Ecosystems and Human Well-being

Biodiversity Synthesis

MILLENNIUM ECOSYSTEM ASSESSMENT

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Ecosystems and Human Well-being

Biodiversity Synthesis

A Report of the Millennium Ecosystem Assessment

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Suggested citation:

Millennium Ecosystem Assessment, 2005. *Ecosystems and Human Well-being: Biodiversity Synthesis*. World Resources Institute, Washington, DC.

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Library of Congress Cataloging-in-Publication data.

British Cataloguing-in-Publication data available.

Printed on recycled, acid-free paper

Book design by Dever Designs

Manufactured in the United States of America

Contents

Foreword

The Millennium Ecosystem Assessment set out to assess the consequences of ecosystem change for human well-being and to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being. Biological diversity plays a critical role in underpinning ecosystem services. Governments supported the establishment of the MA through decisions taken by the Convention on Biological Diversity and other international conventions. The MA was initiated in 2001 under the auspices of the United Nations and governed by a multistakeholder board that included representatives of international institutions, governments, indigenous peoples, NGOs, and business. The secretariat was coordinated by the United Nations Environment Programme. More than 1,360 scientists from 95 countries contributed to the assessment.

This report presents a synthesis and integration of the findings concerning biodiversity contained in the reports of the four MA Working Groups (Condition and Trends, Scenarios, Responses, and Sub-global Assessments). From the outset, the MA was designed to meet the needs of the Convention on Biological Diversity, among other users. The Conference of the Parties welcomed the contribution of the MA to the assessment work of the Convention. It encouraged Parties to participate in the MA and nominated the Chair of the Subsidiary Body on Scientific, Technical, and Technological Advice and the Executive Secretary to be represented on the MA Board. Parties to the CBD have provided review comments on underlying chapters of the assessment as well as this synthesis report. In addition, the penultimate draft of the synthesis report was presented to the tenth meeting of SBSTTA in February 2005, and the comments made there were taken into account in its finalization. As requested by the Conference of the Parties, SBSTTA will consider the final products of the Millennium Ecosystem Assessment at its eleventh meeting—including this synthesis report on biodiversity—in order to prepare recommendations to the Conference of the Parties concerning the implications of the findings for the future work of the Convention.

This report would not have been possible without the extraordinary commitment of the more than 2,000 authors and reviewers worldwide who contributed their knowledge, creativity, time, and enthusiasm to the development of the assessment. We would like to express our gratitude to the Synthesis Team that prepared this report and to the MA Assessment Panel, Coordinating Lead Authors, Lead Authors, Contributing Authors, Board of Review Editors, and Expert Reviewers who contributed to this process, and we wish to acknowledge the in-kind support of their institutions, which enabled their participation. We would also like to thank the current and past members of the MA Board (and their alternates), the members of the MA Exploratory Steering Committee, the Convention on Biological Diversity secretariat staff, and the MA secretariat staff, interns, and volunteers for their contributions to this process.

We are extremely grateful to the donors that provided major financial support for the MA: Global Environment Facility; United Nations Foundation; The David and Lucile Packard Foundation; The World Bank; Consultative Group on International Agricultural Research; United Nations Environment Programme; Government of China; Ministry of Foreign Affairs of the Government of Norway; Kingdom of Saudi Arabia; and the Swedish International Biodiversity Programme. The full list of organizations that provided financial support to the MA is available at www.MAweb.org.

We hope that this report will prove useful to all those concerned with the Convention on Biological Diversity and with its objectives—the conservation and sustainable use of biological diversity and the fair and equitable sharing of benefits arising from the use of genetic resources.

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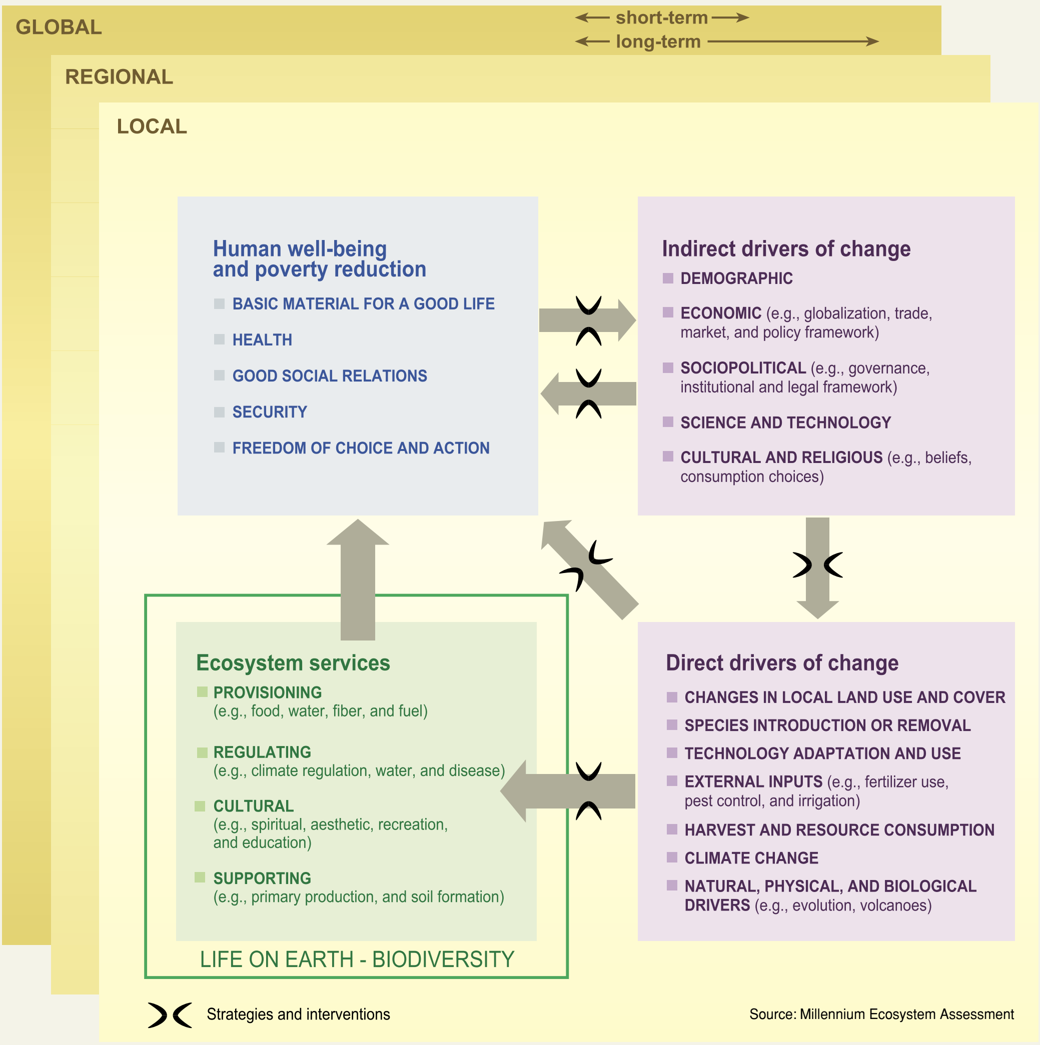
Preface

The goal of the Millennium Ecosystem Assessment is to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to meeting human needs. Because the basis of all ecosystems is a dynamic complex of plants, animals, and microorganisms, biological diversity (or biodiversity, for short) has been a key component of the MA. The MA recognizes that interactions exist between people, biodiversity, and ecosystems. That is, changing human conditions drive, both directly and indirectly, changes in biodiversity, changes in ecosystems, and ultimately changes in the services ecosystems provide. Thus biodiversity and human well-being are inextricably linked. (See Figure A.) The MA also recognizes that many other factors independent of changes in biodiversity affect the human condition and that biodiversity is influenced by many natural forces that are not associated with humans.

Figure A. Millennium Ecosystem Assessment Conceptual Framework of Interactions between Biodiversity, Ecosystem Services, Human Well-being, and Drivers of Change

Changes in drivers that indirectly affect biodiversity, such as population, technology, and lifestyle (upper right corner), can lead to changes in drivers directly affecting biodiversity, such as the catch of fish or the application of fertilizers to increase food production (lower right corner). These result in changes to biodiversity and to ecosystem services (lower left corner), thereby affecting human well-being. These interactions can take place at more than one scale and can cross scales. For example, international demand for timber may lead to a regional loss of forest cover, which increases flood magnitude along a local stretch of a river. Similarly, the interactions can take place across different time scales. Actions can be taken either to respond to negative changes or to enhance positive changes at almost all points in this framework. Local scales refer to communities or ecosystems and regional scales refer to nations or biomes, all of which are nested within global scale processes.

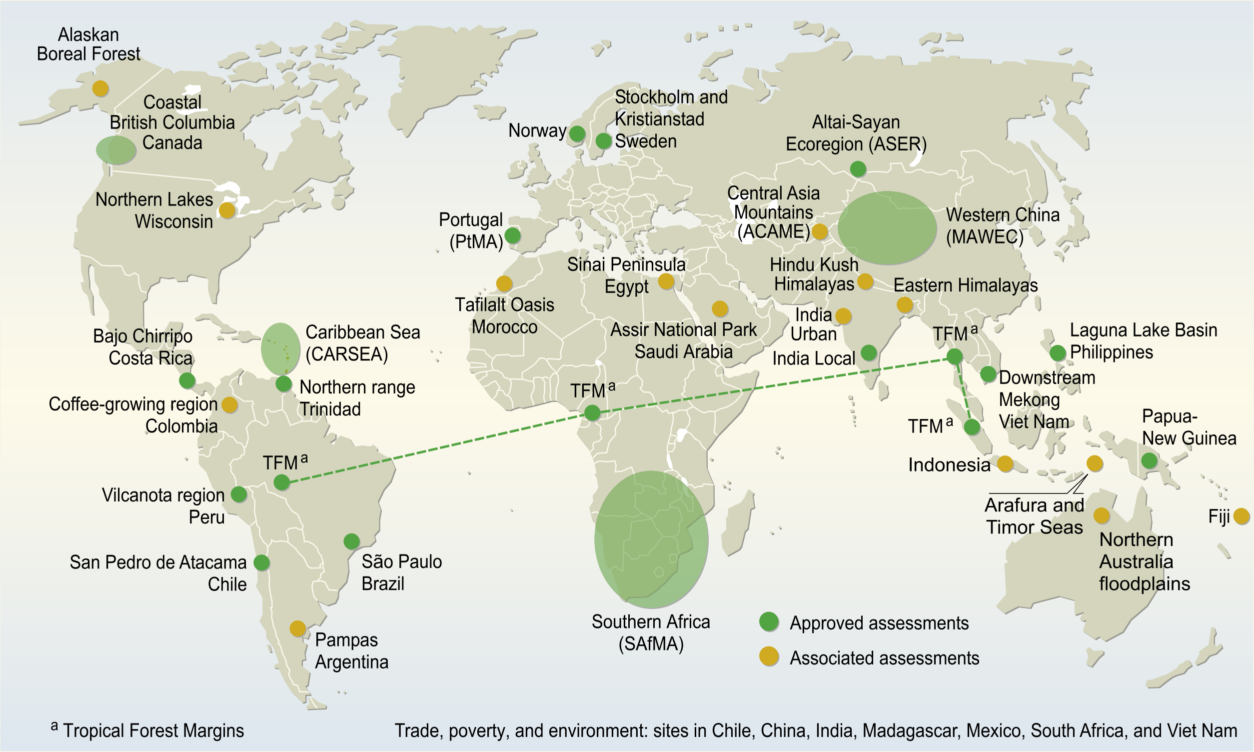


Human well-being is the central focus for the MA, but biodiversity and ecosystems also have intrinsic value. People make decisions concerning ecosystems based on considerations of well-being as well as intrinsic value.

