populations under future conditions, and help increase our understanding of the complex interactions between biophysical and socioeconomic components of ecosystems. The use of models is not simple, however, and requires location-specific data and validation, which are often time and resource intensive; many sub-global assessments therefore did not apply modeling techniques.

The Western China assessment used the Agroecological Zoning model to estimate the carrying capacity of land: this is the maximum number of individuals that can be supported by ecosystem services in a unit area assuming sustainable development (Western China). In the Tropical Forest Margins assessment, the CENTURY model was used for simulating the change of carbon storage for different land use scenarios. Argentine Pampas used the Agro-Eco-Index model (Viglizzo et al. 2003) to incorporate data and calculate indicators of the environmental sustainability of agriculture. The SAfMA Gariep assessment made use of the PODIUM model (Kamara and Sally 2002) to assess trade-offs between food and water provisioning services. SAfMA Regional made use of the IMAGE model to predict land cover change under different scenarios.

8.2.1.6 Participatory Approaches and Expert Opinion

The sub-global assessments made extensive use of participatory approaches, with participants ranging from scientific experts at regional scales to community members at local scales. (See Chapter 11 for a more detailed discussion of local stakeholder involvement in participatory data collection.) These approaches allowed for the collection of forms of data not available in the literature, for example, from traditional and indigenous knowledge at the local scale. At broader scales, data gaps in the conditions and trends of various ecosystem services could be filled through workshops where experts and stakeholders were asked to qualitatively assess the condition of ecosystem services.

The assessments used several techniques of participant involvement, including focus group workshops, semi-structured interviews with key informants, interactive theater, participatory mapping, ranking and scoring, trend lines, problem trees, role-playing, and seasonal calendars (for a discussion of these methods see FAO 2005). Portugal, SAfMA, and Norway made use of participatory ranking and scoring for the condition and trends of ecosystem services and biodiversity. In the SAfMA Livelihoods assessment, community members were asked to rank various ecosystem services and their importance in the region. (See Table 8.1) Community members were also asked to use the number of stones to score the water quality in various areas under different forms of tenure over the last 40 years.

The use of participatory approaches, different types of knowledge and data, and local and regional expert input was one of the strengths of the sub-global assessments. (See Chapter 5.) Using these methods involved the development of new frameworks, methods of assessment, and systems of peer review in order to include these forms of knowledge and data as an input to assessments. In addition, it encouraged wide stakeholder involvement and buy-in. (See Chapter 6.)

Table 8.1. Ranking of the Relative Importance of Ecosystem Services Using a Participatory Approach: SAfMA Gariep. Ecosystem services ranked by the amaXhosa people of the Eastern Cape, from highest (1) to lowest (11).

Ranking	Ecosystem Service
1	mountain water
2	cultural species
3	fuelwood
4	livestock
5	medicinal plants
6	building materials
7	river water
8	agricultural crops
9	*imiFino* (wild vegetables)
10	honey
11	wild fruits

8.2.1.7 Economic Valuation

Economic valuation is a technique used to place a value on the benefits derived by humans from ecosystems and their services. This value is expressed in monetary terms in order to measure the benefits of a wide variety of services using a common metric. Although this metric is an economic one, it does not imply that only ecosystem services that generate direct monetary benefits can be valued. In fact, much of the recent work on economic valuation of ecosystem services has focused on how to value services that are not marketed (Bingham et al. 1995; Boumans et al. 2002; Costanza et al. 1997; DeGroot et al. 2002; Desvouges et al. 1998; Freeman 1993). Several techniques are used in the economic valuation of services (these techniques are summarized in Chapter 2 of MA *Current State and Trends*).

Although the methods and importance of economic valuation were highlighted in the MA conceptual framework (MA 2003), few sub-global assessments used this method of assessment. Exceptions included Portugal, where several marketed and non-marketed ecosystem services of forests were valued (see Box 8.2), and SAfMA Regional, which estimated the economic value of tourism as a recreational service.

Reasons for the lack of economic valuation in the sub-global assessments are varied but appear to relate to a lack of capacity, time, and the absence of markets. It is important to note that the assessment of non-marketed services (particularly supporting and regulating services is possible but time-consuming), and the time frames of the sub-global assessments were relatively short. In addition, some assessments and their users were not convinced of the benefits of assessing economic value compared to other measures of human well-being (particularly in rural areas where markets for many ecosystem services do not exist).

8.2.2 Challenges in Assessing Condition and Trends

This section examines different ways in which sub-global assessments assessed condition and trends, and then discusses the associated challenges in terms of spatial heterogeneity, fluctuations in time, lack of data, and expressing uncertainty.

8.2.2.1 Defining and Assessing Condition and Trends

In general, the sub-global assessments analyzed the condition of ecosystem services in a qualitative manner, sometimes supported by quantitative data. For instance, the Downstream Mekong assessment described the food products cultivated in the region and also gave time-series data for these products for the last decade. The India Local assessment described the recent history of the forest in the region. The Laguna Lake Basin assessment described the declining lake water quality during the decade 1990–99,

BOX 8.2

Economic Valuation of Services: Portugal

In 1998, the forestry sector represented about 3% of Portugal's GNP and 11% of its exports. Among the fifteen European Union members at the time (EU-15), only Finland and Sweden had forestry sectors with a larger role in the respective national economies. This statistic includes only provisioning services; an assessment of the value of some other ecosystem services provided by forests suggests that their inclusion would increase the economic value of forests in Portugal by at least 20%. Furthermore, the forestry sector employs over 228,000 people, about 5.14% of total employment (Portugal).

Economic Value of Forest Goods and Services, 1998 (Carvalho Mendes 2004)

Forest Commodity/Service	Value *(million euros)*
Timber	257.6
Cork	221.9
Total, timber goods	**479.5**
Resins	13.1
Honey	5.6
Fruits	41.2
Wild mushrooms	32.5
Aromatic and medicinal plants	1.9
Game	58.7
Fodder	125.2
Acorn forage	6.7
Scrubland and heathland forages	17.8
Total, non-wood goods	**302.7**
Recreational use	5.9
Carbon sequestration	26.5
Agricultural land protection	75
Water resources protection	29
Landscape aesthetic value	20.1
Total, environmental services	**156.5**
Total, forest goods and services	**938.7**

which resulted in declining biological productivity. These descriptions tended to emphasize drivers of ecosystem change and the trends of certain indicators such as food production.

Some assessments complemented these descriptions with an overall qualitative ranking of the condition of the ecosystem service, relative to some baseline (examples include Portugal, Norway, Trinidad, Caribbean Sea, Altai-Sayan, and San Pedro de Atacama). The overall condition of the service was reported by ranking the condition on a scale, which ran in most cases from 1 (Bad) to 5 (Excellent). These qualitative rankings were based on expert opinion, often gathered through participatory approaches. (See Box 8.3.) This method was later adapted at a working group meeting of the sub-global assessments, where information from a knowledge market was used to derive a qualitative ranking of the condition of the ecosystem services in each sub-global assessment. (See Appendix 8.1.) Such qualitative rankings can have the limitation of reflecting the perceptions of the experts doing the assessment, particularly when there is little data to support the rankings made.

One difficulty faced by the sub-global assessments was the lack of data to serve as a baseline for the analysis of condition. The Norway assessment evaluated the current condition of ecosystem services relative to their condition 100 years ago, but when historical data are not available, as is the case in many developing countries, seeking to establish this kind of baseline is impractical. In fact, many assessments collected data on ecosystem service condition in the study areas for the first time; this information can serve as a baseline for future assessments of condition.

One alternative to using a temporal baseline is to use a baseline that is spatially segregated from the area being assessed. For example, the Tropical Forest Margins assessment compared its results to the conditions found in natural and undisturbed forest. The Portugal assessment resorted instead to a conceptual baseline, defined as the current capacity of the ecosystem to provide a service, relative to the level at which the service could be maximized in a sustainable way. Another approach is to compare the value of an indicator to some standard or normal value. For instance, desired and actual values for indicators of water quality are given in the Laguna Lake Basin assessment; based on those indicators, it is clear that the water in the Laguna Lake is not suitable for drinking and its fishery productivity is threatened. Finally, the condition of a service may be analyzed relative to the capacity of the ecosystem to respond to the local demand for the service; the supply-demand approach was widely used in SAfMA. (See Figure 8.1.)

The supply-demand approach has the advantage of being easily quantifiable and communicated to decision-makers, but it can fail to detect deterioration or improvements in the capacity of the ecosystem to continue to provide the service in question. For instance, for provisioning services, the Portugal assessment reported both trends in the ecological capacity of the system to provide the service, and trends in the production of the service itself. These two trends are distinct and can differ: while marine fish landings have diminished in Portugal recently, stock levels have been improving (Portugal). Another limitation of the supply-demand approach is that it ignores spatial transfers of services. For instance, in the Gariep Basin, there are extensive systems of water transfer and food distribution so that even where supply is less than demand, overall demand may be met (SAfMA Gariep). Nevertheless, even where these transfer systems exist, the supply-demand approach reveals that: (1) access to services and security of access are also important and (2) the costs to ecosystems of these transfer systems (particularly of water) can be high and may threaten longer-term security of supplies.

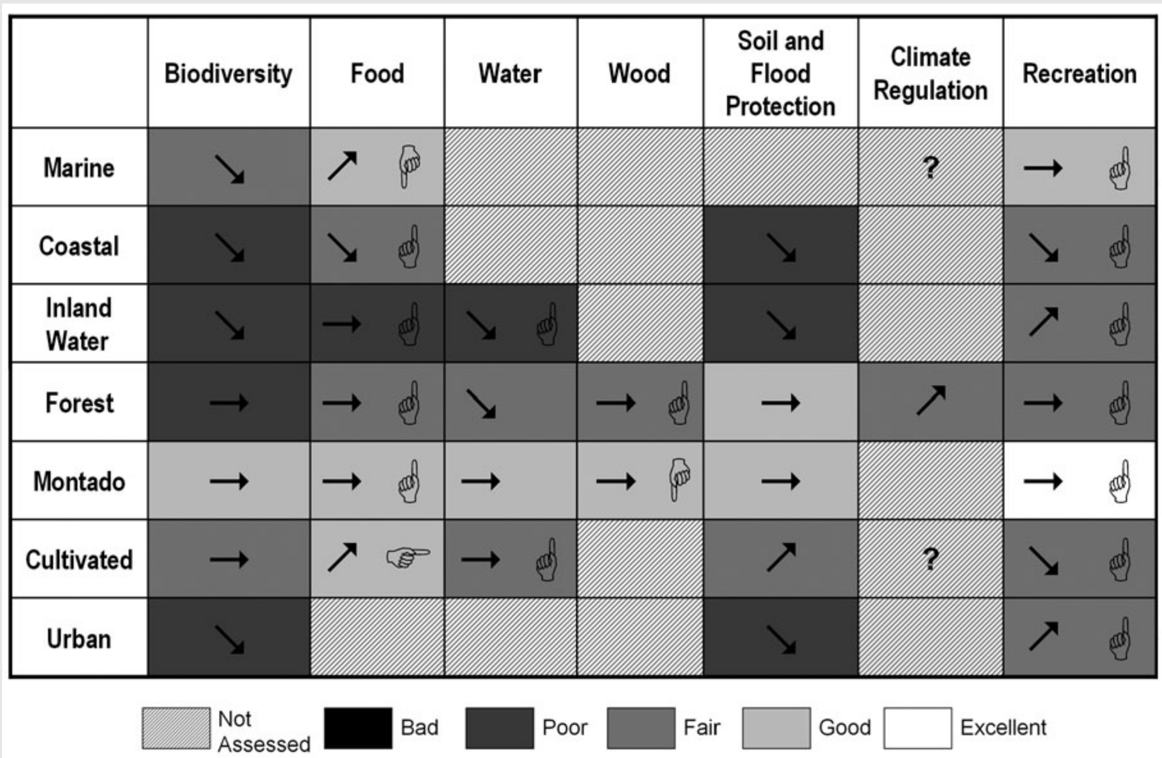
Not only did the methods of assessing condition vary among assessments, but so too did the time frames over which trends were assessed. The Portugal assessment standardized trends to look 40 years backwards and 10 years forward. Some assessments took a particular year as the start of the trend analysis; often it was a year associated with a political change and thus a change in the ecosystem man-

BOX 8.3

Qualitative Assessment of Condition and Trends of Ecosystem Services: Portugal

In the Portugal assessment, a joint workshop of the assessment team and users was dedicated to a qualitative assessment of the condition and trends of ecosystem services. The condition of services was assessed according to five categories ranging from *bad* to *excellent,* and was defined as the current capacity of ecosystems to provide the service relative to the level at which the service could be maximized in a sustainable way.

Two types of trends are shown: *arrows* indicate the trends in condition (the ecological capacity of the system); *hands* indicate the trends in production for provisioning and cultural services. Some services were not assessed because they do not occur or have only marginal importance. Question marks indicate services that would have been assessed if data were available.



agement regime. The Papua New Guinea assessment used the date of independence, 1975, as a reference point, while SAfMA Gariep used the transition to democracy in 1994 in some of their analyses. However, most assessments that had some form of trend information were constrained by the available data, and even within one study area the trend period could vary widely. For instance, in the Laguna Lake Basin assessment, the data used for trends in water quality started in 1990, while the data for trends in fish productivity started in 1963. In the Caribbean Sea assessment, the time frames for data on twelve ecosystem services varied widely. (See Table 8.2.) This variation in data made the comparison of condition and trends among ecosystem services or among sub-global assessments difficult.

8.2.2.2 Spatial Heterogeneity

Heterogeneity among the condition of services in different areas of each assessment was high. Spatial heterogeneity was found in local, sub-national, national, and regional assessments. For instance, in SAfMA Gariep, the results in water quality differed between two types of land tenure; using a nearby state forest as a benchmark, people at Machibi village reported that during the past four decades, water quality on community land had deteriorated compared to that on state land.

The Bajo Chirripó assessment provides an example of heterogeneity at the sub-national scale; there were differences between the condition of the midlands and uplands, managed by the Cabécar indigenous population, and the condition of the lowlands managed for agriculture and livestock production, owned by non-indigenous people and livestock companies. In the midlands, there was a decrease of some game species and selective logging of trees with timber value. This poaching and logging took place at a large scale before the lands were returned to the indigenous populations in the 1970s. Today, about 90% of the midlands and uplands are covered by forest, which allows the local population to benefit from ecosystem services such as water provisioning and cultural traditions associated with sacred places. In contrast, in the lowlands, there is not much forest left, and the waters from rivers and wetlands are polluted, with large decreases in the populations of crocodiles, caimans, fish, and birds.

Different ecosystems provide particular bundles of ecosystem services and vary in their response to human pressure. This has to be taken into account when making

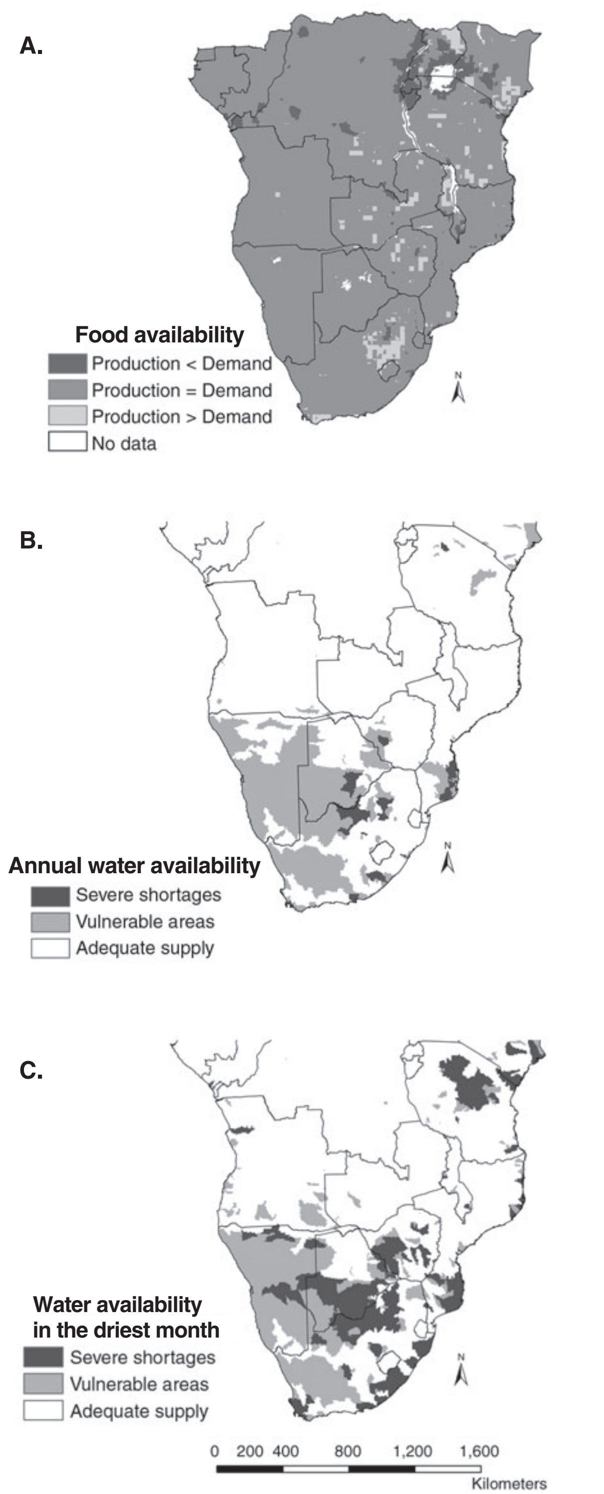


Figure 8.1. Supply–demand Assessment of Food and Water Provisioning in Southern Africa (SAfMA-Regional). Although the region as a whole is approximately self-sufficient in staple crops (maize, sorghum, and millet) and water in good years, the spatial pattern of food and water supply does not match demand, resulting in shortages in certain areas.