A full assessment of the interactions between people and biodiversity requires a multiscale approach, as this better reflects the multiscale nature of decision-making, allows the examination of driving forces from outside particular regions, and provides a means of examining the differential impact of changes in biodiversity, ecosystem services, and policy responses on different regions and groups within regions. The MA thus consists of a global assessment and 33 sub-global assessments. (See Figure B.)

Figure B. MA Sub-global Assessments

Eighteen sub-global assessments were approved as components of the MA. These were not designed to provide a scientific sample of any feature of ecosystems or human well-being. Instead, the choice of assessment locations was determined by a combination of interest in undertaking the assessment, interest in using the findings, and availability of resources to undertake the assessment. These assessments thus were primarily designed to meet needs of decision-makers in the locations where they were made, but they also informed the global MA findings with information and perspectives from the sub-global scale and vice versa. The MA also drew on information from 15 other sub-global assessments affiliated with the MA that met a subset of these criteria or were at earlier stages in development.



Reader's Guide

This report synthesizes findings from the MA global and sub-global assessments on biodiversity and human well-being. All of the MA authors and Review Editors have contributed to this draft through their contributions to the underlying assessment chapters on which this material is based.

Five additional synthesis reports were prepared for ease of use by other audiences: general overview, UNCCD (desertification), Ramsar Convention (wetlands), business, and the health sector. Each MA sub-global assessment will also produce additional reports to meet the needs of its own audience. The full technical assessment reports of the four MA Working Groups will be published in mid-2005 by Island Press. All printed materials of the assessment, along with core data and a glossary of terminology used in the technical reports, will be available on the Internet at www.MAweb.org. Appendix A lists the acronyms and abbreviations used in this report and includes additional information on sources for some of the Figures. Throughout this report, dollar signs indicate U.S. dollars and tons mean metric tons.

References that appear in parentheses in the body of this synthesis report are to the underlying chapters in the full technical assessment reports of each Working Group. (A list of the assessment report chapters is provided in Appendix B.) To assist the reader, citations to the technical volumes generally specify sections of chapters or specific Boxes, Tables, or Figures, based on final drafts of the chapter. Some chapter subsection numbers may change during final copyediting, however, after this report has been printed.

In this report, the following words have been used where appropriate to indicate judgmental estimates of certainty, based on the collective judgment of the authors, using the observational evidence, modeling results, and theory that they have examined: very certain (98% or greater probability), high certainty (85–98% probability), medium certainty (65–85% probability), low certainty (52–65% probability), and very uncertain (50–52% probability). In other instances, a qualitative scale to gauge the level of scientific understanding is used: well established, established but incomplete, competing explanations, and speculative. Each time these terms are used they appear in italics.

Key Messages

- *Biodiversity benefits people through more than just its contribution to material welfare and livelihoods. Biodiversity contributes to security, resiliency, social relations, health, and freedom of choices and actions.*
- *Changes in biodiversity due to human activities were more rapid in the past 50 years than at any time in human history, and the drivers of change that cause biodiversity loss and lead to changes in ecosystem services are either steady, show no evidence of declining over time, or are increasing in intensity. Under the four plausible future scenarios developed by the MA, these rates of change in biodiversity are projected to continue, or to accelerate.*
- *Many people have benefited over the last century from the conversion of natural ecosystems to human-dominated ecosystems and from the exploitation of biodiversity. At the same time, however, these gains have been achieved at growing costs in the form of losses in biodiversity, degradation of many ecosystem services, and the exacerbation of poverty for other groups of people.*
- *The most important direct drivers of biodiversity loss and ecosystem service changes are habitat change (such as land use changes, physical modification of rivers or water withdrawal from rivers, loss of coral reefs, and damage to sea floors due to trawling), climate change, invasive alien species, overexploitation, and pollution.*
- *Improved valuation techniques and information on ecosystem services demonstrate that although many individuals benefit from biodiversity loss and ecosystem change, the costs borne by society of such changes are often higher. Even in instances where knowledge of benefits and costs is incomplete, the use of the precautionary approach may be warranted when the costs associated with ecosystem changes may be high or the changes irreversible.*
- *To achieve greater progress toward biodiversity conservation to improve human well-being and reduce poverty, it will be necessary to strengthen response options that are designed with the conservation and sustainable use of biodiversity and ecosystem services as the primary goal. These responses will not be sufficient, however, unless the indirect and direct drivers of change are addressed and the enabling conditions for implementation of the full suite of responses are established.*
- *Trade-offs between achieving the 2015 targets of the Millennium Development Goals and the 2010 target of reducing the rate of biodiversity loss are likely, although there are also many potential synergies between the various internationally agreed targets relating to biodiversity, environmental sustainability, and development. Coordinated implementation of these goals and targets would facilitate the consideration of trade-offs and synergies.*
- *An unprecedented effort would be needed to achieve by 2010 a significant reduction in the rate of biodiversity loss at all levels.*
- *Short-term goals and targets are not sufficient for the conservation and sustainable use of biodiversity and ecosystems. Given the characteristic response times for political, socioeconomic, and ecological systems, longer-term goals and targets (such as for 2050) are needed to guide policy and actions.*
- *Improved capability to predict the consequences of changes in drivers for biodiversity, ecosystem functioning, and ecosystem services, together with improved measures of biodiversity, would aid decision-making at all levels.*
- *Science can help ensure that decisions are made with the best available information, but ultimately the future of biodiversity will be determined by society.*

Summary for Decision-makers

The Millennium Ecosystem Assessment was carried out between 2001 and 2005 to assess the consequences of ecosystem change for human well-being and to analyze options available to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being. The MA responds to requests for information received through the Convention on Biological Diversity and other international conventions (the United Nations Convention to Combat Desertification, the Ramsar Convention on Wetlands, and the Convention on Migratory Species) and is also designed to meet the needs of other stakeholders, including business, civil society, and indigenous peoples. It was carried out by approximately 1,360 experts from 95 countries through four Working Groups and encompassed both a global assessment and 33 sub-global assessments. An independent Review Board has overseen an extensive review by governments and experts. Each Working Group and each sub-global assessment has produced detailed technical assessment reports.

This report synthesizes and integrates findings related to biological diversity (or biodiversity, for short) from the four MA Working Groups. Biodiversity is defined by the MA as the variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part. The material presented in this report and in the full MA is an assessment of the current state of knowledge. The purpose of the assessment is to:

- provide an authoritative source of information,
- mobilize knowledge and information to address specific policy questions,
- clarify where there are areas of broad consensus within the scientific community and where important controversies remain, and
- provide insights that emerge from a broad review of knowledge that might not be apparent in individual studies.

Consistent with the ecosystem approach (see CBD Decision V/6), the MA acknowledges that people are integral parts of ecosystems. That is, a dynamic interaction exists between people and other parts of ecosystems, with the changing human condition serving to drive, both directly and indirectly, change in ecosystems. However, changes in ecosystems cause changes in human well-being. At the same time, many other factors independent of the environment change the human condition, and many natural forces influence ecosystems. The MA places human well-being as the central focus for assessment, while recognizing that biodiversity and ecosystems also have intrinsic value—value of something in and for itself, irrespective of its utility for someone else—and that people make decisions concerning ecosystems based on consideration of their own well-being and that of others as well as on intrinsic value.

Biodiversity can be described as "the diversity of life on Earth" and is essential for the functioning of ecosystems that underpin the provisioning of ecosystem services that ultimately affect human well being. Although described simply, in practice what biodiversity encompasses can be complex, and there are conceptual pitfalls that need to be avoided. (See Box 1.) For example, because biodiversity has many components—including the diversity of all organisms, be they plants, animals, or microorganisms, the diversity within and among species and populations, and the diversity of ecosystems—no single component, whether genes, species, or ecosystems, is consistently a good indicator of overall biodiversity, as the components can vary independently.

The MA focuses on the linkages between ecosystems and human well-being and in particular on "ecosystem services"—the benefits people obtain from ecosystems. These include provisioning services such as food, water, timber, and fiber; regulating services such as the regulation of climate, floods, disease, wastes,

Box 1. Biodiversity and Its Loss—Avoiding Conceptual Pitfalls

Different interpretations of several important attributes of the concept of biodiversity can lead to confusion in understanding both scientific findings and their policy implications. Specifically, the value of the diversity of genes, species, or ecosystems per se is often confused with the value of a particular component of that diversity. Species diversity in and of itself, for example, is valuable because the presence of a variety of species helps to increase the capability of an ecosystem to be resilient in the face of a changing environment. At the same time, an individual component of that diversity, such as a particular food plant species, may be valuable as a biological resource. The consequences of changes in biodiversity for people can stem both from a change in the diversity per se and a change in a particular component of biodiversity. Each of these aspects of biodiversity deserves its own attention from decision-makers, and each often requires its own (albeit connected) management goals and policies.

Second, because biodiversity refers to diversity at multiple scales of biological organization (genes, populations, species, and ecosystems) and can be considered at any geographic scale (local, regional, or global), it is generally important to specify the specific level of organization and scale of concern. For example, the introduction of widespread weedy species to a continent such as Africa will increase the species diversity of Africa (more species present) while decreasing ecosystem diversity globally (since the ecosystems in Africa then become more similar in species composition to ecosystems elsewhere due to the presence of the cosmopolitan species). Because of the multiple levels of organization and multiple geographic scales involved, any single indicator, such as species diversity, is generally a poor indicator for many aspects of biodiversity that may be of concern for policy-makers.

These two considerations are also helpful in interpreting the meaning of biodiversity "loss." For the purposes of assessing progress toward the 2010 targets, the Convention on Biological Diversity defines biodiversity loss to be "the long-term or permanent qualitative or quantitative reduction in components of biodiversity and their potential to provide goods and services, to be measured at global, regional and national levels" (CBD COP VII/30). Under this definition, biodiversity can be lost either if the diversity per se is reduced (such as through the extinction of some species) or if the potential of the components of diversity to provide a particular service is diminished (such as through unsustainable harvest). The homogenization of biodiversity—that is, the spread of invasive alien species around the world—thus also represents a loss of biodiversity at a global scale (since once-distinct groups of species in different parts of the world become more similar) even though the diversity of species in particular regions may actually increase because of the arrival of new species.

and water quality; cultural services such as recreation, aesthetic enjoyment, and spiritual fulfillment; and supporting services such as soil formation, photosynthesis, and nutrient cycling. The MA assesses the indirect and direct drivers of change in ecosystems and their services, the current condition of those services, and how changes in ecosystem services have affected human well-being. It uses a broad definition of human well-being, examining how ecosystem changes influence income and material needs, health, good social relations, security, and freedom of choice and action. The MA developed four global scenarios exploring plausible future changes in drivers, ecosystems, ecosystem services, and human well-being. (See Box 2.) Finally, the assessment examined the strengths and weaknesses of various response options that have been used to manage ecosystem services and identified promising opportunities for enhancing human well-being while conserving ecosystems.

What is the problem?

Finding #1. ***Human actions are fundamentally, and to a significant extent irreversibly, changing the diversity of life on Earth, and most of these changes represent a loss of biodiversity. Changes in important components of biological diversity were more rapid in the past 50 years than at any time in human history. Projections and scenarios indicate that these rates will continue, or accelerate, in the future.***

Virtually all of Earth's ecosystems have now been dramatically transformed through human actions. More land was converted to cropland in the 30 years after 1950 than in the 150 years between 1700 and 1850. Between 1960 and 2000, reservoir storage capacity quadrupled, and as a result the amount of water stored behind large dams is estimated to be three to six times the amount of water flowing through rivers at any one time. Some 35% of mangroves have been lost in the last two decades in countries where adequate data are available (encompassing about half of the total mangrove area). Already 20% of known coral reefs have been destroyed and another 20% degraded in the last several decades. Although the most rapid changes in ecosystems are now taking place in developing countries, industrial countries historically experienced comparable changes.

Over half of the 14 biomes that the MA assessed have experienced a 20–50% conversion to human use, with temperate and Mediterranean forests and temperate grasslands being the most affected (approximately three quarters of these biome's native habitat has been replaced by cultivated lands).[1] In the last 50 years, rates of conversion have been highest in tropical and subtropical dry forests.

Globally, the net rate of conversion of some ecosystems has begun to slow, although in some instances this is because little habitat remains for further conversion. Generally, opportunities

[1] Biomes represent broad habitat and vegetation types, span across biogeographic realms, and are useful units for assessing global biodiversity and ecosystem services because they stratify the globe into ecologically meaningful and contrasting classes. Throughout this report, and elsewhere in the MA, the 14 biomes of the WWF terrestrial biome classification are used, based on WWF terrestrial ecoregions (C4.2.2).

Box 2. MA Scenarios

The MA developed four scenarios to explore plausible futures for ecosystems and human well-being based on different assumptions about driving forces of change and their possible interactions:

Global Orchestration—This scenario depicts a globally connected society that focuses on global trade and economic liberalization and takes a reactive approach to ecosystem problems but that also takes strong steps to reduce poverty and inequality and to invest in public goods such as infrastructure and education. Economic growth in this scenario is the highest of the four scenarios, while it is assumed to have the lowest population in 2050.

Order from Strength—This scenario represents a regionalized and fragmented world, concerned with security and protection, emphasizing primarily regional markets, paying little attention to public goods, and taking a reactive approach to ecosystem problems. Economic growth rates are the lowest of the scenarios (particularly low in developing countries) and decrease with time, while population growth is the highest.

Adapting Mosaic—In this scenario, regional watershed-scale ecosystems are the focus of political and economic activity. Local institutions are strengthened and local ecosystem management strategies are common; societies develop a strongly proactive approach to the management of ecosystems. Economic growth rates are somewhat low initially but increase with time, and population in 2050 is nearly as high as in *Order from Strength*.

TechnoGarden—This scenario depicts a globally connected world relying strongly on environmentally sound technology, using highly managed, often engineered, ecosystems to deliver ecosystem services, and taking a proactive approach to the management of ecosystems in an effort to avoid problems. Economic growth is relatively high and accelerates, while population in 2050 is in the mid-range of the scenarios.

The scenarios are not predictions; instead they were developed to explore the unpredictable features of change in drivers and ecosystem services. No scenario represents business as usual, although all begin from current conditions and trends.

Both quantitative models and qualitative analyses were used to develop the scenarios. For some drivers (such as land use change and carbon emissions) and ecosystem services (water withdrawals, food production), quantitative projections were calculated using established, peer-reviewed global models. Other drivers (such as rates of technological change and economic growth), ecosystem services (particularly supporting and cultural services, such as soil formation and recreational opportunities), and human well-being indicators (such as human health and social relations) were estimated qualitatively. In general, the quantitative models used for these scenarios addressed incremental changes but failed to address thresholds, risk of extreme events, or impacts of large, extremely costly, or irreversible changes in ecosystem services. These phenomena were addressed qualitatively by considering the risks and impacts of large but unpredictable ecosystem changes in each scenario.

Three of the scenarios—*Global Orchestration, Adapting Mosaic,* and *TechnoGarden*—incorporate significant changes in policies aimed at addressing sustainable development challenges. In *Global Orchestration* trade barriers are eliminated, distorting subsidies are removed, and a major emphasis is placed on eliminating poverty and hunger. In *Adapting Mosaic*, by 2010, most countries are spending close to 13% of their GDP on education (as compared to an average of 3.5% in 2000), and institutional arrangements to promote transfer of skills and knowledge among regional groups proliferate. In *TechnoGarden* policies are put in place to provide payment to individuals and companies that provide or maintain the provision of ecosystem services. For example, in this scenario, by 2015, roughly 50% of European agriculture, and 10% of North American agriculture is aimed at balancing the production of food with the production of other ecosystem services. Under this scenario, significant advances occur in the development of environmental technologies to increase production of services, create substitutes, and reduce harmful trade-offs.

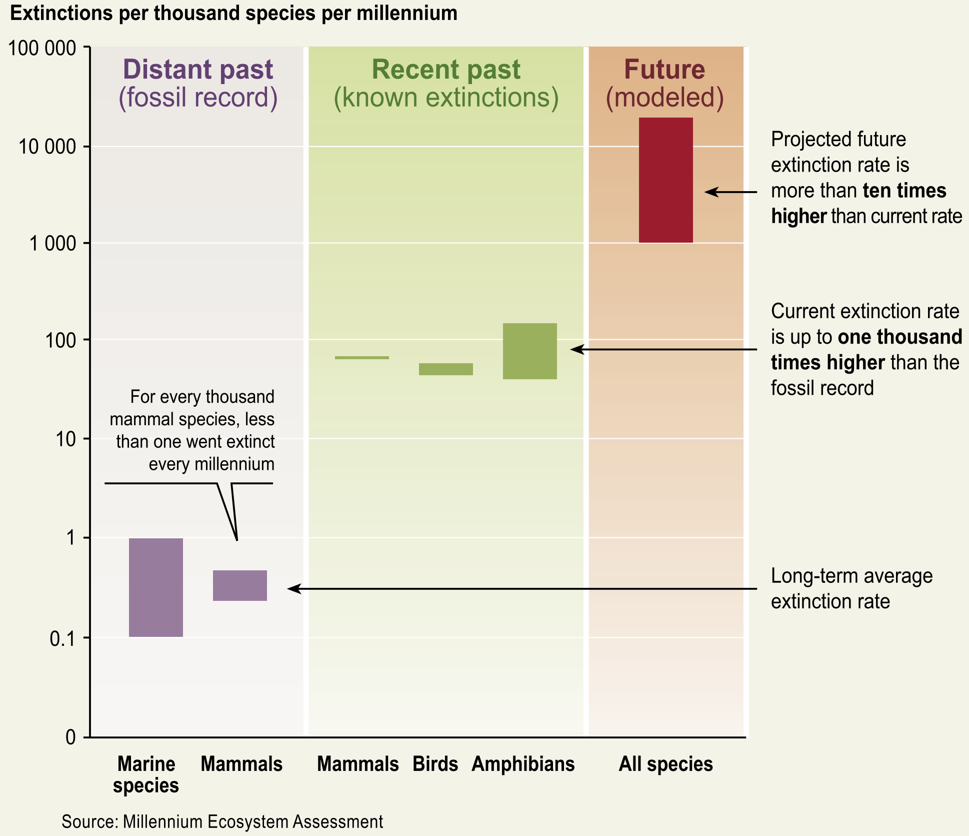
for further expansion of cultivation are diminishing in many regions of the world as the finite proportion of land suitable for intensive agriculture continues to decline. Increased agricultural productivity is also diminishing pressures for agricultural expansion. Since 1950, cropland areas in North America, Europe, and China have stabilized, and they even decreased in Europe and China. Cropland areas in the former Soviet Union have decreased since 1960. Within temperate and boreal zones, forest cover increased by approximately 3 million hectares per year in the 1990s, although about 40% of this increase consisted of forest plantations.

Across a range of taxonomic groups, the population size or range (or both) of the majority of species is declining. Studies of amphibians globally, African mammals, birds in agricultural lands, British butterflies, Caribbean and IndoPacific corals, and commonly harvested fish species show declines in populations of the majority of species. Exceptions include species that have been protected in reserves, that have had their particular threats (such as overexploitation) eliminated, and that tend to thrive in landscapes that have been modified by human activity. Marine and freshwater ecosystems are relatively less studied than terrestrial systems, so overall biodiversity is poorly understood; for those species that are well studied, biodiversity loss has occurred through population extirpation and constricted distributions.