Table 8.2. Data Availability to Assess Ecosystem Services: Caribbean Sea

Ecosystem Service	Time Frame Evaluated
Fish production	1950–2000
Desalinated water	1992–2000
Live coral exports	1997
Oil and gas	1990–98
Beach sand removal	sporadic
Mangrove production	1993–99
Coral reef cover	1997–2002
Seagrass production	1993–99
Water quality	sporadic
Shoreline stabilization	sporadic, 1985–94
Tourism	1990–2001
Climate regulation	1950–2000

comparisons of the condition of services across different ecosystems. Heterogeneity at the national scale in the condition of services across systems is clearly illustrated in the Portugal assessment, with most services in the *montado* system in better condition than in the forest system. Similarly, in the Altai-Sayan assessment, services provided by forests are in better condition than services provided by grazing lands. Even within a given system, the condition of services can vary significantly.

Assessments conducted across more than one country showed high levels of heterogeneity due to different ecological, social, economic, and political drivers in those countries, which result in dissimilar land use and ecosystem management practices. For example, SAfMA Regional, which covered countries south of the equator in Africa, showed very different rates of forest loss in the region (ranging from 0.1% to 0.7% per annum). The Tropical Forest Margins assessment, where the humid tropical broadleaf forest biome is being assessed through several benchmark sites on three continents, is perhaps one of the best cases to illustrate the heterogeneity found within an assessment. (See Box 8.4.)

These results have three implications. First, when the condition of a service is expressed using a mean value across the entire assessment area, there is a tendency to derive intermediate values for the condition of all ecosystem services. Second, it is clear that responses based on these mean values would be inappropriate; instead responses should be considered at the finest scale appropriate. Third, assessments that span several ecosystems have to deal with heterogeneity among the different ecosystems, and within each ecosystem as well.

8.2.2.3 Fluctuations in Time

The analysis of a trend over a period of time is often complicated by fluctuations in the condition of the service. For instance, in the Caribbean Sea, fish landings peaked in the mid to late 1990s, but have since declined by about 33%. In the Laguna Lake Basin, fish production from open water fluctuated from 1963 to 1996 but showed an overall declin-

BOX 8.4

Heterogeneity of Conditions and Trends: Tropical Forest Margins

Not only does the condition of ecosystem services provided by the tropical forest biome vary dramatically across assessment sites, but it also varies within each assessment site. This heterogeneity reflects the irregular pattern of deforestation and land use change at the tropical forest margins, and the importance of the scale at which the assessment is conducted. If the Tropical Forest Margins assessment had been conducted only at Yaounde and Lampung (where there has been considerable loss of forest cover and the current land use systems focus on annual cropping) or only at Acre and Ebolowa (where forest is still the predominant land cover type), the findings of the assessment would have been quite different. This example stresses the importance of scale in designing, conducting, and reporting an assessment: to be representative, the area in which an assessment is conducted must attempt to include the full range of condition of the ecosystems and their services.

Condition of Ecosystems Services at the Tropical Forest Margins Sites, on a scale from 1 (bad) to 5 (excellent)

	Plant Biodiversity	Soil Nutrients	Carbon Sequestration	Fresh Water	Flood Protection	Food	Fuelwood
Brazil							
Acre	4	4	5	5	5	5	5
Rondonia	2	3.5	3	5	5	5	4
Cameroon							
Ebolowa	5	5	4	5	5	5	4
Yaounde	3	4	3	5	5	5	3
Indonesia							
Jambi	4	4	4	5	?	5	3
Lampung	1	2	2	5	?	5	1

ing trend at an average rate of 2.9% per year over a 33-year period; this decline has been generally attributed to declining water quality. In the 1970s, the Laguna Lake Development Authority introduced aquaculture, which first increased fish production, reaching its peak in 1984, after which a decline was again noted. (See Figure 8.2.)

These two cases illustrate the problems associated with using a single trend to describe changes in a service over time. One possible approach is to report both the trend and the size of the fluctuations. Another approach is to shorten the window of analysis to one in which the trend is linear (likely to be more relevant for short time projections). The window suggested in the MA conceptual framework (MA 2003), 40 years into the past and 10 years into the future, can be too long for services that evolve over shorter time

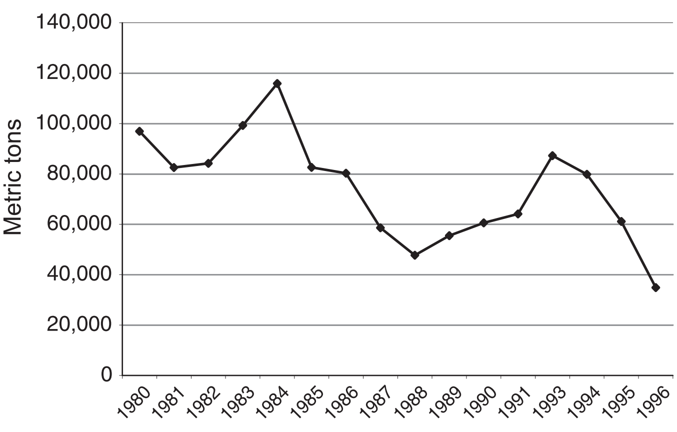


Figure 8.2. Total Fish Production in Laguna Lake, Philippines, 1980–1996. Data for 1992 was not reported.

scales. The choice of approach will depend on the goal of the assessment. For instance, when the goal is to compare response options, it is convenient to assess the trend in a time window similar to the time scale of the responses being considered.

8.2.2.4 Lack of Data

One of the most important weaknesses identified by sub-global assessments was the lack of comprehensive data in the study areas with which to assess the condition and trends of ecosystem services. Some sub-global assessments dealt with gaps in data by performing primary data collection. Alternatively, assessments resorted to expert opinion or excluded certain aspects from the assessment.

Supporting services were not thoroughly assessed in most sub-global assessments. (See Appendix 8.1 and Chapter 3.) This gap is of concern as the condition of supporting services has direct implications for the condition of most other services. Regulating services such as climate regulation and run-off regulation received more attention, but were still not assessed in several sub-global assessments. In contrast, provisioning services are easily conceptualized, quantified, and evaluated (MA 2003); almost all sub-global assessments included food and water provisioning in their analyses. Cultural services were relatively well assessed, especially tourism. Tourism is an important component of the economies of many of the sub-global assessments' study areas and data were readily available. Other elements of cultural services such as spiritual and aesthetic services were not as well assessed. Biodiversity was assessed by most sub-global assessments, but in a limited fashion, as data were available on current species composition or current extent of ecosystems, but trend data were rarely available.

Many assessments found that data were not uniformly available across the area studied. This was particularly the case for sub-global assessments that covered more than one country (for example, SAfMA Regional, Tropical Forest Margins, and Caribbean Sea). In some cases, sub-global assessments resorted to modeling to fill gaps in the data sets. For instance, species occurrence data are often biased toward areas close to urban centers, roads, and nature parks. The Portugal assessment filled the gaps in species data using realized niche models (Thuiller et al. 2003).

Another problem is the comparability of data sets across sub-global assessments. Issues include different techniques used to collect the data, varying scales of data collation, and differing dates, concepts, and definitions. SAfMA Regional found that using different data sets to assess area under cultivation resulted in different estimates. (See Table 8.3.)

8.2.2.5 Expressing Uncertainty

In addition to uncertainty in the assessment of ecosystem services created by spatial heterogeneity, lack of data, and fluctuations in time, uncertainties also arise from the drivers influencing those services. Uncertainties in the evolution of drivers such as governmental policy, climate change, technological development, and limited understanding of how drivers impact ecosystem functioning, propagate to uncertainties in the assessment of trends of ecosystem services.

Qualitative assessments by experts, scientists, community members and other stakeholders provided information and classifications of ecosystem condition for most sub-global assessments, but the uncertainty of qualitative assessments is difficult to quantify. Few sub-global assessments provided indications of the uncertainty associated with estimates of the condition of each ecosystem service. Exceptions include the Caribbean Sea and San Pedro de Atacama which ranked uncertainty on a qualitative scale from 1 (uncertain) to 3 (very certain). An alternative approach was followed by the Norway assessment, which listed the data quality issues associated with the assessment of each service, such as unknown variables or effects, data reliability, and gaps in the data.

Table 8.3. Land under Cultivation in Southern Africa: Various Estimates. The area estimated to be under cultivation in southern Africa varies considerably among different data sources (SAfMA Regional). The "core" areas given by the Global Land Cover Characteristics Database (GLCDD) of the International Geosphere-Biosphere Programme and the Global Land Cover (GLC) 2000 product are comparable to the areas given by MODLAND (land validation of MODIS satellite data), the Southern African Development Community (SADC) Land Cover Database, and FAO's Land Cover Classification System. The "total" areas include areas classified as cropland/natural vegetation mosaics, and therefore represent an upper estimate of the total area affected by cultivation.

	GLCCD IGBP				GLC 2000 Africa				MODLAND		SADC LC		FAO Statistics 2000	
	1,000 sq. km. core	percent	1,000 sq. km. total	percent	1,000 sq. km. core	percent	1,000 sq. km. total	percent	1,000 sq. km.	percent	1,000 sq. km.	percent	1,000 sq. km.	percent
Angola	63	5	127	10	48	4	49	4	28	2			33	3
Botswana	27	5	119	21	36	6	36	6	20	4			4	1
Burundi	1	4	17	61	9	33	9	33	6	12			13	45
Congo Rep.	5	1	13	4	2	1	14	4	5	1			5	1
Democratic Rep. of Congo	65	3	244	10	8	0	123	5	27	1			79	3
Equatorial Guinea	0	2	5	19	0	0	4	13	0	1			2	8
Gabon	6	2	20	7	0	0	12	4	3	1			5	2
Kenya	39	7	112	19	53	9	59	10	60	10			45	8
Lesotho	1	2	8	27	3	10	3	10	2	5	7	23	3	11
Malawi	23	19	29	25	31	26	31	26	12	10	59	50	22	19
Mozambique	219	27	282	35	71	9	73	9	19	2	48	6	41	5
Namibia	10	1	68	8	3	0	3	0	3	0			8	1
Rwanda	1	6	12	46	13	48	13	49	8	29			12	44
South Africa	150	12	462	38	134	11	138	11	92	8	144	12	157	13
Swaziland	11	66	12	67	0	0	0	0	5	31	4	20	2	11
Tanzania	221	23	358	38	178	19	178	19	74	8	101	11	50	5
Uganda	62	26	85	35	67	28	70	29	41	17			70	29
Zambia	114	15	256	34	64	8	64	8	59	8			53	7
Zimbabwe	160	41	211	54	119	30	119	30	26	7	107	27	34	9
Region	**1,178**	**11**	**2,442**	**23**	**842**	**8**	**998**	**9**	**494**	**5**			**634**	**6**

8.3 Findings

8.3.1 Biodiversity

The MA adopted the Convention on Biological Diversity's definition of biodiversity: the variability among living organisms from all sources including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part, including diversity within and among species and diversity within and among ecosystems (MA 2003). This definition of biodiversity is very broad, and the sub-global assessments tended to tackle particular components of biodiversity. For instance, the Sinai assessment focused on the diversity and abundance of medicinal plants, the Portugal assessment focused on the species diversity of selected taxonomic groups and on the extent of native forest, and the Caribbean Sea assessment focused on the remaining cover of live coral.

8.3.1.1 Drivers

Habitat loss was one of the most studied drivers in the assessment of biodiversity condition, with several assessments basing their results on land cover information derived from remote sensing data (Tropical Forest Margins, Western China, Downstream Mekong, PNG, SAfMA, Norway, Laguna Lake Basin, and Colombia). In fact, many sub-global assessments used the conversion of natural land cover to other forms of land use (for example, cultivation and pastures) as an indication of the condition of biodiversity. Other impacts of land cover change are fragmentation and degradation of the remaining natural habitat, which are often linked to losses of biodiversity. Fragmentation and its impacts on biodiversity were not assessed in detail by the sub-global assessments.

Degradation of ecosystems through overgrazing (a form of overexploitation) was evaluated in several of the sub-global assessments (Altai-Sayan, Argentine Pampas, and SAfMA Regional). In the Northern Range assessment, the overutilization of natural resources was identified as an important driver where the most sought-after timber species are no longer available and new species are now being harvested. The Western China assessment highlighted that hunting of wildlife and exploitation of plant species have had significant consequences for biodiversity, including the extinction of the Caspian Tiger (*Panthera tigris virgata),* Przewalski's horse (*Equus przewalski*), and the Saiga Antelope (*Saiga tatarica*).

The impacts of introduced alien organisms include altering the structure and function of ecosystems, as well as local and global extinctions of indigenous species. Some alien organisms thrive in the new environment and spread rapidly, becoming invasives. The Portugal assessment reports that one of the worst alien invasives in the country is the tree *Acacia sp.,* which is very costly to control or remove. But plantations of alien species can be a problem even when those species do not become invasives. For instance, in Portugal *Eucalyptus globulus* plantations have low biodiversity in comparison with native oak forests, and when poorly managed have negative impacts on soil and water resources. The Downstream Mekong assessment reported significant numbers of alien species, including decorative and food plants, industrial crops providing oil and fiber, and other accidental introductions impacting on both biodiversity and food production. In South Africa, 503 alien plant species are classified as harmful, invasive, or pests (SAfMA Regional). Invasive alien plants have reduced water flow by 10% (Görgens and van Wilgen 2004; SAfMA Regional), and in the Cape Floristic Region, they have resulted in total losses of ecosystem services of more than $100 million per year (Turpie et al. 2003; SAfMA Gariep). The cost of controlling invasive plants in South Africa is estimated to be about $100 million per year (SAfMA Gariep).

Two additional direct drivers of ecosystem degradation were levels of pollutants in water and air (Laguna Lake Basin, Coastal BC, SAfMA Gariep). Major sources of pollution entering the river systems of Laguna de Bay are domestic wastes (the largest source), food processing plant wastes, livestock wastes, chemical manufacturing spillage, various industrial effluents, fertilizers and pesticides from agricultural runoff, and eroded soils from the watersheds, which affect the tourism and fish production services of the lake (Laguna Lake Basin). Laguna de Bay offers examples of the impacts of eutrophication on lakes and their services.

Many sub-global assessments highlighted climate change as an important direct driver of change in biodiversity condition; however, much of the evidence was anecdotal and only in a few cases were scientific studies referenced. SAfMA Regional reported on climate change impacts to coral reefs, plant species distributions, and tree cover expansion into grassland and savannas. SAfMA Gariep projected that flagship protected areas may lose some of their current species by 2050. The Altai-Sayan assessment reviewed existing literature and determined that there is inconclusive evidence that changes in the tree line are related to climate change. The Caribbean Sea assessment reported coral bleaching and sea temperature change.

Of interest is the role of tourism and recreation as an indirect driver of change in biodiversity condition. Although tourism is often put forward as a way of promoting both conservation and development, it was advanced by many sub-global assessments as a driver of decreases in biodiversity condition (Northern Range, SAfMA Regional, Portugal, Caribbean Sea). This is particularly the case in coastal areas, where tourism infrastructure development destroys sensitive coastal habitats and decreases landscape value, while wastewater affects marine life and water quality (Portugal, Caribbean Sea). The intensive religious use of some areas can also introduce threats to biodiversity, as was found in the India Local assessment (India Local), despite the known importance of sacred groves for biodiversity conservation (Ramanujam and Cyril 2003).

Other indirect drivers include economic and governance factors. For example, the Northern Range assessment highlighted that inequitable distribution of wealth has led to increasing numbers of people seeking low-income housing on hillsides, especially in close proximity to urban areas. This in turn has led to deforestation and the subsequent degradation of land. The Colombia assessment reported that direct correlation was found between indicators of economic activity and indicators of quality of life in the coffee-growing region, where municipalities with greater economic activity also showed higher levels of quality of life. Coffee production has increased the rural employment rate, but it has also led to significant deterioration in biodiversity condition through ecosystem degradation and natural vegetation loss. In the future, the minimization of biodiversity loss will depend on the expansion of farming practices that are biodiversity-friendly, such as traditional shaded coffee (Moguel and Toledo 1999), and on the protection of forest fragments in the rural landscape (Ricketts et al. 2001). Some sub-global assessments also cited ineffective and uncoordinated land use planning as the main reason for the poor condition of biodiversity, since this can lead to overexploitation of natural resources, pollution, and the introduction of alien invasive species.

The Northern Range assessment identified cultural and behavioral changes as indirect drivers of change in biodiversity condition. The assessment found that in places where there is inadequate information and understanding about the relationship between human activities and their impacts on ecosystem services, culture and behavior may exacerbate driving forces like land use change and overexploitation of resources.

8.3.1.2 Indicators

There are many possible measures of biodiversity condition and trends, and no strong consensus as to which are the best measures to use. (See MA *Current State and Trends,* Chapter 4). Most sub-global assessments, as well as the global assessment, focused on assessing the condition and trends of particular species and habitats.

Our knowledge and data on species distribution are incomplete, particularly in the tropics (MA *Current State and trends,* Chapter 4). Therefore, field surveys should target selected groups of species that may give indications of the overall condition of biodiversity. Examples include:

- threatened species (India Local, SAfMA Gariep, Portugal),
- invasive species (Downstream Mekong, SAfMA Regional, Laguna Lake Basin),
- indicator species linked to some particular element of biodiversity condition (for example, pioneer species),
- sensitive species that react to changes in the environment before other species,
- species of economic importance that can be exploited and even overexploited in unmanaged systems (India Local),
- nuisance and pest species as ecosystem disservices (India Local),
- flagship species (for example, the Western China assessment studied the impacts of land cover change on the Giant Panda, *Ailuropoda melanoleuca*), and
- species belonging to functional groups (Tropical Forest Margins), which are species particularly related to ecosystem processes and thus are essential to the production of ecosystem services (MA *Current State and Trends,* Chapter 11).

Simple species lists (or species inventories), and associated measures such as species richness and diversity are in most cases inadequate as measures of biodiversity condition and trends. Indicators such as the proportion of threatened species or the percentage cover of invasive species can be used, but a deeper understanding of the condition and trends of biodiversity can only be gained with time series data for these species lists. This information can then be used to calculate changes in geographic ranges and quantities (Ceballo and Ehrlich 2002; Thomas et al. 2004). For example, an increase in the abundance of alien invasive or pioneer species could indicate a disturbed ecosystem, while a decline in the numbers of a sensitive species would be indicative of some environmental change. Although species lists are quite common for many regions of the globe, these lists are rarely collected in a periodic and consistent way. The lack of historical data for population sizes is even greater. In the cases where historical data were not available, some assessments used expert opinion on the trends in species numbers (examples include Portugal and Sinai).

Local inventories of species can also be a method for engaging the community in the assessment. For example, in the India Local assessment, schoolchildren and teachers conducted nature studies in one or two square kilometer zones around their schools. The students recorded the various landscape element types and prepared an inventory of local plants and animals (India Local).

Sub-global assessments did not restrict their attention to biodiversity at the species and population levels, but also assessed the condition of biodiversity at the ecosystem and biome level, using a variety of methods including:

- linking species data to particular ecosystems, that is, numbers of threatened species per ecosystem (Portugal);
- assessing land cover and land cover change where ecosystems with high levels of converted land cover or rapid change in land cover can be highlighted (Western China, SAfMA, Tropical Forest Margins, Laguna Lake Basin)–in this case the indicator of condition is also the direct driver of ecosystem change; and
- identifying protected areas on the assumption that ecosystems with significant protected area coverage have biodiversity in good condition (SAfMA Gariep).

Protected area coverage has limited value for assessing biodiversity condition because many protected areas exist only on paper and do not correspond to real zones of effective protection on-the-ground (Liu et al. 2001; see also Bruner et al. 2001). In addition, the condition of biodiversity outside of the protected area is also important because of the impacts that the human-dominated matrix can have on the biodiversity within a protected area (Pereira et al. 2004). Finally, the establishment of protected areas can have negative consequences for human well-being by excluding people from natural resource access (Musters et al. 2000). Nevertheless, 4.2% of the coffee-growing region in Colombia is under protection (over 260,000 hectares), and these ecosystems are in a less disturbed state and are subject to fewer pressures than ecosystems outside of protected areas (Colombia).

Several sub-global assessments applied novel approaches to the assessment of biodiversity. These included composite measures such as the Biodiversity Intactness Index in SAfMA Regional, irreplaceability in the Portugal assessment, conservation status of ecosystems in SAfMA Gariep, the Reef Condition Index in PNG, and the Ecological Integrity Index in Coastal BC.

The Biodiversity Intactness Index provides a useful analysis of biodiversity condition that can be mapped and communicated to user groups. (See Box 8.5.) Irreplaceability, in the Portugal assessment, is a measure of conservation options lost if the site were to be converted or further degraded (Pressey et al. 1993). High irreplaceability values indicate high importance to the conservation targets of a region. The irreplaceability value is not an indicator of biodiversity condition, but can be useful in prioritizing areas for conservation. (See Figure 8.3 in Appendix A.)

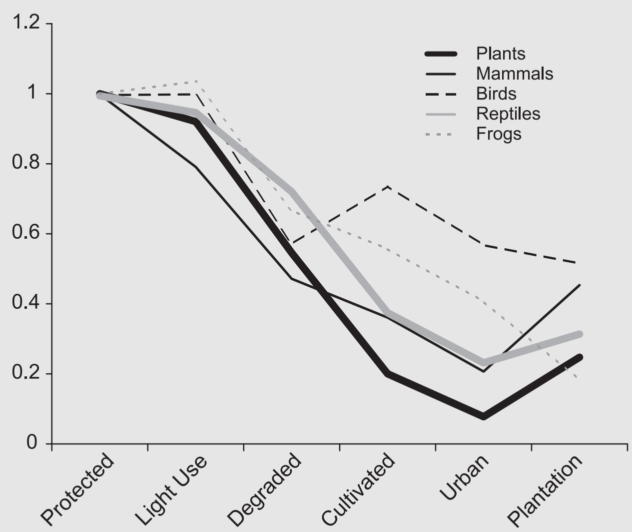
Conservation status analysis of vegetation units provides an indication of the condition of biodiversity at the ecosystem level as measured by land cover change (SAfMA Gariep); here, a gap assessment highlights ecosystems with little protection. (See Box 8.6.) The composite Reef Condition Index is generated by a number of parameters, including coral cover and diversity, as well as fish densities and diversity (PNG). The Ecological Integrity Index is based on measures of ecosystem diversity; species and genetic diversity; soil, water, and air quality; and provisioning and cultural services. (See Box 8.7.) All of these composite indicators were useful in communicating complex information to policy-makers and other stakeholders.

The use of indicators of condition requires a baseline value against which the current value can be compared. SAfMA Regional compared the Biodiversity Intactness Index with levels in protected areas and found that although most of the study area was in good condition, some of the areas and taxa were in poor condition (SAfMA Regional). The Coastal BC assessment applied an innovative approach of comparing their ecosystem dynamics with thresholds of the range of natural variability (Coastal BC); these benchmarks included natural disturbance regimes of canopy gap creation in forests, and flooding events. Setting targets for maintaining the diversity of ecosystems requires the identification of thresholds at which disturbances greater than the natural range would result in detrimental changes.

BOX 8.5

Biodiversity Intactness: SAfMA Regional

SAfMA Regional developed a new index, called the Biodiversity Intactness Index (BII). The BII measures the fraction of the original *populations* of organisms that remain in a given area, integrating across all land uses and all well-described categories of biodiversity. The index has three components: the spatial distribution of land uses of varying intensity; the spatial distribution of species richness per functional type within each main group of organisms and biome; and the impact of land use intensity on each functional type within each biome. These estimates, averaged over biomes and functional types in the graph, are based on three independent assessments by specialists.



Effect of Increasing Land Use Intensity on Fraction of Inferred Original Wildlife Population that Remains.

Some general patterns are evident: non-mobile species such as plants are more adversely affected than mobile species such as birds. Larger organisms and predators are more affected by human activity than are smaller, non-predatory species. Mammals and reptiles tend to track (plant) habitat changes, whereas birds and amphibians show marked non-linearities in their response. The graph shows the BII as applied to South Africa. The results are richness and area weighted averages of BII as estimated at a base resolution of 1 kilometer. Values of BII refer to the average abundance of all species in the particular area, expressed as a fraction of preindustrial era abundance.

8.3.1.3 Condition and Trends

Sub-global assessments reported a variety of conditions for biodiversity, from *excellent* (KM–São Paulo); to *good* (SAfMA, Tropical Forest Margins–Africa, India Local, KM–Eastern Himalayas, and KM–PNG); to *poor* (Tropical Forest Margins–Indonesia and KM–Laguna Lake Basin); to *bad* (Caribbean Sea), with the rest in *fair* condition. Worryingly, the vast majority of sub-global assessments reported a decline in the condition of biodiversity. (See Appendix 8.1.) This suggests that in several places in the globe and across a variety of systems, there is a consistent trend of biodiversity loss. This result is supported by the global analysis of biodiversity trends (MA *Current State and Trends,* Chapter 4) and is of concern because biodiversity is the resource base upon which all ecosystem services are founded (MA 2003). It should be pointed out, however, that the coverage of the sub-global assessments was not uniform across the globe and may have had a bias toward regions undergoing fast ecological change.

Figure 8.4 in Appendix A shows biodiversity condition in the sub-global assessments and the amount of native habitat remaining in each ecoregion of the world (Olson et al. 2001) using data from the MA Scenarios Working Group. This comparison was constrained by the use of arbitrary thresholds for scoring land use change at the ecoregion scale, the use of broad descriptive categories of condition in the sub-global assessments, and the difference between the scales of the sub-global assessments and the scale of the

BOX 8.6

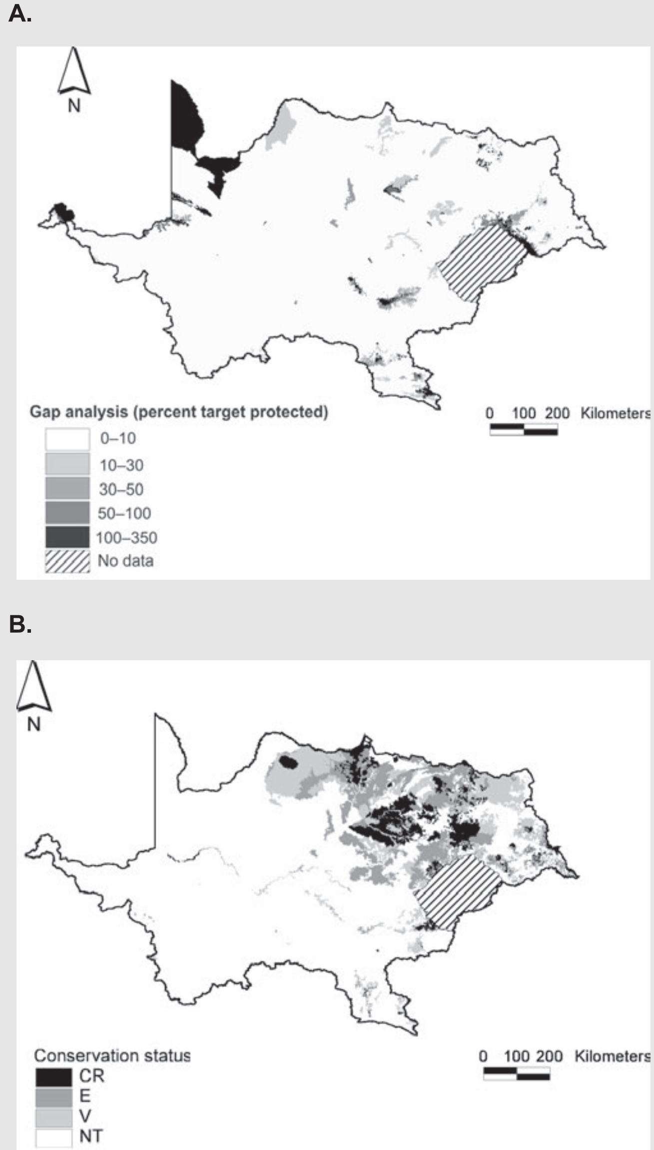
Conservation Targets, Gap Assessments, and Conservation Status: SAfMA Gariep

Conservation targets are an idea gaining strength in the conservation planning literature and represent the extent of occurrences of biodiversity features that a conservation area network should include (Pressey et al. 1993). These targets can be simple and include one occurrence of each species or a cover of, for example, 10% of a vegetation type. However, several techniques now exist to weight targets according to criteria of importance, sensitivity, or rarity. SAfMA Gariep set targets for each of the approximately 2,000 land classes in the Gariep Basin, based on existing methods in Pressey and Taffs (2001) and Reyers (2004). The target for each land use class was defined as a percentage of the original extent and is

$$\text{Conservation Target (\%)} = 10\,(1 + NR + VU)$$

where NR is the natural rarity of the land class (1—area of the land class relative to the largest land class in the area) and VU is the land class vulnerability to conversion to other forms of land use (from 0 to 1). Based on these targets for each land class, a gap assessment of protected area coverage could be done as well as a conservation status assessment. The gap assessment identifies how well the existing protected areas do in reaching the target for each land class, while the conservation status assessment measures how much of the land class remains in a pristine condition relative to the target area required. The land classes can then be classified in different categories: *Critically endangered* ecosystems are land classes with less area remaining than required by the target, *endangered* ecosystems are those that have lost more than 40% of their original cover, and *vulnerable* are those that have lost more than 20%. These thresholds correspond with the threshold of ecological integrity as proposed by Franklin and Forman (1987).

The figure shows gap assessment (a) and conservation status (b) of land classes in the Gariep Basin (excluding Lesotho, stripes) with (a) representing darker areas that are protected up to and above their target requirements and in lighter colors those that do not yet meet their targets and (b) showing areas that are critically endangered (CR), endangered (E), vulnerable (V), and not threatened (NT)



Gap assessment (a) and conservation status of land classes in Gariep Basin (b) (excluding Lesotho, diagonal stripes).

ecoregions. From this comparison, it seems that there is consistency between the results at the two scales. Exceptions include Norway, which assigned a much lower condition score than found at the ecoregion level; SAfMA G–M, which assigned a much higher score than found at the ecoregion level; and some sites in the Tropical Forest Margins assessment, which showed differences both ways. Note that for sub-global assessments that span several ecoregions, such as Western China, Altai-Sayan, and SAfMA Gariep, the score from the sub-global assessment has to be compared to the average score of the ecoregions.