Over the past few hundred years, humans have increased species extinction rates by as much as 1,000 times background rates that were typical over Earth's history. (See Figure 1.) There are approximately 100 well-documented extinctions of birds,

Figure 1. Species Extinction Rates (adapted from C4 Fig 4.22)

"Distant past" refers to average extinction rates as calculated from the fossil record. "Recent past" refers to extinction rates calculated from known extinctions of species (lower estimate) or known extinctions plus "possibly extinct" species (upper bound). A species is considered to be "possibly extinct" if it is believed to be extinct by experts but extensive surveys have not yet been undertaken to confirm its disappearance. "Future" extinctions are model-derived estimates using a variety of techniques, including species-area models, rates at which species are shifting to increasingly more threatened categories, extinction probabilities associated with the IUCN categories of threat, impacts of projected habitat loss on species currently threatened with habitat loss, and correlation of species loss with energy consumption. The time frame and species groups involved differ among the "future" estimates, but in general refer to either future loss of species based on the level of threat that exists today or current and future loss of species as a result of habitat changes taking place roughly from 1970 to 2050. Estimates based on the fossil record are *low certainty*. The lower-bound estimates for known extinctions are *high certainty*, while the upper-bound estimates are *medium certainty*; lower-bound estimates for modeled extinctions are *low certainty*, and upper-bound estimates are *speculative*.



Source: Millennium Ecosystem Assessment

mammals, and amphibians over the last 100 years—a rate 100 times higher than background rates. If less well documented but highly probable extinctions are included, the rate is more than 1,000 times higher than background rates.

The distribution of species on Earth is becoming more homogenous. By homogenous, we mean that the differences between the set of species at one location and the set of species at another location are, on average, diminishing. Two factors are responsible for this trend. First, species unique to particular regions are experiencing higher rates of extinction. Second, high rates of invasion by and introductions of species into new ranges are accelerating in pace with growing trade and faster transportation. Currently, documented rates of species introductions in most regions are greater than documented rates of extinction, which can lead to anomalous, often transient increases in local diversity. The consequences of homogenization depend on the aggressiveness of the introduced species and the services they either bring (such as when introduced for forestry or agriculture) or impair (such as when loss of native species means loss of options and biological insurance).

Between 10% and 50% of well-studied higher taxonomic groups (mammals, birds, amphibians, conifers, and cycads) are currently threatened with extinction, based on IUCN–World Conservation Union criteria for threats of extinction. Some 12% of bird species, 23% of mammals, and 25% of conifers are currently threatened with extinction. In addition, 32% of amphibians are threatened with extinction, but information is more limited and this may be an underestimate. Higher levels of threat (52%) have been found in the cycads, a group of evergreen palm-like plants. Aquatic (including both marine and freshwater) organisms, however, have not been tracked to the same degree as terrestrial ones, masking what may be similarly alarming threats of extinction (*low certainty*).

Genetic diversity has declined globally, particularly among domesticated species. Since 1960 there has been a fundamental shift in the pattern of intra-species diversity in farmers' fields and farming systems as a result of the "Green Revolution." Intensification of agricultural systems, coupled with specialization by plant breeders and the harmonizing effects of globalization, has led to a substantial reduction in the genetic diversity of domesticated plants and animals in agricultural systems. Such declines in genetic diversity lower the resilience and adaptability of domesticated species. Some of these on-farm losses of crop genetic diversity have been partially offset by the maintenance of genetic diversity in seed banks. In addition to cultivated systems, the extinction of species and loss of unique populations (including commercially important marine fishes) that has taken place has resulted in the loss of unique genetic diversity contained in those species and populations. This loss reduces overall fitness and adaptive potential, and it limits the prospects for recovery of species whose populations are reduced to low levels.

All scenarios explored in the Millennium Ecosystem Assessment project continuing rapid conversion of ecosystems in the first half of the twenty-first century. Roughly 10–20% (*low to medium certainty*) of current grassland and forestland is projected to be converted to other uses between now and 2050, mainly due to the expansion of agriculture and, second, due to the expansion of cities and infrastructure. The habitat losses projected in the MA scenarios will lead to global extinctions as species numbers approach equilibrium with the remnant habitat. The equilibrium number of plant species is projected to be reduced by roughly 10–15% as a result of habitat loss over the period 1970–2050 in the MA scenarios (*low certainty*), but this projection is likely to be an underestimate as it does not consider reductions due to stresses other than habitat loss, such as climate change and pollution. Similarly, modification of river water flows will drive losses of fish species.

Why is biodiversity loss a concern?

Finding #2. *Biodiversity contributes directly (through provisioning, regulating, and cultural ecosystem services)and indirectly (through supporting ecosystem services) to many constituents of human well-being, including security, basic material for a good life, health, good social relations, and freedom of choice and action. Many people have benefited over the last century from the conversion of natural ecosystems to human-dominated ecosystems and the exploitation of biodiversity. At the same time, however, these losses in biodiversity and changes in ecosystem services have caused some people to experience declining well-being, with poverty in some social groups being exacerbated.*

Substantial benefits have been gained from many of the actions that have caused the homogenization or loss of biodiversity. For example, agriculture, fisheries, and forestry—three activities that have placed significant pressures on biodiversity—have often been the mainstay of national development strategies, providing revenues that have enabled investments in industrialization and economic growth. The agricultural labor force currently contains approximately 22% of the world's population and accounts for 46% of its total labor force. In industrial countries, exploitation of natural resources continues to be important for livelihoods and economies in rural regions. Similarly, many species introductions, which contribute to the homogenization of global biodiversity, have been intentional because of the benefits the species provide. In other cases, humans have eradicated some harmful components of biodiversity, such as particular disease organisms or pests.

Modifications of ecosystems to enhance one service generally have come at a cost to other services due to trade-offs. Only 4 of the 24 ecosystem services examined in this assessment have been enhanced: crops, livestock, aquaculture, and (in recent decades) carbon sequestration. In contrast, 15 other services have been degraded, including capture fisheries, timber production, water supply, waste treatment and detoxification, water purification, natural hazard protection, regulation of air quality, regulation of regional and local climate, regulation of erosion, and many cultural benefits (spiritual, aesthetic, recreational, and others). The impacts of these trade-offs among ecosystem services affect different people in different ways. For example, an aquaculture farmer may gain material welfare from management practices that increase soil salinization and thereby reduce rice yields and threaten food security for nearby subsistence farmers.

Beneficial changes in ecosystem services have not been equitably distributed among people, and many of the costs of changes in biodiversity have historically not been factored into decision-making. Even where the net economic benefits of changes leading to the loss of biodiversity (such as ecosystem simplification) have been positive, many people have often been harmed by such changes. In particular, poor people, particularly those in rural areas in developing countries, are more directly dependent on biodiversity and ecosystem services and more vulnerable to their degradation. Such biodiversity loss is equivalent to the loss of biological insurance or of alternative biological resources important for maintaining the flow of goods and services. Richer groups of people are often less affected by the loss of ecosystem services because of their ability to purchase substitutes or to offset local losses of ecosystem services by shifting production and harvest to other regions. For example, as fish stocks have been depleted in the north Atlantic, European and other commercial capture fisheries shifted their fishing to West African seas, but this has adversely affected coastal West Africans who rely on fish as a cheap source of protein.

Many costs associated with changes in biodiversity may be slow to become apparent, may be apparent only at some distance from where biodiversity was changed, or may involve thresholds or changes in stability that are difficult to measure. For example, there is *established but incomplete* evidence that reductions in biodiversity reduce ecosystem resilience or the ability of an ecosystem to recover from a perturbation. But costs associated with such reductions in resilience may not be apparent for years until a significant perturbation is experienced and the lost ability to recover manifests itself. An example of where the effect of a change in biodiversity in one location can have impacts in other locations is the conversion of forest to agriculture in one region that affects river flows in downstream areas far removed from the conversion.

Threshold effects—abrupt or nonlinear changes or regime shifts in a system in response to a gradual or linear change in single or multiple drivers—have been commonly encountered in aquatic ecosystems and are often associated with changes in biodiversity. For instance, a steady increase in fishing pressure can cause abrupt changes in species populations in coastal ecosystems. An example of a regime shift in response to changes in multiple drivers is the case of tropical coral reefs, where nutrient loading, declines in herbivorous fish, and reef degradation collectively trigger shifts to algal-dominated systems. An example of instability caused by a change in biodiversity is that of the introduction of the invasive, carnivorous ctenophore *Mnemiopsis leidyi* (a jellyfish-like animal) in the Black Sea, which caused the rapid loss of 26 major fisheries species and has been implicated (along with other factors) in the continued growth of the oxygen-deprived "dead" zone. The species was subsequently introduced into the Caspian and Aral Seas, where it is having similar impacts.

Biodiversity loss is important in its own right because biodiversity has cultural values, because many people ascribe intrinsic value to biodiversity, and because it represents unexplored options for the future (option values). People from all walks of life value biodiversity for spiritual, aesthetic, recreational, and other cultural reasons. Species extinction at the global level is also of particular significance, since such permanent, irreversible losses of species are a loss in the constitutive elements of well-being. Population extirpation and loss of habitat are particularly important at national and local levels, because most ecosystem services are delivered at the local and regional level and strongly depend on the type and relative abundance of species.

What is the value of biodiversity?

Finding #3. *Improved valuation techniques and information on ecosystem services tells us that although many individuals benefit from the actions and activities that lead to biodiversity loss and ecosystem change, the costs borne by society of such changes is often higher. Even in instances where our knowledge of benefits and costs is incomplete, the use of the precautionary approach may be warranted when the costs associated with ecosystem changes may be high or the changes irreversible.*

In a number of existing studies of changes in economic value associated with changes to biodiversity in specific locations (such as the conversion of mangrove forests, draining of wetlands, and clear-felling of forests), the total economic cost of ecosystem conversion (including both market and nonmarket values of ecosystem services) is found to be significant and to sometimes exceed the benefits of the habitat conversion. Despite this, in a number of these cases conversion was promoted because the cost associated with the loss of ecosystem services was not internalized, because the private gains were significant (although less than the public losses), and sometimes also because subsidies distorted the relative costs and benefits. Often, the majority of local inhabitants were disenfranchised by the changes.