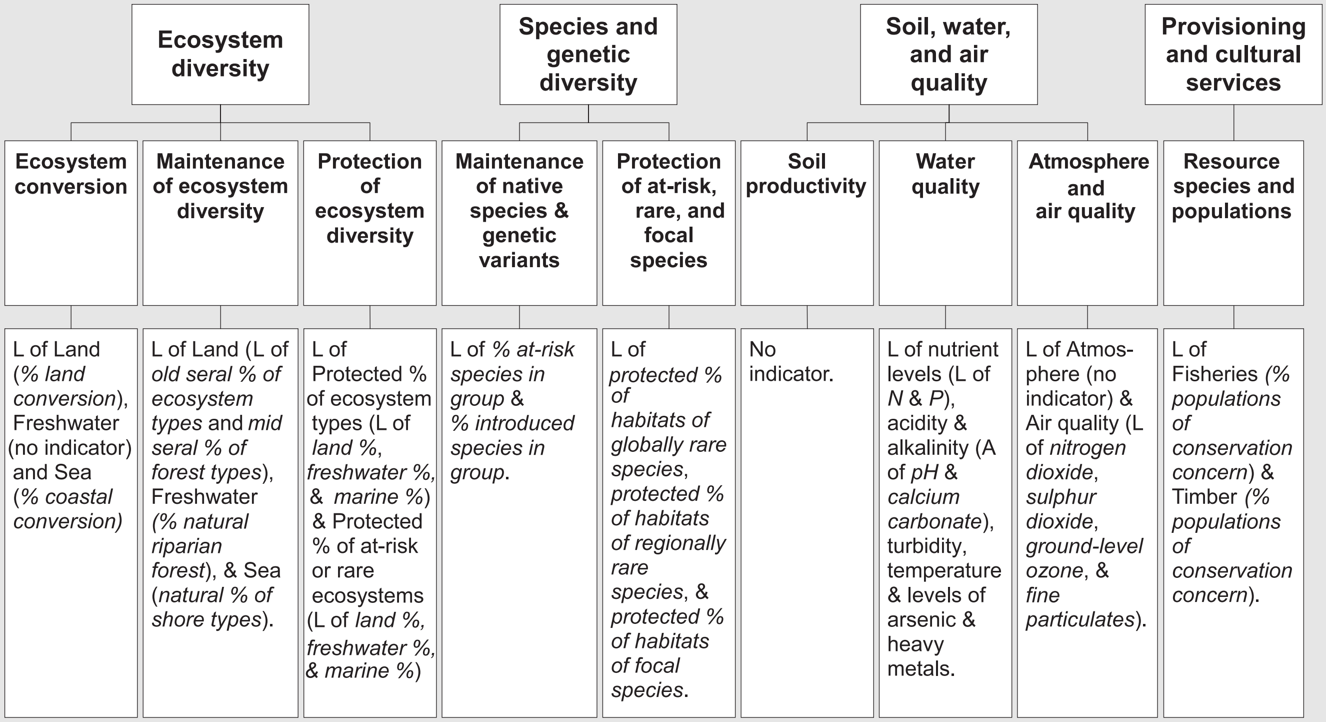
Several sub-global assessments highlighted grasslands as areas of concern due to high impacts of land use and degradation (SAfMA Gariep, Altai-Sayan, Western China). Problems were also reported at the global level, where the Temperate Grasslands biome had lost nearly 70% of its native cover by 1950 and has lost an additional 15.4% since then (MA *Current State and Trends,* Chapter 4).

As highlighted in the section on heterogeneity, the mean condition score in a sub-global assessment does not reflect the complex range of conditions that can be found in the assessment area. For example, the Caribbean Sea assessment found mangrove forests to be in fair condition, and coral reefs in bad condition, but the score assigned to overall biodiversity was ''bad.'' The Norway and Portugal assessments found that the condition of biodiversity in a variety of terrestrial, freshwater, and marine environments varied from bad to fair in Norway and from poor to good in Portugal, with declining trends in most of the ecosystems. Similarly, SAfMA Regional found very different conditions of biodiv-

BOX 8.7

The Ecological Integrity Index: Coastal BC

The Ecological Integrity Index is the unweighted average of scores for four element groups (top line): ecosystem diversity; species and genetic diversity; soil, water, and air quality; and provisioning and cultural services. Element group scores are the unweighted average of element scores (middle line). Element scores are the lowest indicator score, where L = lower/lowest and A = average (bottom line).



The following table shows the EII applied to the different sub-regions of North and Central Coastal BC. Sub-regions with no data on air (square brackets) were given a dummy score of 91 (the score of Lower Mid Coast, the lowest of the recorded sub-regions).

Subregion	Ecosystem diversity	Species and genetic diversity	Soil, water, and air quality	Provisioning and cultural services	Ecological integrity index (EII)
Haida Gwaii/QCI	44	40	[91]	27	50
Inner north coast	51	0	[91]	22	41
Outer north coast	63	0	95	23	45
Lower north coast	56	0	93	21	42
Outer central coast	62	0	[91]	17	42
Inner central coast	57	0	[91]	17	41
Upper mid-coast	28	3	93	13	34
Lower mid-coast	36	0	91	11	30

Bad | Poor | Fair | Good | Excellent

ersity in areas under different land use management practices; areas under intensive land use practices like cultivation and plantations have much lower biodiversity condition than those with light intensity uses like grazing.

It is important to note that a lack of data on particular threats and drivers (like land degradation, alien invasives, climate change) could result in an underestimation of threats in a region and thus overestimation of condition. For instance, the SAfMA Gariep Basin reported a poor condition of productive landscapes in the eastern grasslands relative to the arid regions of the west, where biodiversity appears to be relatively intact. However, these arid areas are actually threatened by degradation and desertification, drivers that were not studied or mapped for the region. Thus the actual ecological integrity of the arid regions in the west of the Gariep Basin might not be in as good condition as initially estimated.

Although the condition of biodiversity was generally reported to be in decline, some sub-global assessments had more positive results. For example, the Kristianstad wetlands assessment reported that pre-1989 biodiversity in the region was in decline due to abandoned agricultural land (Sweden KW). The area is largely composed of agro-ecosystems that require active management to be maintained. After 1989, traditional management practices were revived in order to combat the trend in ecological deterioration. At the same time, awareness of the value of wetlands in the area increased. The process has been gradual, but after an evaluation of new management practices, the assessment concludes that the condition of biodiversity is improving.

Overall these results call for: (1) a clearer definition of biodiversity condition in order to allow for feasible measurements and cross-assessment comparisons; and (2) the development of biodiversity monitoring programs that use standard biodiversity measurements over time.

8.3.2 Supporting Services

Supporting services are those that are necessary for the production of all other ecosystem services (MA 2003). The supporting services assessed by sub-global assessments include primary production (Western China, Laguna Lake Basin, SAfMA), soil formation (Portugal, Tropical Forest Margins, Norway), nutrient cycling (Tropical Forest Margins), and habitat provisioning (Altai-Sayan). The distinction between a supporting service and a regulating service was in many cases uncertain. For instance, the Portugal assessment analyzed soil protection as a regulating service, but this analysis also included an assessment of the soil condition in terms of nutrient supply, accumulation of salts from irrigation, and pollution from point sources. All of these components were part of an assessment of the soil as a resource base on which other services depend, which is a supporting service. Similarly, primary production is closely related to the regulating service of carbon sequestration (Portugal), and the habitat provisioning service is often an integral component of a biodiversity assessment.

8.3.2.1 Drivers

The primary productivity of an ecosystem is mainly driven by climate and the supply of water and nutrients from the soil (Brown and Lomolino 1998). Human-induced drivers of primary production include eutrophication of water bodies (Laguna Lake Basin), land use change (Western China), and climate change (Western China).

The physical, chemical, and biological properties of soils determine their overall supporting service and are affected directly by the following drivers:

- land use change, including deforestation (Tropical Forest Margins, Norway), afforestation (Portugal), and road construction (Tropical Forest Margins, Norway);
- external inputs such as irrigation, fertilizers, and pesticides (Norway, Portugal, Western China);
- pollution from mining (Portugal);
- agricultural practices such as tilling and crop rotation (Argentine Pampas, Portugal, Norway); and
- fire frequency (Portugal, Altai-Sayan).

In some regions, an important human-induced driver of the nutrient cycling service is the depletion of nutrient stocks through the repeated harvesting and removal of produce without replenishment of those nutrients (Tropical Forest Margins, SAfMA Regional). Finally, habitat provisioning is affected by much the same drivers as biodiversity at the ecosystem level. Sometimes the impacts of a driver can be reversed through restoration measures (Western China). As an example, trees can be planted on cultivated land to accelerate ecological succession from crops and grassland to forest.

8.3.2.2 Indicators

In the Western China assessment, changes in net primary productivity (NPP) were estimated using ecosystem models and land cover maps. (See Box 8.8.) In SAfMA, the difference between grazing pressure and potential capacity (based on NPP) was used as a measure of rangeland degradation, that is, desertification (SAfMA Regional). Desertification can be caused by overgrazing or by a decrease in soil organic matter and leads to a decrease in vegetation cover and primary productivity.

Indicators of soil condition include concentration of salts, depth of soil layer, soil compaction, nutrient loading, and organic matter content (Portugal, Tropical Forest Margins). In order to assess the nutrient cycling service, the Tropical Forest Margins assessment used two indicators: net nutrient export and relative net nutrient replacement cost. Net nutrient export is the nutrient input minus nutrients harvested. Relative nutrient replacement cost equals the cost of putting the exported nutrients of harvested products back into the agroecosystem in the form of chemical fertilizer. Nutrient inputs were assessed primarily through interviews with farmers at the sites but also using national or district level statistics (for mineral fertilizer use, if available). Nutrient contents of organic inputs were obtained from the literature. Nutrients removed through harvesting were determined by the crop or tree product yield (obtained from field interviews and agricultural statistics) and multiplied by the concentration of nutrients in the different products (Stoorvogel and Smaling 1990). The nutrient balance was determined as the difference between inputs and outputs for nitrogen, phosphorus, and potassium. The cost of nutrients in the form of mineral fertilizers and price of crops was obtained from local markets and statistics.

8.3.2.3 Condition and Trends

By analyzing photosynthetic–thermal farmland productivity, the Western China assessment found that from the

BOX 8.8

Supporting Ecosystem Services: China

The Western China assessment monitored land use/cover change in China using remote sensing data, such as satellite images and other data sources, integrated in a GIS system. It was found that between 1990 and 2000, the area of cropland, towns, rural residences, and water bodies increased across western China, while the area of woodland and grassland decreased. By using ecosystem models, the changes in the condition of primary production due to land use changes in China were estimated (Liu et al. 2003). Net primary production has increased over most of China, but has decreased in the Loess Plateau and the western part of the northeastern China. At the same time, food production has also increased in China. (See the Figure for this box in Appendix A.)

1980s to the 1990s, due to climate change, productivity increased by 44 million tons. During the 1990s, due to land use and land cover change, photosynthetic–thermal farmland productivity increased by 22 million tons. In contrast, the Laguna Lake Basin assessment reports a serious problem with the primary production service in a freshwater system. The biological productivity of Laguna de Bay has declined considerably, especially during the last 30 years. Assessment of the levels and trends of primary productivity of the lake during the period 1990–2000 shows erratic behavior, with NPP levels generally below 1 gram of carbon/m^2/day. This is about 20% of the NPP observed in the 1970s. The main reason is the very high water turbidity that limits light penetration and photosynthesis; fish harvests have declined commensurately.

Several sub-global assessments reported a poor condition of soil-related supporting services (Norway, KM–Western China, KM–Eastern Himalayas, KM–Downstream Mekong, Tropical Forest Margins; see Appendix 8.1). This is of great concern because the recovery of degraded soil can be a slow process (Portugal). Soil erosion was identified as a major problem affecting the condition of supporting services in many assessments. In SAfMA Regional, about half of the subhumid and semiarid parts of the region are at moderate to high risk of desertification due to grazing pressure. Overgrazing has reduced yields by a third in Western China and is also a serious problem in the grasslands of the Altai-Sayan ecoregion. In Norway, Portugal, Western China, and Eastern Himalayas, bad agricultural practices and the cultivation of marginal lands have caused erosion of the topsoil in some areas. In China, the government has recently implemented a regulation that calls for existing cultivated land with slopes of more than 25 degrees to be restored gradually to forest and grassland, or changed into terraced land. (See also Portugal for a case study of terrace agriculture.) Problems of salt accumulation in the soil caused by irrigation were reported in the drylands of Western China and Portugal. The Norway assessment reported that intensive extraction of biomass contributes to increased acidification of the soil, with consequent chemical effects on run-off water. Downstream Mekong reported a decrease in the alum-washing process by seasonal inundation and floods because of increased drainage systems, leading to impacts of alum on agriculture.

8.3.3 Provisioning Services

Provisioning services are the products obtained from ecosystems (MA 2003), also known as ecosystem goods (Daily 1997). The provisioning services assessed by the sub-global assessments included: fresh water, food, fuelwood, fiber, and to a lesser extent, biochemicals. Among these, freshwater provisioning was the service most commonly assessed.

8.3.3.1 Drivers

Drivers affecting provisioning services are varied and are explicitly linked to indirect drivers. *Indirect drivers* include population growth, lifestyles, diet, governance, regulations, and markets. *Direct drivers* include:

- land use change;
- external inputs, including irrigation, fertilizer use, pesticide use, and pollution;
- technology adaptation, including aquaculture and agricultural intensification;
- introduction of species and agricultural varieties, including tree species and fish species for aquaculture;
- harvest (deforestation, overfishing); and
- climate change and yearly weather fluctuations.

The links between each indirect driver and changes in provisioning services are often explicit. For instance, the decrease in household size (an indirect driver) directly affects the patterns of fuelwood consumption in the Eastern Himalayas.

Direct drivers can affect several provisioning services. For example, a direct driver of food provisioning such as irrigation may affect water quality indirectly through the accumulation of fertilizers and salts in groundwater (examples include Portugal and Sinai). Another example is deforestation that directly affects food provisioning (by increasing available area for agriculture, as in Tropical Forest Margins) but at the same time can also affect other provisioning services such as water (Northern Range) and fuelwood (SAfMA). But the specific drivers in each of the broad categories mentioned above may also differ across provisioning services. For instance, ''technology adaptation'' drivers of food provisioning include agricultural intensification (examples include Norway, Portugal, PNG, Downstream Mekong) and aquaculture production (Laguna Lake Basin), while ''technology adaptation'' of drivers for water provisioning includes water extraction techniques (PNG) and water use efficiency (SAfMA), and for fuelwood provisioning, it corresponds to alternative energy sources (SAfMA). Similarly the main land use driver affecting food provisioning is the change in area for various crops (San Pedro de Atacama, India Local, Laguna Lake Basin, Portugal, Downstream Mekong), while the land use driver affecting water provisioning includes dam construction and inter-basin water transfers (SAfMA, Portugal).

8.3.3.2 Indicators

Indicators for the condition of provisioning services are more readily available than for other ecosystem services. Therefore, it is not surprising that all the sub-global assessments assessed at least one provisioning service (Appendix 8.1). There are national statistics on food production (FAO 2001), timber production (FAO 2003), water production, and water quality. However, these data were not always available at the scales of the assessments; in some instances, sub-global assessments had to collect their own data (for example, Tropical Forest Margins and Laguna Lake Basin).

Sub-global assessments used a range of indicators to assess the condition of the water provisioning service, measuring different aspects of the service. Measures of water quality, including physical, chemical, and biological parameters can be used to assess the suitability of water for human consumption or irrigation (for example, Laguna Lake Basin, Altai-Sayan, Portugal). Water quality is affected by several point pollution sources, but also by drivers such as soil erosion and dam construction. It is also important to measure the quantity of water available. This can be assessed by simple measures such as lake depth (for example, Laguna Lake Basin and Western China) or more elaborate measures such as a supply–demand analysis (for example, SAfMA Regional, Downstream Mekong, São Paulo). Finally, issues of equity in access to water resources can also be considered (for example, Sinai, SAfMA Gariep).

Similarly, several indicators were used to assess the condition of food provisioning. Indicators of the amount of food produced included agriculture production (for example, San Pedro de Atacama, Downstream Mekong, Sinai, Portugal, Laguna Lake Basin), fish landings (for example, Caribbean Sea, Downstream Mekong), and area under cultivation (for example, Sinai). Because food is less of a local service than water provisioning, supply–demand analysis played a more limited role in the assessment of this service (but see SAfMA). SAfMA also undertook an analysis of food access, equity, and food security.

The supply or production of a service may tell little about the capacity of the system to continue to provide that service. The Portugal assessment looked at indicators of the capacity of ecosystems to provide food, such as the level of fertilizer and pesticide use, soil erosion, aquaculture practices and the condition of fish stocks (measured by the number of species above the precautionary biomass threshold).

Some assessments analyzed the production of fiber and fuelwood. Indicators of production volume (SAfMA, Portugal) and production economic value (Portugal) of fiber were used, as well as indicators of standing stock (Tropical Forest Margins, São Paulo). A supply–demand analysis, comparing rate of wood felling with the rate of wood growth, was performed at the national level by Portugal and at the local level by SAfMA. Other indicators of sustainability included the type of management system and management practices (São Paulo, Portugal). India Local analyzed the history of local forests, including logging, invasion by alien species, and fire frequency.

Few assessments analyzed the provisioning of biochemicals by ecosystems. For instance, the Downstream Mekong assessment surveyed bioactive substances (such as color products) produced by plants, while the Sinai assessment analyzed the condition of the populations of medicinal plants.