A country's ecosystems and its ecosystem services represent a capital asset, but the benefits that could be attained through better management of this asset are poorly reflected in conventional economic indicators. A country could cut its forests and deplete its fisheries and this would show only as a positive gain to GDP despite the loss of the capital asset. When the decline in these "natural capital assets" is factored into the measures of national wealth, the estimates of that wealth decline significantly for countries with economies that are especially dependent on natural resources. Some countries that appeared to have positive growth in the 1970s and 1980s, for example, actually experienced a net loss of capital assets, effectively undermining the sustainability of any gains they may have achieved.

The costs resulting from ecosystem "surprises" can be very high. The United States, for example, spends hundreds of millions of dollars each year controlling alien species that were initially rare and of little consequence but eventually became invasive. Increased insurance premiums for floods, fires, and other extreme events have risen dramatically in recent decades. Changes in ecosystems are sometimes important factors in contributing to the increased frequency and severity of the impacts of these extreme events. Such surprises suggest that the precautionary principle may apply to conserving biodiversity even where data are insufficient to calculate costs and benefits.

The costs and risks associated with biodiversity loss are expected to increase, and to fall disproportionately on the poor. As biodiversity and the provision of some ecosystem services decrease, the marginal value of biodiversity increases. There are also distributional impacts that are not necessarily borne out in economic valuation studies, since the poor have a relatively low "willingness to pay." Many aspects of biodiversity decline have a disproportionate impact on poor people. The decline in fish populations, for example, has major implications for artisanal fishers and the communities that depend on fish as an important source of protein. As dryland resources are degraded, it is the poor and vulnerable who suffer the most.

Tools now exist for a far more complete computation of the different values people place on biodiversity and ecosystem services. However, some ecosystem services are more difficult to value, and therefore many decisions continue to be made in the absence of a detailed analysis of the full costs, risks, and

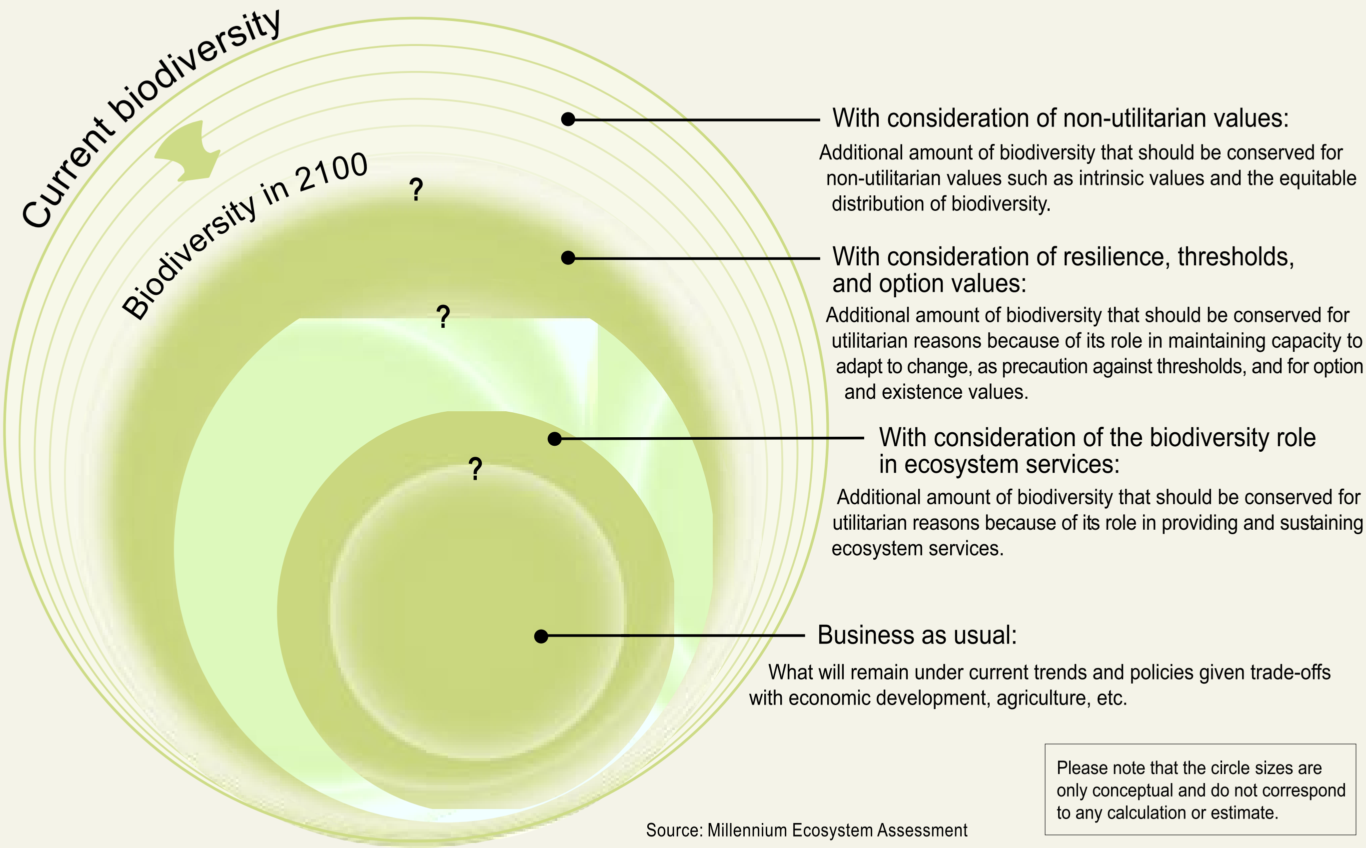
benefits. Economists typically seek to identify the various reasons why biodiversity and ecosystems are valuable to people. These include the fact that ecosystems directly or indirectly support people's own consumption (often referred to as use value) or that they support the consumption of other people or other species (often referred to as non-use value). Various valuation methods are now available to estimate these different sources of value. Despite the existence of these tools, only provisioning ecosystem services are routinely valued. Most supporting, cultural, and regulating services are not valued because the willingness of people to pay for these services—which are not privately owned or traded—cannot be directly observed or measured. In addition, it is recognized by many people that biodiversity has intrinsic value, which cannot be valued in conventional economic terms.

There is substantial scope for greater protection of biodiversity through actions justified on their economic merits for material or other benefits to human well-being. Conservation of biodiversity is essential as a source of particular biological resources, to maintain different ecosystem services, to maintain the resilience of ecosystems, and to provide options for the future. These benefits that biodiversity provides to people have not been well reflected in decision-making and resource management, and thus the current rate of loss of biodiversity is higher than it would be had these benefits been taken into account. (See Figure 2.)

However, the total amount of biodiversity that would be conserved based strictly on utilitarian considerations is likely to be less than the amount present today (*medium certainty*). Even if utilitarian benefits, such as those associated with provisioning and regulating ecosystem services, were fully taken into account in decision-making, Earth would still be losing biodiversity. Other utilitarian benefits often "compete" with the benefits of maintaining greater diversity, and on balance the level of diversity that would exist would be less than is present today.

Figure 2. How Much Biodiversity Will Remain a Century from Now under Different Value Frameworks?

The outer circle in the Figure represents the present level of global biodiversity. Each inner circle represents the level of biodiversity under different value frameworks. Question marks indicate the uncertainties over where the boundaries exist, and therefore the appropriate size of each circle under different value frameworks.



Source: Millennium Ecosystem Assessment

Please note that the circle sizes are only conceptual and do not correspond to any calculation or estimate.

Many of the steps taken to increase the production of ecosystem services (such as agriculture) require the simplification of natural systems, and protecting some other ecosystem services may not necessarily require the conservation of biodiversity (such as timber from monoculture plantation forestry). Ultimately, more biodiversity will be conserved if ethical, equitable distribution and spiritual concerns are taken into account (the outermost area in Figure 2) than if only the operation of imperfect and incomplete markets is relied on.

What are the causes of biodiversity loss, and how are they changing?

Finding # 4. *The drivers of loss of biodiversity and the drivers of changes in ecosystem services are either steady, show no evidence of declining over time, or are increasing in intensity.*

In the aggregate and at a global scale, there are five indirect drivers of changes in biodiversity and ecosystem services: demographic, economic, sociopolitical, cultural and religious, and scientific and technological. Although biodiversity and ecosystem services experience change due to natural causes, current change is dominated by these anthropogenic indirect drivers. In particular, growing consumption of ecosystem services (as well as the growing use of fossil fuels), which results from growing populations and growing per capita consumption, leads to increased pressure on ecosystems and biodiversity. Global economic activity increased nearly sevenfold between 1950 and 2000. Under the MA scenarios, per capita GDP is projected to grow by a factor of 1.9 to 4.4 by 2050. Global population doubled in the last 40 years, reaching 6 billion in 2000, and is projected to reach 8.1–9.6 billion by 2050 in the MA scenarios.

The many processes of globalization have amplified some driving forces of changes in ecosystem services and attenuated other forces. Over the last 50 years there have been significant changes in sociopolitical drivers, including a declining trend in centralized authoritarian governments and a rise in elected democracies, which allows for new forms of management, in particular adaptive management, of environmental resources. Culture conditions individuals' perceptions of the world, and—by influencing what they consider important—has implications for conservation and consumer preferences and suggests courses of action that are appropriate and inappropriate. The development and diffusion of scientific knowledge and technologies can on the one hand allow for increased efficiency in resource use while on the other hand provide the means to increase exploitation of resources.