8.3.3.3 Condition and Trends

Serious problems with the water provisioning service were found in four sub-global assessments. In San Pedro de Atacama in Chile, water is a scarce resource and high levels of arsenic occur naturally in the water; there is much uncertainty, conflict, and misinformation regarding water availability, with total requests for irrigation, mining, and potable water exceeding available volumes (San Pedro de Atacama). In the Laguna Lake Basin, the quality of the water in the lake and tributary rivers is poor, with total coliform counts exceeding the class ''C'' maximum standards (suitable for fisheries, according to the Water Quality Criteria of the Philippine Department of Environment and Natural Resources). Other problems include very low levels of dissolved oxygen, an NPP rate characteristic of a hypereutrophic lake, and the presence of toxic and hazardous substances such as mercury, cadmium, chromium, copper, and lead. Major sources of pollution entering the river systems of Laguna de Bay are domestic wastes (the largest source), food processing plant wastes, livestock wastes, chemical manufacturing spillage, various industrial effluents, fertilizers and pesticides from agricultural runoff, and eroded soils from the watersheds (Laguna Lake Basin). In the Gariep Basin, average per capita runoff is 1,096 cubic meters per year, nearly placing it in the ''chronic scarcity'' category (Falkenmark and Widstrand 1992). Ecological reserve requirements—16% of the basin's total annual runoff set aside to ensure proper ecological functioning—are not met in 43% of the Gariep's catchments. Furthermore, as of 1998, 12 million South Africans did not have access to an adequate supply of potable water (King and Louw 1998). One of the problems was that riparian property rights favored owners with water on their land, but there is now a government strategy aimed at more equitable distribution of water (SAfMA Gariep). In Northwestern China, water is a scarce resource. With economic development and population growth in the region, the decreasing allocation of water to the ecological reserve has caused ecosystem deterioration. The continuous expansion of artificial oases and widespread irrigation has not only wasted the limited water resources but has also caused land salinization (Western China).

Figure 8.5 in Appendix A compares the world distribution of population relative to a water scarcity threshold, defined as the ratio of water withdrawal or water use to discharge (MA *Current State and Trends,* Chapter 7), with the qualitative assessments of water provisioning from selected sub-global assessments. Agreement is good overall, with sub-global assessments reporting a poor to bad condition of water provisioning in regions where water demand is above the threshold (KM–SAfMA Gariep, San Pedro de Atacama, KM–India Urban, KM–Western China—for northern parts, and KM–Laguna Lake Basin), and a good to excellent condition in areas where water demand is below the threshold (KM–Bajo Chirripó, Tropical Forest Margins, KM–SAfMA GM, Norway, KM–Western China—for southern parts, and Altai-Sayan). The analysis of the assessments that reported a fair condition of water provisioning was more difficult, because they covered very heterogeneous areas (examples include Portugal and KM–Sinai). At least one clear disagreement occurred with Trinidad's Northern Range; the global assessment suggests that the island is above the water scarcity threshold, but the local assessment identified a trend of decreasing water quality and quantity due to watershed degradation (for example, deforestation), projecting that by 2025 there will be a shortage of water (Northern Range). This led the assessment team to report a fair value for the water provisioning service.

Three sub-global assessments reported serious problems with food provisioning services (Appendix 8.1). In Southern Africa, there has been a downward trend in per capita protein consumption over the last 25 years, and total protein intake averaged over the entire region is 8% below the recommended WHO minimum for adequate nutrition, with some areas such as the Democratic Republic of Congo and Mozambique much below this minimum (SAfMA Regional). Protein hunger contributes to negative impacts on wild mammal and bird populations, through the ''bushmeat'' trade. There is little scope for increased off-take from natural fisheries, half of which are already overfished. However, there is a technical opportunity for greater protein off-take from livestock. The situation for carbohydrate crops is less serious, with the region on the whole producing enough to meet minimum needs even though up to 15% of the population is undernourished due to distribution inequities (SAfMA; Bob Scholes, personal communication). In the Caribbean Sea, fish catches peaked in the mid to late 1990s but have since declined by 30%, probably due to overfishing. (See Figure 8.6 in Appendix A.) The increased harvest in the mid 1990s was due to an increase in the catch of small herring-like fish, while the late 1960s peak was associated with the harvest of piscivorous perch-like fish. This suggests the possibility of a ''fishing down the food web'' pattern (Caribbean Sea). Finally, the Laguna Lake shoreland supplies 14% of the total rice requirement in the Laguna Lake region. However, this production is affected by a multitude of factors, such as the decrease in water level, quality of rice culture, and land conversion. Furthermore, the fisheries of Laguna Lake have been affected by human, industrial, and environmental factors that resulted in significant decline in both production and species diversity.

At the other extreme, some sub-global assessments considered the food provisioning service to be in good condition. For instance, the Tropical Forest Margins assessment focused on the edges of forests, where food production is higher relative to the baseline used in that assessment—food production inside the forest. In Portugal, despite food production in the cultivated systems having grown at a much slower rate than national food demand, this was not considered a critical problem by local experts. Instead, attention was focused on the sustainability of agricultural practices and fish harvesting. Use of fertilizers and pesticides is generally low, when compared with other EU countries, but there is excessive fertilizer use in some places. Other problems include soil erosion and loss of fertile soil to urban sprawl. Oceanic fish stocks have improved over the last decade but coastal fisheries are doing worse, partially because of pollution and eutrophication (Portugal).

About half the sub-global assessments assessed timber and fuelwood provisioning (Appendix 8.1). The only critical case occurred in Tropical Forest Margins-Indonesia, where the assessment team reported a bad condition for the service. In Portugal, two types of wood provisioning were distinguished: timber from plantation forests and cork from the cork-oak woodland (*montado*). Portugal produces more than 50% of the world cork supply. The ecological sustainability of cork production is high, and cork production has been practiced in a way that has helped to protect the southern woodlands over the last several decades. As a consequence, the *montado* is faring well for a range of services. In contrast, some practices of the forest industry, including the planting of eucalyptus in inappropriate soils, and excessive fertilizer use, garnered only a fair score from the Portugal assessment team.

Only a few assessments analyzed the provisioning of biochemical substances (examples include Downstream Mekong and Sinai). The Downstream Mekong assessment compiled an inventory of the species providing different types of substances. The assessment identified 16 plant species providing toxic products, 28 species providing color products, and 21 species providing tannins. In addition, it was found that other biochemicals could be extracted from snake venom, scorpions, and honeybees.

8.3.4 Regulating Services

Regulating services are the benefits obtained from the regulation of ecosystem processes (MA 2003). Regulating services assessed by sub-global assessments included:

- runoff regulation, flood protection and soil protection,
- regulation of water quality,
- regulation of air quality,
- climate regulation (local regulation through albedo, and global regulation through carbon sequestration), and
- disease regulation.

8.3.4.1 Drivers

Drivers affecting the condition of regulating services in the sub-global assessments include:

- climate change,
- land use and topographical changes,
- invasion of alien species,
- loss of important species,
- human population growth,
- government and policy changes, and
- technological developments.

For example, alteration of precipitation induced by climate change has the potential to affect the spatial runoff pattern and the ability of ecosystems to regulate flooding. Land use change can substantially alter ecosystem type and result in tremendous effects on the regulating services of ecosystems (Laguna Lake Basin, Western China, SAfMA Gariep). The Western China assessment reported that the transformation of forest to cultivated land resulted in the upstream portion of China's Yangtze River becoming a fragile ecosystem. This caused an increasingly serious soil erosion problem and decreased the ability of the soil to conserve water during heavy rain events, resulting in more frequent flooding problems in the Yangtze catchment.

Indirect drivers such as policy change and population growth alter anthropogenic pressures on ecosystems and their ability to regulate the environment. Changes in government policies were recognized most widely as important drivers influencing the services (including regulating services) of ecosystems in many sub-global assessments, including Western China, SAfMA, Laguna Lake Basin, India Local, São Paulo, PNG, Downstream Mekong, and Altai-Sayan.

8.3.4.2 Indicators

The Coastal BC assessment did not attempt to determine the condition of regulating and supporting services but instead focused on the ecosystem conditions required for those services. This approach was taken by other sub-global assessments as well; for example, the Caribbean Sea assessment used indicators of biodiversity condition (mangrove extent) as proxies for the condition of regulating services.

A soil erosion map can show where an ecosystem has lost the capacity to conserve its soil layer and where the ecosystem still conserves that capacity. In the São Paulo assessment, areas with exposed soil, high landslide frequency, and high rates of sediment transfer were used as an an indicator of soil stability and runoff regulation. Land use is an important driver affecting the regulating services of an ecosystem, and a map of land cover change can serve as an indicator of changes in the condition of regulating services such as climate regulation (Laguna Lake Basin).

Water quality was assessed by many sub-global assessments. In some cases, water quality was assessed as part of the provisioning service of fresh water; in others, it was evaluated as an indicator of the condition of water quality regulation services. Laguna Lake Basin, SAfMA, Coastal BC, San Pedro de Atacama, Caribbean Sea, Portugal, Sinai, India Urban, and Northern Range all assessed water quality using indicators of levels of pollutants and other physical measures (for example, nitrates, phosphates, heavy metals, pH, calcium carbonate, harmful bacteria). Air quality was also assessed using levels of pollutants (nitrogen and sulfur dioxide, ozone, fine particulates) in Coastal BC and SAfMA Gariep.

In some assessments, the condition of forest ecosystems was used as an indicator of regulating services. Forests (especially those upstream of an important water resource) are an important component of water resource protection. They play an important role in the regulation of runoff, increasing the flow during the dry season and minimizing flooding during the wet season. Forests also prevent soil erosion. The forest canopy intercepts the rainfall thus reducing its kinetic energy and promoting water infiltration in the soil (Portugal). The tree roots protect the soil, minimizing the accumulation of sediments in reservoirs and rivers, therefore improving water quality. (See Box 8.9.) Forests also maintain the air quality by absorbing carbon dioxide, air particles and pollutant gases, and by producing oxygen. However, in some instances, plantation forests of alien species can be a serious threat to regulating services through the alteration of runoff and hydrological regimes (SAfMA Gariep).

8.3.4.3 Condition and Trends

Most sub-global assessments report a fair to poor condition of regulating services in their ecosystems (Appendix 8.1). The exceptions include Coastal BC, where air and water quality are in good condition as would be expected in an area with a low human population density and low levels of industry. In most cases, regulating services are either stable or declining in condition. The Laguna Lake Basin assessment of climate regulation found that the loss of forest has implications for the amount of carbon that can be sequestered; reforestation of these degraded lands has the potential to sequester more than 1,338 kilotons of carbon dioxide per year, which is enough to turn the basin into a net carbon sink (Laguna Lake Basin).

8.3.5 Cultural Services

The MA conceptual framework defines cultural services as the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, and recreation (MA 2003). These benefits include cultural diversity, a sense of place, tourism, educational values, and aesthetic values. As is obvious from this definition, cultural services are complex (see Chapter 11) and perceptions of these services vary across individuals and communities. Recognizing and evaluating the condition of cultural services is relatively new and the MA aimed to explore new ways of evaluating these services and their condition.

The sub-global assessments evaluated a few of the wide range of cultural services. Most assessments—including Caribbean Sea, Laguna Lake Basin, Portugal, Downstream Mekong, SAfMA Regional, and São Paulo—focused on tourism as a cultural service. India Local assessed spiritual services through expert workshops; SAfMA Livelihoods and Sweden KW assessed spiritual and aesthetic services; Sweden SU assessed recreational and educational services. Trinidad assessed a wide variety of cultural services including recreation, eco- and agrotourism, cuisine, and religious and spiritual values. Coastal BC found that in rural societies provisioning and cultural services are often viewed as being identical. Thus the assessment grouped services into economic services (provisioning services that provide direct monetary benefits) and cultural services (provisioning services that provide material and nonmaterial benefits including the provision of food, raw materials for art, and sites of spiritual value).

8.3.5.1 Drivers

Tourism and recreational use (for example, driving on beaches) were identified as drivers of change in the condition of sensitive ecosystems. Tourism is one of the fastest growing industries in the world (WTTC 2004). Nature-based tourism, that is, tourism motivated by a desire to visit places of natural beauty, is a particular area of growth. This form of tourism includes many activities from fishing to lazing on a beach and relies on the presence of attractive biodiversity, unspoiled scenery, and other ecosystem services that provide clean water and air. Most of the sub-global assessments that assessed tourism were in actual fact assessing nature-based tourism. Many claimed to be assessing ecotourism, which is defined as nature-based tourism that is environmentally and culturally sensitive while being sustainable.

Other drivers of change in ecosystem condition—for example, pollution and land cover change—were also identified as drivers of change in the cultural services of ecosystems. The Laguna Lake Basin found that water pollution is affecting the Lake's tourism potential negatively.

8.3.5.2 Indicators

Some cultural services can be directly linked to a harvesting activity such as recreational fishing or hunting (MA 2003).

BOX 8.9

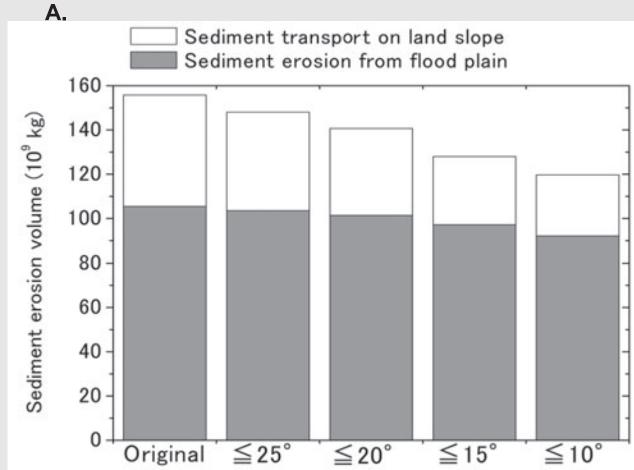
Controlling Floods and Decreasing Sediment: Western China

The Western China assessment studied the effect of land use change on sediment loads in the Jialingjiang River catchment (160,000 square kilometers), which is a tributary of the Changjiang (Yangtze) River, using a hydrologic model (Hayashi et al. 2004). The validation of the model was based on the observed daily flow rates and sediment loads of 1987. The effect of converting farmland to forest in steep slopes was examined with scenarios. Afforestation is one of the main policies of the Chinese government for flood protection, and aims to mitigate the flood peak and decrease sediment loads.

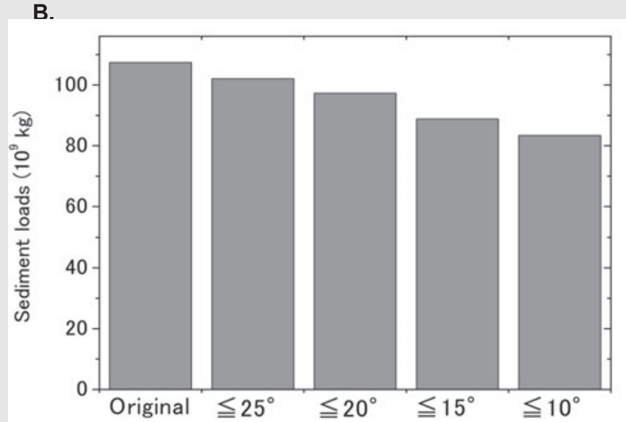
Afforestation in areas in four grade classes were considered: >25°, >20°, >15°, and >10°. Farmlands with a slope value greater than 25°, 20°, 15°, and 10° cover 0.6%, 1.5%, 3.2%, and 6.3% of the Jialingjiang catchment, respectively. Also, these corresponded to 1.6%, 3.8%, 8.2%, and 16% of the total area of farmlands in the catchment, respectively. No differences were found for runoff between the different slope classes. However, volume of sediment erosion decreased with afforestation, particularly for the scenarios where more area was afforested, showing afforestation to be effective for the protection of sediment production. The simulated annual total sediment loads from the whole catchment decreased up to 22% in the scenario with largest afforestation (slopes > 10°).

Figure A shows annual total sediment erosion volume including sediment transport on land slope and sediment erosion from floodplain, for the different scenarios. Figure B shows annual total sediment loads from the whole Jialingjiang River catchment for the different scenarios.

A.



B.



Other cultural services can be linked to particular ecosystem features that are of cultural, aesthetic, or spiritual value (for example sacred pools). (See Box 8.10.) These features can then be assessed and trends in their condition used to infer condition of the cultural services. However, many cultural services do not link to particular features or provisioning services and thus require new techniques for their assessment.

The large number of sub-global assessments investigating tourism is perhaps understandable as it is one of the easier cultural services to quantify. In fact, some sub-global assessments assessed the economic value of nature-based tourism (for example, SAfMA Regional). (See Table 8.4.) Other assessments analyzed visitor numbers (Colombia) or ecotourism potential (Laguna Lake Basin, Downstream Mekong). These indicators were used to assess the condition of tourism as a cultural service of the ecosystems in question. Sub-global assessments also viewed tourism as a tool for development and an important source of economic growth, with stakeholders often requesting its inclusion in the sub-global assessments.

Although tourism was assessed across sub-global assessments at most spatial scales, spiritual, religious, recreational, and educational services tended to be assessed only in small local-scale studies (for example, India local and SAfMA Livelihoods)—perhaps because the data required for these assessments are not available at coarse scales. In conducting such fine-scale analysis, local assessments relied on community workshops to garner information.