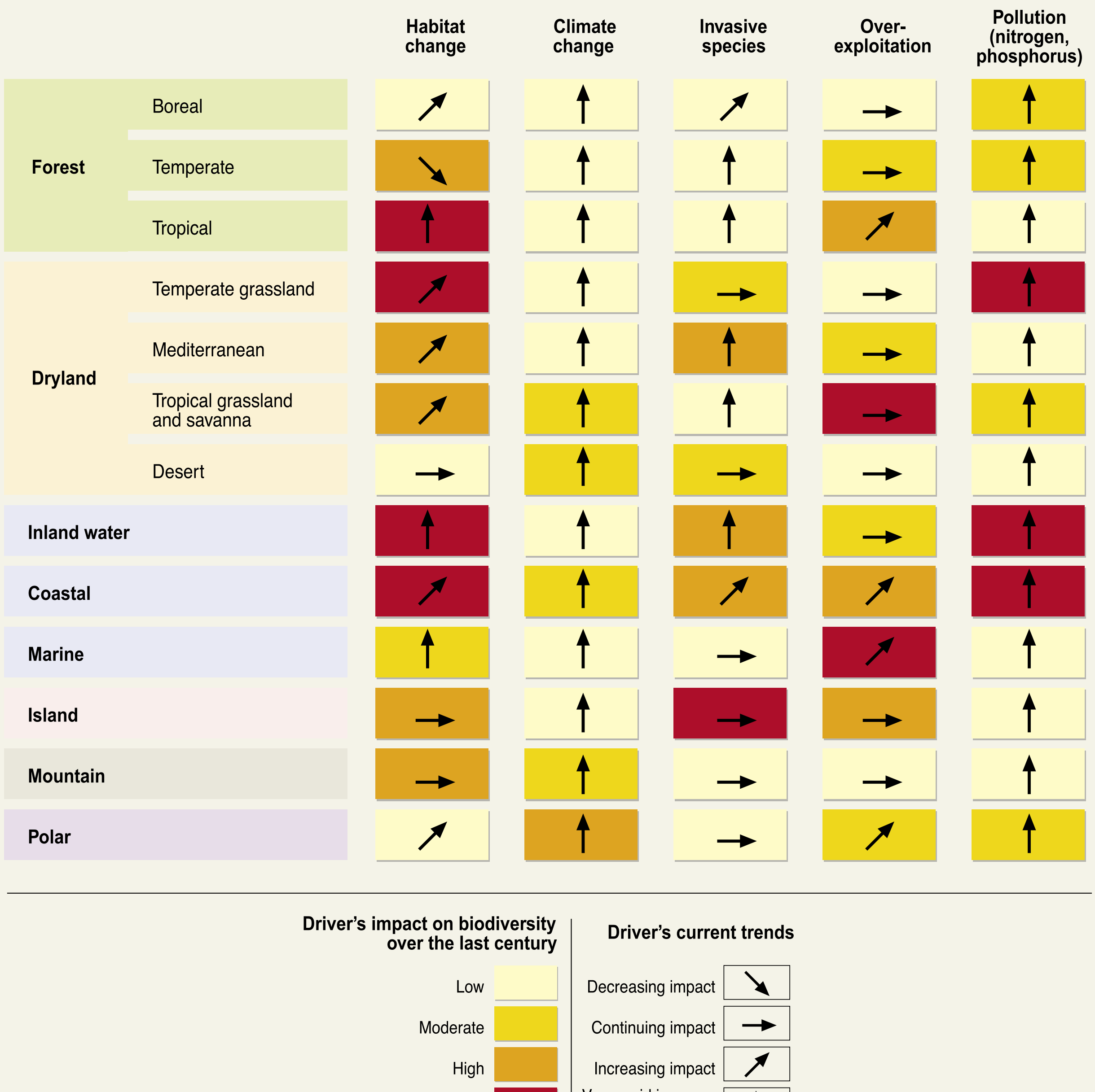
The most important direct drivers of biodiversity loss and change in ecosystem services are habitat change—such as land use change, physical modification of rivers or water withdrawal from rivers, loss of coral reefs, and damage to sea floors due to trawling—climate change, invasive alien species, overexploitation of species, and pollution. For virtually all these drivers, and for most ecosystems where they have been important, the impact of the driver currently remains constant or is growing. (See Figure 3.) Each of these drivers will have important impacts on biodiversity in the twenty-first century:

- *Habitat transformation, particularly from conversion to agriculture.* Cultivated systems (areas where at least 30% of the landscape is in croplands, shifting cultivation, confined livestock production, or freshwater aquaculture) now cover one quarter of Earth's terrestial surface. Under the MA scenarios, a further 10–20% of grassland and forestland is projected to be converted by 2050 (primarily to agriculture). While the expansion of agriculture and its increased productivity is a success story of enhanced production of one key ecosystem service, this success has come at high and growing costs in terms of trade-offs with other ecosystem services, both through the direct impact of land cover change and as a result of release of nutrients into rivers and water withdrawals for irrigation (globally, roughly 15–35% of such irrigation withdrawals are estimated to be unsustainable (*low to medium certainty*). Habitat loss also occurs in coastal and marine systems, though these transformations are less well documented. Trawling of the seabed, for instance, can significantly reduce the diversity of benthic habitats, while destructive fishing and coastal development can lead to losses of coral reefs.
- *Overexploitation* (*especially overfishing*). For marine systems, the dominant direct driver of change globally has been overfishing. Demand for fish as food for people and as feed for aquaculture production is increasing, resulting in increased risk of major, long-lasting collapses of regional marine fisheries. Over much of the world the biomass of fish targeted in fisheries (including that of both the target species and those caught incidentally) has been reduced by 90% relative to levels prior to the onset of industrial fishing. About three quarters (75%) of the world's commercial marine fisheries are either fully exploited (50%) or overexploited (25%).
- *Biotic exchange.* The spread of invasive alien species and disease organisms has increased because of increased trade and travel, including tourism. Increased risk of biotic exchange is an inevitable effect of globalization. While increasingly there are measures to control some of the pathways of invasive species—for example, through quarantine measures and new rules on the disposal of ballast water in shipping—several pathways are not adequately regulated, particularly with regard to introductions into freshwater systems.
- *Nutrient loading.* Since 1950, nutrient loading—anthropogenic increases in nitrogen, phosphorus, sulfur, and other nutrient-associated pollutants—has emerged as one of the most important drivers of ecosystem change in terrestrial, freshwater, and coastal ecosystems, and this driver is projected to increase substantially in the future (*high certainty*). For example, synthetic production of nitrogen fertilizer has been a key driver for the remarkable increase in food production during the last 50 years. Humans now produce more reactive (biologically available) nitrogen than is produced by all natural pathways combined.

Aerial deposition of reactive nitrogen into natural terrestrial ecosystems, especially temperate grasslands, shrublands, and forests, leads directly to lower plant diversity; excessive levels of reactive nitrogen in water bodies, including rivers and other wetlands, frequently leads to algal blooms and eutrophication in inland waters and coastal areas. Similar problems have resulted from phosphorus, the use of which has tripled between 1960 and 1990. Nutrient loading will become an increasingly severe problem, particularly in developing countries and particularly in East and South Asia. Only significant actions to improve the efficiency of nutrient use or the maintenance or restoration of wetlands that buffer nutrient loading will mitigate these trends.

Figure 3. Main Direct Drivers

The cell color indicates the impact to date of each driver on biodiversity in each biome over the past 50–100 years. The arrows indicate the trend in the impact of the driver on biodiversity. Horizontal arrows indicate a continuation of the current level of impact; diagonal and vertical arrows indicate progressively increasing trends in impact. This Figure is based on expert opinion consistent with and based on the analysis of drivers of change in various chapters of the assessment report of the Condition and Trends Working Group. This Figure presents global impacts and trends that may be different from those in specific regions.



Source: Millennium Ecosystem Assessment

■ *Anthropogenic climate change*. Observed recent changes in climate, especially warmer regional temperatures, have already had significant impacts on biodiversity and ecosystems, including causing changes in species distributions, population sizes, the timing of reproduction or migration events, and an increase in the frequency of pest and disease outbreaks. Many coral reefs have undergone major, although often partially reversible, bleaching episodes when local sea surface temperatures have increased during one month by 0.5–1° Celsius above the average of the hottest months. By the end of the twenty-first century, climate change and its impacts may be the dominant direct driver of biodiversity loss and changes in ecosystem services globally.

The scenarios developed by the Intergovernmental Panel on Climate Change project an increase in global mean surface temperature of 2.0–6.4° Celsius above preindustrial levels by 2100, increased incidence of floods and droughts, and a rise in sea level of an additional 8–88 centimeters between 1990 and 2100. The impact on biodiversity will grow worldwide with both increasing rates of change in climate and increasing absolute change in climate. Although some ecosystem services in some regions may initially be enhanced by projected changes in climate (such as increases in temperature or precipitation), and thus these regions may experience net benefits at low levels of climate change, as climate change becomes more severe the harmful impacts on ecosystem services are likely to outweigh the benefits in most regions of the world. The balance of scientific evidence suggests that there will be a significant net harmful impact on ecosystem services worldwide if global mean surface temperature increases more than 2° Celsius above preindustrial levels or at rates greater than 0.2° Celsius per decade (*medium certainty*).

Climate change is projected to further adversely affect key development challenges, including providing clean water, energy services, and food; maintaining a healthy environment; and conserving ecological systems and their biodiversity and associated ecological goods and services:

■ Climate change is projected to exacerbate the loss of biodiversity and increase the risk of extinction for many species, especially those already at risk due to factors such as low population numbers, restricted or patchy habitats, and limited climatic ranges (*medium to high certainty*).

■ Water availability and quality are projected to decrease in many arid and semiarid regions (*high certainty*).

■ The risk of floods and droughts is projected to increase (*high certainty*).

■ The reliability of hydropower and biomass production is projected to decrease in some regions (*high certainty*).

■ The incidence of vector-borne diseases such as malaria and dengue and of waterborne diseases such as cholera is projected to increase in many regions (*medium to high certainty*), and so too are heat stress mortality and threats of decreased nutrition in other regions, along with severe weather traumatic injury and death (*high certainty*).

■ Agricultural productivity is projected to decrease in the tropics and sub-tropics for almost any amount of warming (*low to medium certainty*), and there are projected adverse effects on fisheries.

■ Projected changes in climate during the twenty-first century are very likely to be without precedent during at least the past 10,000 years and, combined with land use change and the spread of exotic or alien species, are likely to limit both the capability of species to migrate and the ability of species to persist in fragmented habitats.

What actions can be taken?

Finding # 5. ***Many of the actions that have been taken to conserve biodiversity and promote its sustainable use have been successful in limiting biodiversity loss and homogenization to rates lower than they would otherwise have been in the absence of such actions. However, further significant progress will require a portfolio of actions that build on current initiatives to address important direct and indirect drivers of biodiversity loss and ecosystem service degradation.***

Less biodiversity would exist today had not communities, NGOs, governments, and, to a growing extent, business and industry taken actions to conserve biodiversity, mitigate its loss, and support its sustainable use. Many traditional cultural practices have served to protect components of biodiversity important for utilitarian or spiritual reasons. Similarly, a number of community-based resource management programs have slowed the loss of biodiversity while contributing benefits to the people by placing community-level benefits as central objectives for sustainable management. Substantial investments have also been made by NGOs, governments, and the private sector to reduce negative impacts on biodiversity, protect threatened biodiversity, and use biodiversity sustainably.

To achieve greater progress toward biodiversity conservation, it will be necessary (but not sufficient) to strengthen response options that are designed with the conservation and sustainable use of biodiversity and ecosystem services as the primary goal.

Responses with a primary goal of conservation that have been partly successful and could be further strengthened include the following:

■ *Protected areas*. Protected areas, including those managed primarily for biodiversity conservation and those managed for a wide range of sustainable uses, are extremely important, especially in environments where biodiversity loss is sensitive to changes in key drivers. PA systems are most successful if they are designed and managed in the context of an ecosystem approach, with due regard to the importance of corridors and interconnectivity of PAs and to external threats such as pollution, climate change, and invasive species. At the global and regional scales, however, the current system of protected areas is not sufficient for conservation of all (or even representative) components of biodiversity. PAs need to be better located, designed, and managed to deal with problems like lack of representativeness, impacts of human settlement within protected areas, illegal harvesting of plants and animals, unsustainable tourism, impacts of invasive species, and vulnerability to global change. Marine and freshwater ecosystems are even less well protected than terrestrial ones, although new developments in marine protected areas and PA networks show promise. Marine protected areas often provide striking examples of the potential synergies between conservation and sustainable use, since appropriately placed ones can significantly increase fishery harvests in adjoining areas. In all cases, better policy and institutional options are needed to promote the fair and equitable sharing of costs and benefits of protected areas at all levels.

- *Species protection and recovery measures for threatened species*. Considerable scope exists to conserve and use biodiversity sustainably through more effective management of individual species. Although "habitat-based" approaches to species conservation are critical, they are by no means a replacement for "species-based" approaches, and likewise, species-based approaches are insufficient for habitat conservation.

- *Ex situ and in situ conservation of genetic diversity*. The benefits from ex situ conservation of genetic diversity, such as genebanks, are substantial. While the technology continues to improve, the major constraint is ensuring that an adequate range of genetic diversity is contained within the ex situ facilities and that these remain in the public domain where, for example, they can serve the needs of poor farmers. In addition, significant benefits can be gained through better integration of ex situ and in situ conservation strategies, particularly for species that are difficult to maintain in ex situ facilities.

- *Ecosystem restoration*. Ecosystem restoration activities are now common in many countries and include actions to restore almost all types of ecosystems, including wetlands, forests, grasslands, estuaries, coral reefs, and mangroves. Restoration will become an increasingly important response as more ecosystems become degraded and as demands for their services continue to grow. Ecosystem restoration, however, is generally far costlier than protecting the original ecosystem, and it is rare that all of the biodiversity and services of a system can be restored.

Responses with a primary goal of sustainable use that have been partly successful and could be further strengthened include the following:

- *Payments and markets for biodiversity and ecosystem services*. Market mechanisms have helped to conserve some aspects of biodiversity and to support its sustainable use—for example, in the context of ecotourism. In many countries, tax incentives, easements, tradable development permit programs, and contractual arrangements (such as between upstream landowners and those benefiting from watershed services) are becoming more common and have often been shown to be useful for conserving land and ecosystem services. Between 1996 and 2001, for example, Costa Rica provided $30 million to landowners to establish or protect over 280,000 hectares of forests and their environmental services. Similarly, carbon markets, which offer long-term gains in carbon sequestration, can provide incentives for conservation, especially if designed well such that they do not harm biodiversity conservation efforts. While more market-oriented approaches such as these show considerable promise, many challenges remain, such as the difficulty of obtaining the information needed to ensure that the buyers are indeed obtaining the services that they are paying for and the need to establish underlying institutional frameworks required for markets to work and ensure benefits are distributed in an equitable manner. Market reforms can be made to work better, and in a world of decentralized decision-making, improving market mechanisms may be essential to both sustainable use and conservation.

- *Incorporating considerations of biodiversity conservation into management practices in sectors such as agriculture, forestry, and fisheries*. Two types of opportunities exist. First, more diverse systems of production can often be as effective as alternative low-diversity systems, or sometimes even more effective. For example, integrated pest management can increase biodiversity on farms, lower costs by reducing the need for pesticides, and meet the growing demand for organic food products. Second, strategies that promote the intensification of production rather than the expansion of the total area of production allow more area for conservation, as described later. Agricultural policy reforms in a number of countries are now beginning to take biodiversity into account, but much more can be done to reduce harmful impacts on biodiversity and ecosystem services.

■ *Capture of benefits by local communities*. Response strategies designed to provide incentives for biodiversity conservation by ensuring that local people benefit from one or more components of biodiversity (such as products from single species or from ecotourism) have proved to be very difficult to implement. They have been most successful when they have simultaneously created incentives for local communities to make management decisions consistent with overall biodiversity conservation. However, while "win-win" opportunities for biodiversity conservation and local community benefits do exist, local communities can often achieve greater economic benefits from actions that lead to biodiversity loss. More generally, actions to increase income generation from biodiversity can provide incentives for conservation but can also lead to degradation without the appropriate enabling environment, which involves appropriate rights to the resources, access to information, and stakeholder involvement.

Integrated responses that address both conservation and sustainable use that could be further strengthened include the following:

■ *Increased coordination among multilateral environmental agreements and between environmental agreements and other international economic and social institutions*. International agreements are indispensable for addressing ecosystem-related concerns that span national boundaries, but numerous obstacles weaken their current effectiveness. The limited, focused nature of the goals and mechanisms included in most bilateral and multilateral environmental treaties does not address the broader issue of ecosystem services and human well-being. Steps are now being taken to increase coordination among these treaties, and this could help broaden the focus of the array of instruments. However, coordination is also needed between the multilateral environmental agreements and the more politically powerful international legal institutions, such as economic and trade agreements, to ensure that they are not acting at cross-purposes.

■ *Public awareness, communication, and education*. Education and communication programs have both informed and changed preferences for biodiversity conservation and have improved implementation of biodiversity responses. Improved communication and education to the public and to decision-makers are essential to achieve the objectives of environmental conventions, sustainable development (including the Johannesburg Plan of Implementation), and sustainable management of natural resources more generally. While the importance of communication and education is well recognized, providing the human and financial resources to undertake effective work is a continuing barrier.

■ *Enhancement of human and institutional capacity for assessing the consequences of ecosystem change for human well-being and acting on such assessments*. Technical capacity for agriculture, forestry, and fisheries management is still limited in many countries, but it is vastly greater than the capacity for effective management for ecosystem services not derived from these sectors.

■ *Increased integration of sectoral responses*. Biodiversity issues in agriculture, fishery, and forestry management in many countries are the responsibility of independent ministries. In order to encourage sustainable use and conservation of biodiversity, these ministries need to establish a process to encourage and foster the development of cross-sectoral policies.

Many of the responses designed with the conservation or sustainable use of biodiversity as the primary goal will not be sustainable or sufficient, however, unless other indirect and direct drivers of change are addressed and enabling conditions are established. For example, the sustainability of protected areas will be severely threatened by human-caused climate change. Similarly, the management of ecosystem services cannot be sustainable globally if the growth in consumption of services continues unabated. Responses also need to address the enabling conditions that determine the effectiveness and degree of implementation of the biodiversity-focused actions.

In particular, changes in institutional and environmental governance frameworks are often required to create these enabling conditions. Today's institutions were not designed to take into account the threats associated with the loss of biodiversity and the degradation of ecosystem services. Nor were they well designed to deal with the management of common pool resources, a characteristic of many ecosystem services. Issues of ownership and access to resources, rights to participation in decision-making, and regulation of particular types of resource use or discharge of wastes can strongly influence the sustainability of ecosystem management and are fundamental determinants of who wins and who loses from changes in ecosystems. Corruption, a major obstacle to effective management of ecosystems, also stems from weak systems of regulation and accountability. In addition, conditionality restrictions by multilateral agencies, such as Structural Adjustment Programs, have also created obstacles to effective ecosystem service management.

Responses that address direct and indirect drivers and that seek to establish enabling conditions that would be particularly important for biodiversity and ecosystem services include the following:

■ *Elimination of subsidies that promote excessive use of ecosystem services (and, where possible, transfer of these subsidies to payments for nonmarketed ecosystem services)*. Subsidies paid to the agricultural sectors of OECD countries between 2001 and 2003 averaged over $324 billion annually, or one third the global value of agricultural products in 2000. And a significant proportion of this total involved production subsidies that lead to overproduction, reduce the profitability of agriculture in developing countries, and promote overuse of fertilizers and pesticides. Similar problems are created by fishery subsidies, which amounted to approximately $6.2 billion in OECD countries in 2002, or

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about 20% of the gross value of production. Many countries outside the OECD also have inappropriate input and production subsidies.

Although removal of perverse subsidies will produce net benefits, it will not be without costs. Some of the people benefiting from production subsidies (through either the low prices of products that result from the subsidies or as direct recipients) are poor and would be harmed by their removal. Compensatory mechanisms may be needed for these groups. Moreover, removal of agricultural subsidies within the OECD would need to be accompanied by actions designed to minimize adverse impacts on ecosystem services in developing countries. But the basic challenge remains that the current economic system relies fundamentally on economic growth that disregards its impact on natural resources.

■ *Sustainable intensification of agriculture*. The expansion of agriculture will continue to be one of the major drivers of biodiversity loss well into the twenty-first century. In regions where agricultural expansion continues to be a large threat to biodiversity, the development, assessment, and diffusion of technologies that could increase the production of food per unit area sustainably, without harmful trade-offs related to excessive consumption of water or use of nutrients or pesticides, would significantly lessen pressure on biodiversity. In many cases, appropriate technologies already exist that could be applied more widely, but countries lack the financial resources and institutional capabilities to gain and use these technologies. Where agriculture already dominates landscapes, the maintenance of biodiversity within these areas is an important component of total biodiversity conservation efforts, and, if managed appropriately, can also contribute to agricultural productivity and sustainability through the ecosystem services that biodiversity provides (such as through pest control, pollination, soil fertility, protection of water courses against soil erosion, and the removal of excessive nutrients).