In general, except for tourism, the assessment of cultural services relied on descriptive information rather than quantitative data, generated mostly through participatory approaches. These assessments sometimes only provided a description of the service and not necessarily an assessment of the condition of the service.

8.3.5.3 Condition and Trends

It would appear from the sub-global assessments that tourism and recreation are in a fair to good condition with improving trends (Appendix 8.1), with no sub-global assessment reporting a poor condition. Yet within these findings, there is considerable heterogeneity. For example, SAfMA Regional found that tourism is high and growing in some regions but low in others. In its attempts to explain the large amount of variation in the condition of tourism in southern Africa, SAfMA Regional paid a lot of attention to the condition of nature-based tourism. The factors responsible for the importance of tourism include the quality and extent of natural assets, ease of access to these assets, and perceptions

BOX 8.10

The Cultural Importance of Ecosystem Services: SAfMA Gariep

In the Great Fish River area, local Xhosa people of the Eastern Cape, South Africa, place great cultural and utilitarian value on key resource patches such as mountains, forests in various stages of succession, and a variety of grazing lands. In many cases, the diversity of resource patches is the consequence of people interacting with the land, where these patches are created through a variety of induced disturbances. The different types of resource patches provide different kinds of resources, thus satisfying the villagers' basic needs. These include both practical, physical needs and cultural and spiritual needs.

Rituals and traditions are central to the culture and identity of the Xhosa people. Key resource areas are fundamental to the performance of these rituals and include sacred pools, dense forests, and mountains. Each of these sites has particular rituals associated with them, with specific benefits. The most important of these sites are sacred pools. In the assessment area, these are typically places of still deep water, with water flowing above and below; they often have steep banks and are surrounded by particular species of trees and plants such as *Salix capensis,* which is regarded as the tree of the "river people," *Cyperus textilus,* and a variety of small plants and creepers such as *Tecomaria capensis.* The plants indicate the presence of the ancestors and the river people: mermaid-like creatures associated with the generation of water, rain, healing, and fertility of the land.

The sacred pools provide people a place of direct communication with the spirit world where they can access blessing and health and also give thanks and veneration through the performance of particular traditions. The sites are critical points in the landscape where culture in the form of traditions and connection with the ancestors is maintained.

Sacred pools also have a practical benefit, in that they are important water sources during times of severe drought. The reason they do not dry up is related to the many taboos associated with sacred pools where, for example, one is not allowed to harvest medicinal and other useful plants unless one is a diviner or *igqirha.* The vegetation surrounding sacred pools is therefore denser and provides a protective canopy, thus reducing the effect of evaporation.

Table 8.4. Nature Tourism Numbers and Revenue: SAfMA Regional, 2000

	Nature Tourism Arrivals (thousands)			Income from Nature Tourism ($ millions)			
	Non-African	African	Domestic	Non-African	African	Domestic	Total
Angola	0.8	0.1	..	0.3	0.0	..	0.3
Botswana	110.4	362.5	..	30.6	100.6	..	131.3
Burundi	0.0	0.0	..	0.0	0.0	..	0.0
Congo	0.0	0.0	..	0.0	0.0	..	0.0
Dem. Rep. Congo	0.0	0.0	..	0.0	0.0	..	0.0
Equatorial Guinea	0.0	0.0	..	0.0	0.0	..	0.0
Gabon	28.0	0.0	..	1.3	0.0	..	1.3
Kenya	552.8	201.6	0.2	178.2	65.0	7.5	250.7
Lesotho	5.4	48.4	..	0.6	4.9	..	5.5
Malawi	18.4	91.0	..	2.2	10.8	..	13.0
Mozambique	6.0	36.0	..	1.2	7.2	..	8.4
Namibia	96.6	263.4	..	45.3	202.3	..	247.6
Rwanda	1.7	0.0	..	2.7	0.0	..	2.7
South Africa	1,203.3	3,425.6	5.6	504.4	1,436.0	358.4	2,298.8
Swaziland	77.3	166.6	..	15.9	11.0	..	27.0
Tanzania	203.7	0.0	..	299.9	0.0	..	299.9
Uganda	28.0	92.8	..	27.6	91.6	..	119.2
Zambia	137.6	321.6	..	21.85	1.0	..	72.8
Zimbabwe	358.4	1,136.0	..	34.4	109.1	..	143.5
TOTAL	**2,828.4**	**6,145.6**		**1,166.4**	**2,089.5**		**3,622.0**

by visitors of risks to personal safety and health. Natural assets can refer to a particular site or a landscape as a whole. SAfMA Regional evaluated the relationship between biodiversity and tourism, but found the relationship to be indirect and often not immediate. For the majority of visitors, a few particular elements of biodiversity (for example, the "Big Five": lion, elephant, rhinoceros, buffalo, and leopard) are the attraction. Other tourists are more interested in the variety of life itself (for example, botanists and birdwatchers). Whatever the attraction, tourists appear to distinguish natural and artificial experiences (resource reserve versus zoo) and prefer the former, which explains the attraction of many sites in southern Africa. SAfMA Regional assessed the limits to nature-based tourism and suggests that the carrying capacity of wilderness areas for this service is roughly one visitor per square kilometer.

Although most sub-global assessments found tourism to be in good and improving condition, some found declines. Portugal, for example, reported a declining trend in the condition of recreation in cultivated and coastal systems. This was caused not by a decrease in the demand for recreation services, but instead by a decrease in the capacity of those ecosystems to support recreation. The coast in Portugal is showing some signs of saturation, and the cultivated system is becoming either intensively farmed or abandoned, which is less attractive for tourism than traditional agriculture systems. The San Pedro de Atacama assessment reported a decline in mass tourism counterbalanced by increasing special-interest tourism. Some sub-global assessments expressed concerns that tourist activities are causing declines in the capacity of ecosystems to provide this cultural service (SAfMA Regional, Caribbean Sea).

In general, the improvement in the condition of tourism and recreational services, measured mostly through tourist numbers, economic value, or qualitative potential, seems to indicate positive future trends for these services, if managed appropriately. This is not surprising, considering that the demand for these services is increasing. SAfMA Regional found that tourists in the study area enjoy significant "consumer surplus," with tourists willing to pay more than they actually do. This has led to growth in privately owned conservation land, private concessions on state-owned land, and a two-tiered payment system.

Assessment of non-recreational cultural services such as religious and spiritual services produced different results; assessment reports on the condition of these services are descriptive and generally indicate a fair but declining condition. India Local highlights the impacts of overuse of some sites; India Urban reports a decline based on loss of wilderness areas and declines in cultural value of sites; and Downstream Mekong reports decreases in condition due to a loss of inspirational values. In a similar vein, SAfMA Livelihoods blames land use pressures that have threatened sites of cultural importance and that—together with increasing urban contact, modernization, and influences of other cultures—have made inroads into cultural beliefs and norms. According to the older generation, a decline in cultural identity and respect from youths explains the deterioration of the landscape due to the anger and disappointment of the ancestors. This links well with the findings of the MA's global assessment of cultural services, which identified the following causes of the decline in traditional value systems: rapid urbanization, the break down of traditional families in rural areas leading to the increase in nuclear families, economic development–related market forces, replacement of traditional institutions with modern ones, and resulting inter-institutional conflicts. The global assessment also found that these forces are countered by changing global attitudes toward recognizing the links between natural and cultural heritage values.

In the past in Costa Rica, spiritual values and beliefs associated with local ecosystems protected ecosystem services (Bajo Chirripó). The indigenous people of the Cabécar territory believed in the existence of spiritual entities, guardians of the ecosystems that controlled natural resources. Access to sacred woods was limited, which maintained biological diversity. Unfortunately, these spiritual values have been eroded, and part of the assessment effort has been directed at finding mechanisms to rebuild these values. The Quechua people of the Peruvian Andes believe in mountains as living beings, owners of the vital energy that controls all the animals and plants (Vilcanota). The well-being of the community depends on harmony in the relationship between local people and elements of the landscape. In both the Cabécar and the Quechua communities, the existence of these spiritual values is the basis for the conservation of other services such as those provided by biodiversity and water cycle and climatic regulation. With current globalization trends, change of habits, values, and beliefs can become important drivers affecting cultural services.

Educational services were assessed by Sweden SU, São Paulo, and Portugal. These sub-global assessments reported an increase in educational activities associated with social-ecological systems, due to increasing levels of awareness of the value and benefits of, and thus demand for, environmental education.

Thus it appears that the cultural services of tourism and recreation are in good condition and increasing, while local-scale services of a spiritual nature are more variable. Spiritual services vary from place to place and may undergo cycles of collapse and revival, depending on policies, interventions, and context-specific factors such as changes in leadership, making it difficult to identify trends. Spiritual values act as strong incentives for ecosystem conservation in many communities, as found in Vilcanota, Bajo Chirripó, India Local, and SAfMA. (See also Chapter 11.)

These conclusions must, however, be tempered with some degree of caution. The suite of cultural services assessed in the sub-global assessments is limited, with a major focus on tourism and some spiritual services. The definitions of cultural services and the sub-categories of these services are vague; furthermore these services are interrelated (for example, tourism services rely on aesthetic services). In addition to the uncertainty associated with the definition of various cultural services, there was a lack of appropriate data, indicators, and tools with which to assess them. Despite these limitations, the sub-global assessments provide a first picture of the importance and condition of cultural services across cultures, ecosystems, and continents.

8.4 Linkages and Trade-offs among Ecosystem Services

Ecosystem services are interdependent (Heal et al. 2001), that is, increasing the production of a service such as timber production may decrease that of another service such as carbon sequestration. In other instances, it is possible to increase the production of two ecosystem services simultaneously. This section focuses on some of the linkages among ecosystem services found by the sub-global assessments. It then presents frameworks developed and used by the sub-global assessments to communicate these linkages and trade-offs to decision-makers.

8.4.1 Examples from the Sub-global Assessments

One of the most complex examples of linkages among ecosystem services comes from the Laguna Lake Basin assessment. The establishment of fishpens and fishcages in the lake has had both positive and negative impacts on the fish provisioning service, and negative impacts on water quality and biodiversity. Pen and cage culture have contributed significantly to fish production in the lake. Net enclosures also provide indirect stocking for some open water fisheries (for example, the Manila catfish, *Arius manillensis*); but they also led to the invasion of alien species, with negative impacts on the fisheries and biodiversity, including on two native catfish species (*Clarias batrachus* and *Hypostomus plecostomus*). Species diversity has declined significantly: of the 33 species (both native and alien) reported to have thrived in Laguna Lake at different times, only 5 out of the 14 native species have remained. Of these 14 native species, all 5 migratory species have disappeared and the catch at present is dominated by the alien species introduced for aquaculture. Aquaculture has also had a negative impact on the water quality of the lake, through the loading of nutrients in the form of unassimilated food and metabolic wastes, which add to the significant influx of nitrogen and phosphorus from agricultural activities (and domestic wastes). The high levels of phosphate and nitrogen trigger the occurrence of algal blooms that either kill or impart an off-flavor taste to fish (Laguna Lake Basin).

Many sub-global assessments reported declines in some ecosystem services that were related to the increase or utilization of other ecosystem services. In Southern Sinai, intensive agriculture has increased food security and income (through increased employment), but has also had some negative impacts on regulating services. Irrigation with the use of saline groundwater has resulted in the salinization of soils and decreases in productivity.

The Papua New Guinea assessment reported unsustainable use of mangroves for building materials and fuel, which resulted in loss of regulating (shore protection), supporting (nurseries), and provisioning (invertebrate fisheries) services. Oil palm and cocoa plantations also present substantial trade-offs between provisioning and supporting/regulating services. These crops have some negative impacts on soil fertility, soil structure, and pest and disease regulation (Hairiah et al. in press); but more importantly, certain smallholder schemes (for example, lease-back schemes used for oil palm) can result in negative impacts on human well-being (Koczberski et al. 2001). Oil palm plantations have also been the locus of introduction of exotic weed species (Casson 2003).

The trade-offs among ecosystem services, particularly between provisioning and regulating services, are often viewed from a field or plot-scale perspective, with the general conclusion being that when an area is harvested for food, fuel, or fiber, other services are lost. In fact, the utility of many ecosystem services, particularly the regulating services, often emerges at a landscape scale. As such, while specific parts of the landscape may provide food or fuel, other ecosystem services, such as water provision, pollination, and pest control, are provided more diffusely. The questions then become: what features of the landscape are needed to maintain those regulating services (for example, biologically-diverse communities, water infiltration), what proportion of the landscape must contain those features, and how should they be distributed across the landscape? Such questions pertain to the conversion of natural systems but also to the design of intensively-managed landscapes. These types of questions are relevant to integrated pest management (Landis et al. 2000; Thies et al. 2003), pollination ecology, and placement of buffer strips for soil erosion control and water quality, among others. The optimum configuration of the landscape so that all ecosystem services are maintained will not necessarily be the same as the configuration that would maximize individual ecosystem services, but often "sufficient congruence" may be achievable.

8.4.2 Frameworks and Decision-making Tools to Analyze Trade-offs

The use of ecosystem services often involves diverse actors with different values and competing objectives. The need to make choices among various ecosystem services, between specific ecosystem services and biodiversity, or between ecosystems services and human well-being is an inherent part of the decisions that ecosystem users and managers face. Trade-offs among ecosystem services may also occur temporally, through decisions about whether to reap benefits now or reserve them for future generations, or spatially, through use of an ecosystem service in a location affecting the condition of services in another location.

For example, the forests of the Western Ghats have historically been used intensively to meet local community needs, as well as for felling by the state forest department to meet regional needs for timber (Samraj et al. 1988). This resulted in a complex mosaic of relatively undisturbed forest, savanna, grassland, and barren patches, interspersed with monoculture plantations established by the forest department. Virtually all the major rivers in southern India originate in the Western Ghats. The changes in land use and land cover in the upstream catchments of these rivers are of critical importance to the millions of farmers on the eastern portion of the Deccan plateau, especially because of their increasing reliance on irrigation for the dependable production of food from high-yielding varieties. However, the watershed services of forests and associated ecosystems (such as grasslands) are poorly understood. Not all forests have similar influence on all watershed services. Nor do all non-forest land uses necessarily degrade these services. Because the non-wood services generate mostly indirect economic benefit, their value to society, and the distribution of this value, has not been properly quantified. Finally, there is no institutional mechanism by which the information on physical or socioeconomic impacts of land use change on watershed services can be fed systematically into decision-making. Typically, stakeholders are not informed about the science and policy of watershed management or afforestation. Thus, for example, eucalyptus trees were extensively planted on natural montane grasslands. This supports the requirements of industry for paper pulp and tannin, but reduces water yield from catchments by up to 23%, thereby affecting downstream hydropower projects. A lack of communication between foresters and scientists has allowed this trade-off, with a net adverse impact, to prevail.

The example above, while not coming directly from a sub-global assessment, illustrates that, faced with potential conflicts among objectives and users of ecosystem services, policy-makers need accurate, objective information to assist in their decision-making process. The information needs to be presented in a way that allows them to weigh the implications and likely consequences of choosing among various options. Simply stating that fertilization or irrigation of agricultural fields pollutes rivers or compromises the longer-term sustainability of the soils and water supply is insufficient. There must be some means of assessing the magnitude or severity of the impacts or trade-offs of potential decisions.

Within the MA sub-global assessments, a range of techniques were used or developed to evaluate trade-offs in a transparent and informed manner. The methods used in the evaluation of tradeoffs in SAfMA Gariep and in the Tropical Forest Margins assessment are discussed here.

8.4.2.1 SAfMA Gariep: Two Approaches to Evaluating Trade-offs

Trade-offs in the southern African context typically involve the need to achieve social and economic development goals while securing ecosystem functions. In the Gariep basin, the challenge of evaluating trade-offs is intensified by the need to reverse past discrimination in South Africa that prevented the majority of the population from fully realizing or gaining access to the benefits provided by ecosystem services.

Several approaches were used to assess trade-offs among various aspects of the core ecosystem services assessed in SAfMA Gariep—water, food, and biodiversity. Two of these approaches and their results are discussed here.

8.4.2.1.1 Trade-offs between land use and biodiversity

Food production and biodiversity conservation have clashed in southern Africa, where the need to feed a growing and largely impoverished, undernourished population has more often than not been seen as more urgent than the need to conserve biodiversity. SAfMA Gariep used the notion of irreplaceability to assign comparable values to areas of land, based on specified targets of achieving food production and biodiversity conservation goals. Irreplaceability can be thought of as uniqueness: it is the likelihood that the site will be required as part of a network needed to achieve targets and the extent to which the options for achieving the set of targets are reduced if the site is unavailable (Pressey 1994). Several advantages of this approach make it an effective tool for communicating with decision-makers: it is flexible (targets can be set according to specific objectives), dynamic (targets can be updated as decisions are made), visual, and transparent.

SAfMA Gariep applied the irreplaceability concept to food services and biodiversity features. Food production was divided into two components: calorie production from cereal crops and protein from meat. Irreplaceability maps were generated for the Gariep basin based on targets for proteins, calories, and biodiversity. Irreplaceability values ranged from 0 (many options in other locations to achieve the goals) to 1 (totally irreplaceable, the goals for services would not be met if this location was not included). The trade-offs assessment then investigated those sites (represented as mapped grid cells) where there was more than one competing service or where there was conflict between conservation goals and one or more ecosystem services. No site was found to be totally irreplaceable for protein or caloric production, but several sites were totally irreplaceable for biodiversity. A land use plan would therefore optimize for conservation of the irreplaceable sites for biodiversity conservation, and allow grazing or cultivation on sites with low biodiversity irreplaceability. A potential trade-off situation exists at one site in the southeastern part of the Gariep basin, where biodiversity is totally irreplaceable and protein and caloric production are very highly irreplaceable.

8.4.2.1.2 Trade-offs between water and food production

As a consequence of new legislation, efforts to increase the productivity of agricultural water use in the Gariep basin by both commercial farmers and smallholders must aim to improve not only the economic efficiency of irrigation but also equity in water availability. The Podium model, a decision-support tool for policy dialogue, was developed by the International Water Management Institute to assess policy options related to national-level cereal-based food security and water availability in South Africa. The model provides an analytical framework for assessing water and food demand in 2025 resulting from population growth and changing diets. It focuses on four uncertainties: (1) population growth; (2) options for meeting food security through increases in irrigated area; (3) options for meeting food security through increases in the efficiency of irrigation water use or through yield improvements; and (4) the impact of increasing the daily water allocation per capita for basic human needs. The Kamara and Sally (2002) model applied to South Africa reveals that:

- Population growth above that projected under the United Nation's medium-growth estimate for 2025 (resulting in a population of approximately 48 million) will lead to threatened food security if water utilization, irrigation efficiencies, and crop yields remain stable.
- An increase of 40% in irrigated land area (equivalent to about 1.8 million hectares of total irrigated land area would be needed to achieve surplus food production if current yield levels and the trade balance remain unchanged. This would require an increase in total diversions of water, which would require huge financial investments that might not be easily realized.
- An increase in irrigation water use efficiency from 55% to 60% would reduce the degree of development of water resources by 4% and total diversions of water by 9%.

In summary, expanding irrigated area in isolation of other interventions is not likely to significantly improve food security. On the other hand, modest increases in irrigated area and improvements in efficiency are feasible and do not imply the need to allocate large amounts of water to the agricultural sector. This analysis, which focused only on cereal production at the national level (though most cereal production occurs within the Gariep basin), may obscure key trends that would emerge in studies of other crops or specific catchments.

8.4.2.2 The ASB Matrix

Land and resources at the tropical forest margins are used by several sets of users. Forest dwellers, following their traditional ways of life based on hunting and gathering, are losing their land to migrant smallholders. These smallholders clear small amounts of forest for crops and livestock, and are concerned with food security, property rights, and the profitability of their farms. Both forest dwellers and smallholders tend to lose out to more powerful groups—ranchers, plantation owners, large-scale farmers, and logging companies—who are engaged in large-scale commercial exploitation of forests. This exploitation is driven by international consumer demand for wood and for other products from land which has been cleared of forest. Outside the forests, there is also an international community that wishes to see forests preserved as sinks for carbon, which would otherwise contribute to climate change, and for the biological diversity they harbor.

Deforestation continues because converting forests to other uses is almost always profitable for the individual. However, society as a whole bears the costs of lost biodiversity, climate change, smoke pollution, and degraded water resources. Every year, the world loses about 12 million hectares of tropical forest (FAO 2001). No land use system replacing this natural forest can match it in terms of biodiversity richness and carbon storage. However, land use systems vary greatly in the degree to which they combine at least some environmental benefits with their contributions to economic growth and livelihoods of the poor. It is, therefore, always worth asking what will replace forest (and for how long), both under the current mix of policies, institutions, and technologies and compared to possible alternatives. In other words, what can be done to secure the best balance among the conflicting interests of different groups?

Researchers of the Alternatives to Slash-and-Burn consortium (the Tropical Forest Margins assessment is a program component of the ASB consortium) developed a framework known as the ASB matrix to help evaluate the local, national, and global impacts of alternative land use systems practiced at the tropical forest margins and to guide policy decisions (Tomich et al. 1998; Tropical Forest Margins). In the ASB matrix, natural forest and the land use systems that replace it are scored against various criteria reflecting the objectives of different interest groups. To enable results to be compared across sites, the land use systems specific to each site were grouped according to broad categories, ranging from agroforests to grasslands and pastures. The criteria for evaluating the ecosystem services may be fine-tuned for specific locations, but the matrix always comprises indicators for the following:

- two major global environmental concerns on regulating services of ecosystems—carbon storage and biodiversity;
- agronomic sustainability, assessed according to a range of soil ecosystem services, including trends in nutrient cycling and organic matter over time;
- smallholders' livelihood concerns, including their workload, returns on their labor, food security for their family, and start-up costs of new systems or techniques;
- policy objectives, including economic growth and employment opportunities; and
- policy and institutional barriers to adoption by smallholders, including the availability of credit, markets, and improved technology.

Over the past eight years, ASB researchers have calculated this matrix for representative benchmark sites across the humid tropics. The social, political, and economic factors at work at these sites vary greatly, as do their current resource endowments: from the densely populated lowlands of the Indonesian island of Sumatra, through a region of varying population density and access to markets south of Yaoundé in Cameroon, to the remote forests of Acre State in the far west of the Brazilian Amazon, where settlement by small-scale farmers is relatively recent and forest is still plentiful. At each site, ASB researchers evaluated land use systems both as they are currently practiced and in the alternative forms that could be possible through policy, institutional, and technological innovations.

The matrix allowed researchers, policy-makers, environmentalists, and others to identify and discuss trade-offs among the various objectives of different interest groups. The studies in Indonesia and Cameroon revealed the feasibility of a "middle path" of development involving smallholder agroforestry and community forest management for timber and other products. Such a path could deliver an attractive balance between environmental benefits and equitable economic growth. "Could" is the operative word, however, since whether or not this balance is struck in practice will depend on the ability of these countries to deliver the necessary policy and institutional innovations.

Take the examples of Sumatran rubber agroforestry plots (Table 8.5) and their cocoa and fruit counterparts in Cameroon. These systems offer levels of biodiversity which, though not as high as those found in natural forest, are nevertheless far higher than those in monocrop tree plantations or annual cropping systems. Like any tree-based system, these systems also offer substantial levels of carbon storage. Technological innovations have the potential to increase yields of the key commodities in these systems, thereby raising farmers' incomes substantially, to levels that either outperform or at least compete well with virtually all other systems. (It is also interesting to note that several tree-based systems in Cameroon have similar levels of carbon storage but drastically different profitability and hence attractiveness to farmers.)

The Brazilian Amazon, in contrast, presents much starker trade-offs between global environmental benefits and the returns on smallholders' labor. Here the most commonly practiced pasture-livestock system, which occupies the vast majority of converted forest area, is profitable for smallholders but entails huge carbon emissions and biodiversity loss. Systems that are preferable from an environmental point of view, such as coffee combined with *bandarra* (a fast-growing timber tree), can pay better, but have prohibitively high start-up costs and labor requirements and are riskier for farmers. An alternative pasture-livestock system, in which farmers are expressing interest, offers even higher returns on land and labor but only slightly improves biodiversity and carbon storage. In other words, the land use alternatives that are attractive privately are at odds with global environmental interests. Only a radical overhaul of the incentives facing land users—including smallholders—could change things.

Table 8.5. ASB Summary Matrix for the Indonesian Benchmark Sites (Tropical Forest Margins). "nm" indicates not measured; "n.a." indicates not applicable. For *agronomic sustainability*: 0 indicates no difficulty, −0.5 indicates some difficulty, −1 indicates major difficulty. *Returns to labor and land* are output prices based on ten-year (1988–1997) averages, expressed in real US$ in 1997 (US$ = Rp 2400 in 1997), discounted at 20% per annum. For *household food security,* "consumption" and "$" reflect, respectively, whether the technology generates food for own-consumption or income that can be used to buy food, or both. Note (a): social prices rather than private prices; "social prices" means adjusted for factor market and trade policy distortions; however, values have not been adjusted for environmental externalities or public goods.

	Global Environmental Concerns		Agronomic Sustainability			National Policymaker Concerns		Smallholders Concerns/ Adoptability by Smallholders	
	Carbon storage	Biodiversity	Plot-level Production Sustainability			Returns to Land	Labor Requirements	Returns to Labor	Household Food Security
Land Use Systems	Aboveground tC/ha (time-averaged)	Aboveground plants (# species per standard plot)	Soil structure	Nutrient Export	Crop Protection	$/ha (private prices)	Labor person-days/ha/yr	$/ person-day (private prices)	Means of household access to food
Forest	306	120	0	0	0	0	0	0	n.a.
Community-based forest management	120	100	0	0	0	5	0.2 to 0.4	4.77	$ + consumption
Commercial logging	94	90	−0.5	0	0	1,080 (a)	31	0.78	$
Rubber agroforest	79	90	0	0	−0.5	0.70	111	1.67	$
Rubber agroforest with clonal planting material	66	60	−0.5	−0.5	−0.5	878	150	2.25	$
Oil palm	62	25	0	−0.5	0	114	108	4.74	$
Upland rice/bush fallow	37	45	0	−0.5	−0.5	−62	15 to 25	1.47	consumption
Continuous cassava/ imperata	2	15	−0.5	−1.0	−0.5	60	98 to 104	1.78	$ + consumption

8.5 Synthesis

Three main approaches to assessing the condition of ecosystem services emerged from the work of the sub-global assessments. The first, more classical approach was to report the values for a set of indicators and the typical or baseline values for those parameters. Comparisons among assessments can be made when the same set of indicators is used and when there is agreement on the baseline values. A second approach was to classify the condition of ecosystem services on a qualitative scale; it is similar to the first approach, but can also use other types of data and resort to expert opinion. Comparison among assessments is possible when the qualitative categories have been defined similarly in the different assessments. A third approach was to compare the supply of and the demand for ecosystem services. This approach is limited to services that involve some type of commodity (for example, water provisioning, food production, recreation) and is more useful at coarse scales. At fine scales, ecosystem services consumed in a given area are often produced somewhere else, and further analysis such as the ecological footprint (Wackernagel et al. 2002) becomes necessary.

While some data exist on the production of some provisioning services and cultural services, data are generally lacking on the natural capacity of ecosystems to continue to provide those services, as well as regulating and supporting services. There is an urgent need for long-term studies monitoring a common set of indicators of the condition of ecosystem services. In the case of biodiversity, although most of the sub-global assessments assessed biodiversity, historical data were insufficient to perform a quantitative analysis of trends.

The different approaches used to assess the condition of ecosystem services also reflected different interpretations of what is meant by the condition of an ecosystem service. Some assessments assessed the ecological capacity of the system to provide the service (for example, Portugal) while other assessments emphasized the production of and demand for the service (for example, SAfMA) and equity of access to the service (for example, Sinai). These differences in emphasis were partially correlated with the socioeconomic development of the areas being assessed: issues of equity and production versus demand for a service were not the main focus of the assessments in industrial countries (Portugal, Norway, Sweden).

The contrast between the emphases on ecological capacity and production/consumption occurred only in marketed services such as provisioning and cultural services, and can be illustrated with the cultural service of recreation.

Several sub-global assessments reported a positive trend for the recreation service because numbers of tourists are increasing (the production and the consumption of the service are increasing). However, in Portugal, despite increases in the number of tourists in the coastal areas over the last few decades, there has been a degradation of those areas caused by the development of tourism infrastructure; therefore, the ecological capacity of that system to attract and support tourism has decreased. So reporting a positive trend for a service can have different meanings across different sub-global assessments.

Assessing trends in the condition of a service can be simpler than evaluating the current condition of the service. Evaluating the condition of a service (for example, on a qualitative scale from bad to excellent) requires a baseline for comparison. Baselines used by sub-global assessments included the distant past (for example, 100 years in the Norway assessment, pre-industrial times in SAfMA) and a concept (for example, current level of the capacity of the ecosystem to provide the service relative to the level at which the service could be maximized in a sustainable way in Portugal). In contrast, a trend only requires any two data points in time (for example, two successive decades).

Choosing appropriate units for assessment is key both for each assessment and for comparison across assessments. The MA conceptual framework (MA 2003, p. 54–55) proposed ten global reporting categories (Marine, Coastal, Inland Water, Forest, Dryland, Island, Mountain, Polar, Cultivated, and Urban) that were also used as the basic reporting categories in some sub-global assessments (Portugal, Norway). These global reporting categories overlapped partially, and most consisted of a range of ecosystems that shared a suite of biological, climatic, and social factors. Other assessments chose other reporting categories tailored to their region. For instance, the Altai-Sayan assessment studied the forests of the Altai republic and the grazing ecosystems of Western Mongolia, while the Colombia assessment studied the coffee-growing region of Colombia.

The advantages of the assessment-specific reporting categories are that they encompass homogeneous social-ecological regions at a given scale, that provide a bundle of ecosystem services to the population, in contrast with global categories such as forests, that can span very different social-ecological systems. Furthermore, tailoring the reporting categories to each assessment can facilitate the use of data previously collected by local or national authorities. However, if the focus of the assessments is on comparability across locations and spatial scales, standard reporting categories should be adopted. The Portugal assessment solved this problem by using the global reporting categories, but redefining the units where needed to make them compatible with national inventories, and in one instance creating a new category for a social-ecological system of national importance (the *montado*).

The sub-global assessments highlighted that several ecosystem services are in fair to poor condition and declining (Appendix 8.1). Despite some gains in the production of provisioning services, the ecological capacity of the systems to continue to provide these services is at risk in several locations. Problems with provisioning services include deterioration of water quality, deterioration of agricultural soils, and incapacity of supply to meet demand. Problems with regulating services include loss of forest cover and fire frequency. Problems with cultural services include loss of cultural identity and negative impacts from tourism. Problems with biodiversity include loss of area of native habitats and decreasing population sizes, particularly of species that have large body mass or occupy high trophic levels and species that are harvested by humans. A meta-analysis of water provisioning and biodiversity illustrates congruence of results between global and sub-global assessments.

Land use change is the most important driver of change for provisioning, supporting, and regulating services and for biodiversity. Indirect drivers are particularly important for provisioning and cultural services because they control the patterns of demand for those services. Some direct drivers of ecosystem change were also indicators of the condition of the service (for example, harvest pressure for biodiversity). While human controlled drivers play a major role in the condition of ecosystem services, local biophysical constraints such as climate and soils also limit the production of ecosystem services.

Clear trade-offs exist among ecosystem services. The analyses performed by the sub-global assessments, in agreement with global results, generally showed an increase in provisioning services at the expense of regulating services, supporting services, and biodiversity, or at the expense of the capacity of the ecosystems to provide services to future generations. Trade-offs can also occur between provisioning services such as irrigated agriculture and freshwater provisioning. New approaches such as the ASB matrix were developed to communicate and discuss these trade-offs with policy-makers.

Links between human well-being and ecosystem services can be difficult to uncover due to the lack of markets for some services, as well as the spatial disconnect between the supply and the consumption of ecosystem services. (See Chapter 3.) Nevertheless, the sub-global assessments improved understanding of how human well-being depends on ecosystems in several ways. First, the sub-global assessments produced inventories of the bundle of services that ecosystems provide in different parts of the world, such as the different types of food produced, the different uses for water, the variety of cultural services, etc. Second, by emphasizing the sustainability of the service and the classification of the condition of ecosystem services, the sub-global assessments uncovered trade-offs among different services. Third, in some instances, economic values of ecosystem services were estimated, providing valuable data at scales relevant for decision-making. Fourth, in the community assessments where participatory approaches were used, much was learned from the local communities about the connection between ecosystems and human well-being. (See Chapter 11.) Finally, the work of the sub-global assessments increased the prospects of furthering understanding of how human well-being depends on ecosystem services by building local capacity for this type of analysis, and highlighting the need for monitoring the condition of ecosystem services at the local, regional, and global levels.

References

Bingham, G., R. Bishop, M. Brody, D. Bromley, E. Clark, et al. 1995: Issues in ecosystem valuation: Improving information for decision making. *Ecological Economics,* **14,** 73–90.

Bossel, H., 1999: *Indicators for Sustainable Development: Theory, Method, Application.* International Institute for Sustainable Development, Winnipeg, 124 pp.

Boumans, R.M.J., R. Costanza, J. Farley, M.A. Wilson, J. Rotmans, et al. 2002: Modeling the dynamics of the Integrated Earth System and the value of global ecosystem services using the GUMBO model. *Ecological Economics,* **41,** 529–560.

Brown, J.H. and M.V. Lomolino, 1998: *Biogeography.* 2nd ed. Sinauer Associates, Sunderland, MA, 691 pp.

Bruner, A.G., R.E. Gullison, R.E. Rice, and G.A.B. da Fonseca, 2001: Effectiveness of parks in protecting tropical biodiversity. *Science,* **291,** 125–128.

Burrough, P., 1994: Principles of geographical information systems for land resources assessment. Oxford Science Publications, New York, 147–166.

Carpenter, S.R., N.F. Caraco, D.L. Correll, R.W. Howarth, A.N. Sharpley, V.B. Smith, 1998: Non-point pollution of surface waters with phosphorus and nitrogen. *Ecological Applications,* **8,** 559–568.

Casson, A., 2003: *Oil Palm, Soy Beans and Critical Habitat Loss: A Report Prepared for the WWF Forest Conversion Initiative.* Available at www.wwf.ch/images/progneut/upload/oilpalmsoybeanscriticalhabitatloss25August03.pdf.

Ceballo, G. and P.R. Ehrlich, 2002: Mammal population losses and the extinction crisis. *Science,* **296,** 904–907.

Costanza, R., R. d'Arge, R. deGroot, S. Farber, M. Grasso, et al. 1997: The value of the world's ecosystem services and natural capital. *Nature,* **387,** 253–260.

Daily, G., 1997: What are ecosystem services? In: *Nature's Services: Societal Dependence on Natural Ecosystems,* G.C. Daily (ed.). Island Press, Washington, DC, 1–10.

DeGroot, R., M.A. Wilson, and R.M.J. Boumans, 2002: A typology for the classification, description, and valuation of ecosystem functions, goods and services. *Ecological Economics,* **41,** 393–408.

Desvouges, W.H., F.R. Johnson, and H.S. Banzhaf, 1998: *Environmental Policy Analysis with Limited Information: Principles and Applications of the Transfer Method.* Edward Elgar, Northampton, MA.

Falkenmark, M. and C. Widstrand, 1992: Population and water resources: a delicate balance. *Population Bulletin,* **47(3),** 2–35.

FAO, 2001: *Global Forest Resources Assessment 2000: Main Report.* Vol. 140, FAO Forestry Papers, Food and Agriculture Organization of the United Nations, Rome.

FAO, 2003: *World Agriculture towards 2015/30. An FAO Perspective.* Earthscan, London.

FAO, 2005: Field Tools @ Participation. [Online]. Informal Working Group on Participatory Approaches & Methods of the Food and Agriculture Organization of the United Nations. Cited 12 May 2005. Available at http://www.fao.org/Participation/ft_find.jsp.

Foster, D.R., G. Motzkin, and B. Slater, 1998: Land-use history as long-term broad-scale disturbance: Regional forest dynamics in central New England. *Ecosystems,* **1,** 96–119.

Franklin, J.F. and R.T.T. Forman, 1987: Creating landscape patterns by forest cutting: ecological consequences and principles. *Landscape Ecology,* **1,** 5–18.

Freeman, M., 1993: *The Measurement of Environmental and Resource Values.* Resources for the Future, Washington, DC.

Fuller, D.R., D.H. Knight, and J.F. Franklin, 1999: Landscape patterns and legacies resulting from large, infrequent forest disturbances. *Ecosystems,* **1,** 497–510.

Gorgens, A.H.M. and B.W. van Wilgen, 2004: Invasive alien plants and water resources in South Africa: Current understanding, predictive ability and research challenges. *South African Journal of Science,* **100(1),** 27–33.

Hairiah, K., M. van Noordwijk, and S. Weise, in press: Sustainability of tropical land-use systems following forest conversion. In: *Slash and Burn—The Search for Alternatives,* C.A. Palm, P.A. Sanchez, S.A. Vosti, P.J. Ericksen, (eds.), Columbia University Press, New York (in press).

Hayashi, S., S. Murakami, and M. Watanabe, 2004: Simulation of water runoff using estimated global precipitation data: Taking the upper reaches of the Changjiang River as an example. *Journal of Geographical Sciences,* **59(1),** 125–135.

Heal, G., G.C. Daily, P.R. Ehrlich, J. Salzman, C. Boggs, et al. 2001: Protecting natural capital through ecosystem service districts. *Stanford Environmental Law Journal,* **20(2),** 333–364.

Kamara, A. and H. Sally, 2002: Water for food, livelihoods and nature: Simulations for policy dialogue in South Africa. Paper presented at *3rd WARSFA/Waternet Symposium,* October. Arusha, 10 pp.

King, J.M. and M.D. Louw, 1998: Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology. *Aquatic Ecosystem Health and Management,* **1,** 109–124.

Koczberski, G., G. Curry, and K. Gibson, 2001: *Improving the Productivity of the Small-holder Oil Palm Sector in Papua New Guinea.* The Australian National University, Canberra, Australia, 233 pp.

Landis, D., S.D. Wratten, and G. Gurr, 2000: Habitat manipulation to conserve natural enemies of arthropod pest in agriculture. *Annual Review of Entomology,* **45,** 175–201.

Liu, J., M. Linderman, Z. Ouyang, L. An, J. Yang, and H. Zhang, 2001: Ecological degradation in protected areas: The Case of Wolong Nature Reserve for Giant Pandas. *Science,* **292,** 98–101.

Liu, J.-Y., M.-L. Liu., and D.-F. Zhuang, 2003: Study on spatial pattern of land-use change in China during 1995–2000. *Science in China* (Series D), **46,** 373–384.

Carvalho Mendes, A.M.S., in press: Economic valuation of the Portuguese forests. In: *Mediterranean Forests and People: The Total Value,* M. Merlo and L. Croitoru (eds.), CAB International, Wallingford, Oxon, UK, (in press).

MA (Millennium Ecosystem Assessment), 2003: *Ecosystems and Human Well-Being: A Framework for Assessment.* Island Press, Washington, DC, 245 pp.

Moguel, P. and V.M. Toledo, 1999: Biodiversity conservation in traditional coffee systems of Mexico. *Conservation Biology,* **13,** 11–21.

Musters, C.J.M., H.J. de Graaf, and W.J. ter Keurs, 2000: Can protected areas be expanded in Africa? *Science,* **287,** 1759–1760.

Olson, D.M., E. Dinerstein, E.D. Wikramanayake, N.D. Burgess, G.V.N. Powell, et al. 2001: Terrestrial ecoregions of the world: A new map of life on Earth. *BioScience,* **51,** 933–938.

Pereira, H., G.C. Daily, and J. Roughgarden, 2004: A framework for assessing the relative vulnerability of species to land-use change. *Ecological Applications,* **14,** 730–742.

Perman, R., Y. Ma, J. McGilvray, and M. Common, 2003: *Natural Resource and Environmental Economics.* Pearson Education Limited, Harlow, England, 699 pp.

Peuquet, D.J. and D.F. Marble, 1990: *Introductory Readings in Geographic Information Systems.* Taylor and Francis, New York.

Pressey, R.L., 1994: Ad hoc reservations: Forward or backward steps in developing representative reserve systems. *Conservation Biology,* **8(3),** 662–668.

Pressey, R.L., C.J. Humphries, C.R. Margules, R.I. Vanewright, and P.H. Williams, 1993: Beyond opportunism: Key principles for systematic reserve selection. *Trends in Ecology & Evolution,* **8(4),** 124–128.

Pressey, R.L. and K.H. Taffs, 2001: Scheduling conservation action in production landscapes: Priority areas in western New South Wales defined by irreplaceability and vulnerability to vegetation loss. *Biological Conservation,* **100,** 355–376.

Ramanujam, M.P. and K.P.K. Cyril, 2003: Woody species diversity of four sacred groves in the Pondicherry region of South India. *Biodiversity and Conservation,* **12,** 289–299.

Reyers, B., 2004: Incorporating potential land-use threats into regional biodiversity evaluation and conservation area prioritisation. *Biological Conservation,* **118,** 521–531.

Ricketts, T.H., G.C. Daily, P.R. Ehrlich, and J.P. Fay, 2001: Countryside biogeography of moths in a fragmented landscape: Biodiversity in native and agricultural habitats. *Conservation Biology,* **15,** 378–388.

Roughgarden, J., 1998: *Primer of Ecological Theory.* Prentice Hall, Upper Saddle River, NJ.

Royal Society, 2003: *Measuring Biodiversity for Conservation.* Policy Document, London, 56 pp.

Samraj, P., V.N. Sharda, S. Chinnamani, V. Lakshmanan, and B. Haldorai, 1988: Hydrological behavior of the Nilgiri sub-watersheds as affected by bluegum plantations: 1. The annual water-balance. *Journal of Hydrology,* **103(3–4),** 335–345.

Stoorvogel, J.J. and E.M.A. Smaling, 1990: Assessment of Soil Nutrient Depletion in Sub-Saharan Africa, 1983–2000. Report 28, DLO Winand Starring Centre for Integrated Land, Soil, and Water Research, Wageningen, Netherlands.

Thies, C., I. Steffan-Dewenter, and T. Tscharntke, 2003: Effects of landscape context on herbivory and parasitism at different spatial scales. *Oikos,* **101,** 18–25.

Thomas, J.A., M.G. Telfer, D.B. Roy, C.D. Preston, J.J.D. Greenwood, et al. 2004: Comparative losses of British butterflies, birds, and plants and the global extinction crisis. *Science,* **303,** 1879–1881.

Thuiller, W., M.B. Araújo, and S. Lavorel, 2003: Generalized models vs. classification tree analysis: Predicting spatial distributions of plant species at different scales. *Journal of Vegetation Science,* **14,** 669–680.

Tomich, T., M. van Noordwijk, S. Vosti, and J. Witcover, 1998: Agricultural development with rainforest conservation: Methods for seeking best bet alternatives to slash-and-burn, with applications to Brazil and Indonesia. *Agricultural Economics,* **1,** 159–174.

Turpie, J.K., B.J. Heydenrych, and S.J. Lamberth, 2003: Economic value of terrestrial and marine biodiversity in the Cape Floristic Region: Implications for defining effective and socially optimal conservation strategies. *Biological Conservation,* **112,** 233–251.

Viglizzo, E.F., A.J. Pordomingo, M.G. Castro, and F.A. Lértora, 2003: Environmental assessment of agriculture at a regional scale in the pampas of Argentina. *Environmental Monitoring and Assessment,* **87,** 169–195.

Vörösmarty, C.J., P. Green, J. Salisbury, and R.B. Lammers, 2000: Global water resources: Vulnerability from climate change and population growth. *Science,* **289,** 284–288.

Wackernagel, M., N.B. Schulz, D. Deumling, A.C. Linares, M. Jenkins, et al. 2002: Tracking the ecological overshoot of the human economy. *Proceedings of the National Academy of Sciences of the United States of America,* **99(14),** 9266–9271.

WTTC (World Travel and Tourism Council), 2004: *Progress and Priorities 2004–2005.* World Travel and Tourism Council, London. Available at www.wttc.org.

Appendix 8.1. Qualitative Assessment of Condition and Trends: Biodiversity and Provisioning, Regulating, Supporting, and Cultural Services in Selected Sub-global Assessments. Based on expert opinion from the assessment teams as described in assessment reports, answers to survey questionnaires, and interviews in knowledge markets. Condition (C) is classified based on a numerical scale from 1 (poor) to 5 (excellent). Trends (T) can be decreasing (−), stable (0), or increasing (+). Comment columns include information on how services were assessed, with caveats in some cases.

	Biodiversity			Soil Formation			Climate Regulation			Flood Protection			Fresh Water			Food			Fuelwood and Fiber			Cultural Services		
Sub-global Assessment	C	T	Comment	C	T	Comment	C	T	Comment	C	T	Comment	C	T	Comment	C	T	Comment	C	T	Comment	C	T	Comment
Altai-Sayan	3	−	good in forest, poor in steppe	3	−	water and wind soil erosion	2	−	albedo and other landscape properties	4	0		4	−		3	−	based on steppe condition	4			4	−	threatened due to tourism and economic development
San Pedro de Atacama	3	−	number of species										2	−	quantity of groundwater	3	−	agricultural production				5	+	increasing mass tourism, increasing special interests tourism
Caribbean Sea	1	−	live coral cover													2	−	fish landings				5	+	tourism, GDP, employment
India Local	4	−	conservation status, number of species										3	−	quantity (4), quality(3)	3	−	forest foods	3	−	fuelwood (3,-) and fiber (3,0)	4	+	
Norway	3	−		2	−					3	−		4	−	quantity and quality	3	0		3	0		3	0	
PNG	4	−	coral reefs																					
Laguna Lake Basin	2	−	number of species				3	−	greenhouse gas emissions				2	−	quality: levels of coliform bacteria, dissolved oxygen and pollutants; quantity: lake depth	2	−	fish landings (3), rice area (2)						
Portugal	3	−	native habitat cover, number of species, population sizes	3	0	agricultural practices, fire frequency, vegetation cover	3	+	carbon sequestration (tree cover, fire frequency)	3	−	wetland area, tree cover in basins	3	+	surface and underground water quality; some recent positive trends	4	0	fertilizer/pesticide use, pelagic stocks, aquaculture	3	0	sustainability of cork and timber production	3	0	ecological capacity for recreation; offer and demand are increasing
SAfMA G-M (Gorongosa)	4	−	number of ecosystems										5	0	supply minus demand	3		supply minus demand; heterogeneous in space and time						
SAfMA Gariep	3	−	number of species, vegetation types, irreplaceability				3	−	carbon dioxide and sulfur dioxide emissions				2	−	mean annual runoff, runoff per capita, access to water services production	3	0	livestock and cereal production						

SAfMA Regional	4	–	biodiversity intactness index, forest area				4	–	ozone concentration				3	–	quantity (4): cubic meters per capita, heterogeneous in space; quality (3): diarrhea rates	2	–	protein per capita, calories per capita (3, 0)	4	0	cubic meters per capita (supply minus demand), heterogenous	4	+	increasingly recognized (tourism, biodiversity, heritage), but threatened by globalization
Northern Range	3	–	expert opinion							3	–	runoff flow and flooding	3	–		3	–	fish stocks	3	–		4	–	amenity value
Tropical Forest Margins																								
Acre, Brazil	4	–	aboveground plant	4		nutrients	5	–	carbon	5			5		quantity	5			5		timber			
Rondonia, Brazil	2	–	biodiversity	3			3	–	sequestration	5			5			5			4					
Ebolowa, Cameroon	5	–	measured as	5			4		(aboveground)	5			5			5			4					
Yaounde, Cameroon	3	–	number of species	4	–		3	–		5			5			5			3					
Jambi, Indonesia	4	–	and functional	4	–		4	–					5			5			3					
Lampung, Indonesia	1	–	types	2	–		2	–					5			5			1					
Downstream Mekong	3	–	wetland area	2	–	decrease in alum-washing process							4	0	supply minus demand	4	+	agriculture production, fish landings	3	+		4	+	increase in ecotourism, recreation
Western China—NW	2	+		2	+	desertification, soil	4	–	carbon				2	–	surface and	4	+							
Western China—SW	4	–		4	0	erosion	4	–	sequestration				5	0	groundwater	4	0							
Bajo Chirripó	3	0	hunting pressure, timber harvest, biodiversity index, forest cover; heterogeneous across taxa	4	0					4	0	in the lowlands wetlands have disappeared	4	–	condition of water springs in the dry season							5	0	
Eastern Himalayas	4	–	number and distribution of species	2	–	soil erosion							3	–	quantity: run off; quality: turbidity	3	+	quantity						
Sinai	3	–	number and distribution of native species										3	–	quantity: precipitation rate, distribution per capita; quality: salt concentration, infectious diseases	3	–	type of crops, cultivation area, total production						
India Urban	3	0	habitat quantity and quality, number of species, harvest pressure; heterogeneous across taxa				1	–	carbon sequestration (green cover)				1	–	physico-chemical analysis, biological indicators	3	0	market analysis				3	–	loss of wilderness areas; loss of cultural values
São Paulo	4	–	number of species, vegetation cover				3	–	forest surface, vegetation type and growth	4	–	landslides, sediments	3	–	quantity (2): supply minus demand; quality (3): eutrophication level	3	–	production and markets	3	+	reforested area, management systems	4	+	visits to protected and other green areas