■ *Slowing and adapting to climate change*. Significant reductions in net greenhouse gas emissions are technically feasible due to an extensive array of technologies in the energy supply, energy demand, and waste management sectors. Reducing projected emissions will require the development and implementation of supporting institutions and policies to overcome barriers to the diffusion of these technologies into the marketplace, increased public and private-sector funding for research and development, and effective technology transfer. Given the inertia in the climate system, actions to facilitate the adaptation of biodiversity and ecosystems to climate change will also be necessary to mitigate negative impacts. These may include the development of ecological corridors or networks.

■ *Addressing unsustainable consumption patterns*. Consumption of ecosystem services and nonrenewable resources affects biodiversity and ecosystems directly and indirectly. Total consumption is a factor of per capita consumption, population, and efficiency of resource use. Slowing biodiversity loss requires that the combined effect of these factors be reduced.

■ *Slowing the global growth in nutrient loading* (even while increasing fertilizer application in regions where crop yields are constrained by the lack of fertilizers, such as parts of sub-Saharan Africa). Technologies already exist for reduction of nutrient pollution at reasonable costs, but new policies are needed for these tools to be applied on a sufficient scale to slow and ultimately reverse the increase in nutrient loading.

■ *Correction of market failures and internalization of environmental externalities that lead to the degradation of ecosystem services*. Because many ecosystem services are not formally traded, markets fail to provide appropriate signals that might otherwise contribute to the efficient allocation and sustainable use. In addition, many of the harmful trade-offs and costs associated with the management of one ecosystem service are borne by others and so are not weighed in sectoral decisions regarding the management of that service. In countries with supportive institutions in place, market-based tools could be more effectively applied to correct some market failures and internalize externalities, particularly with respect to provisioning ecosystem services. Various economic instruments or market-based approaches that show promise, in addition to the creation of new markets for ecosystem services and payments for ecosystem services noted earlier, include taxes or user fees for activities with "external costs," cap-and-trade systems for reduction of pollutants, and mechanisms to allow consumer preferences to be expressed through markets (through certification schemes, for instance).

■ *Integration of biodiversity conservation and development planning.* Protected areas, restoration ecology, and markets for ecosystem services will have higher chances of success if these responses are reflected in the national development strategies or in poverty reduction strategies, in the case of many developing countries. At the same time, development plans can be more effective if they take into account existing plans and priorities for the conservation and sustainable use of biodiversity.

■ *Increased transparency and accountability of government and private-sector performance in decisions that affect ecosystems, including through greater involvement of concerned stakeholders in decision-making.* Laws, policies, institutions, and markets that have been shaped through public participation in decision-making are more likely to be effective and perceived as just. Stakeholder participation also contributes to the decision-making process because it allows for a better understanding of impacts and vulnerability, the distribution of costs and benefits associated with trade-offs, and the identification of a broader range of response options that are available in a specific context. And stakeholder involvement and transparency of decision-making can increase accountability and reduce corruption.

■ *Scientific findings and data need to be made available to all of society.* A major obstacle for knowing (therefore valuing), preserving, sustainably using, and sharing benefits equitably from the biodiversity of a region is the human and institutional capacity to research a country's biota. The CONABIO initiative in Mexico and INBio in Costa Rica offer examples of successful national models for converting basic taxonomic information into knowledge for biodiversity conservation policies, as well as for other policies relating to ecosystems and biodiversity and for use in education and economic development.

Ecosystem approaches, as adopted by the Convention on Biological Diversity and others, provide an important framework for assessing biodiversity and ecosystem services and evaluating and implementing potential responses. The CBD refers to the ecosystem approach as a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way. Application of the ecosystem approach involves a focus on the functional relationships and processes within ecosystems, attention to the distribution of benefits that flow from ecosystem services, the use of adaptive management practices, the need to carry out management actions at multiple scales, and intersectoral cooperation. A number of other established approaches, such as sustainable forest management, integrated river basin management, and integrated marine and coastal area management, are consistent with the ecosystem approach and support its application in various sectors or biomes.

The usefulness of the ecosystem approach is strongly supported by the MA findings since this approach is well suited to the need to take into account the trade-offs that exist in the management of ecosystems and incorporates the need for both coordination across sectors and management across scales. The ecosystem approach also provides a framework for designing and implementing the entire range of necessary responses, ranging from those directly addressing the needs for conservation and sustainable use of biodiversity to those necessary to address other indirect and direct drivers that influence ecosystems.

What are the prospects for the 2010 target of reducing the rate of biodiversity loss, and what are the implications for the CBD?

Finding #6. ***Unprecedented additional efforts would be needed to achieve, by 2010, a significant reduction in the rate of biodiversity loss at all levels.***

The magnitude of the challenge of slowing the rate of biodiversity loss is demonstrated by the fact that most of the direct drivers of biodiversity loss are projected to either remain constant or to increase in the near future. Moreover, inertia in natural and human institutional systems results in time lags—of years, decades, or even centuries—between actions being taken and their impact on biodiversity and ecosystems becoming apparent. The design of future targets, goals, and interventions for the conservation and sustainable use of biodiversity will require significant advances in the methods used for measuring biodiversity and consideration of the importance of key drivers, inertia in natural and human institutional systems, and trade-offs and synergies with other societal goals.

Several of the 2010 sub-targets adopted by the CBD could be met for some components of biodiversity, or some indicators, in some regions. For example, overall the rate of habitat loss—the main driver of species loss in terrestrial ecosystems—is now slowing in certain regions. This may not necessarily translate, however, into lower rates of species loss for all taxa because of the nature of the relationship between numbers of species and area of habitat, because decades or centuries may pass before species extinctions reach equilibrium with habitat loss, and because other drivers of loss, such as climate change, nutrient loading, and invasive species, are projected to increase. While rates of habitat loss are decreasing in temperate areas, they are projected to continue to increase in tropical areas. At the same time, if areas of particular importance for biodiversity are maintained within protected areas or by other conservation mechanisms, and if proactive measures are taken to protect threatened species, then the rate of biodiversity loss of targeted habitats and species could be reduced.

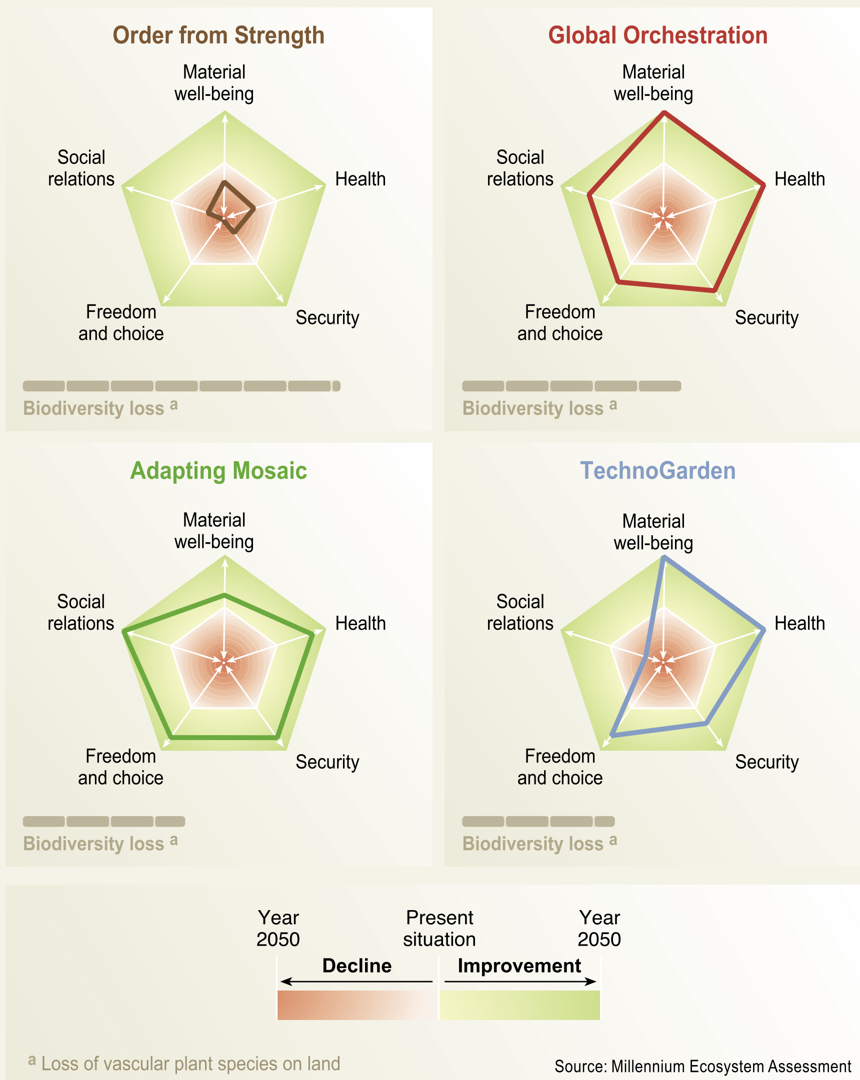
Trade-offs and synergies between achieving the 2015 targets of the Millennium Development Goals and the 2010 target of reducing the rate of biodiversity loss make achieving each of these targets unlikely if tackled independently, but they may be partially achievable if tackled in an integrated manner. Given that biodiversity underpins the provision of ecosystem services, which in turn affects human well-being, long-term sustainable achievement of the MDGs requires that biodiversity loss is controlled as part of MDG 7 (ensuring environmental sustainability). There are potential synergies as well as trade-offs between the shorter-term MDG targets for 2015 and reducing the rate of loss of biodiversity by 2010. For example, improving rural road networks—a common feature of hunger reduction strategies—will likely accelerate rates of biodiversity loss (directly through habitat fragmentation and indirectly by facilitating unsustainable harvests of bushmeat and so on).

Moreover, the MA scenarios suggest that future development paths that show relatively good progress toward meeting the poverty, hunger reduction, and health targets also show relatively high rates of habitat loss and associated loss of species over 50 years. (See Figure 4.) This does not imply that biodiversity loss is, in and of itself, good for poverty reduction. Instead, it indicates that many economic development activities aimed at income generation are likely to have negative impacts on biodiversity unless the values of biodiversity and related ecosystem services are factored in. For a reduction in the rate of biodiversity loss to contribute to poverty alleviation, priority would need to be given to protecting the biodiversity that is of particular importance to the well-being of poor and vulnerable people. Efforts toward the 2010 targets will help to achieve MDG 7.

Short-term goals and targets are not enough. Given the characteristic response times for human political and socioeconomic systems and ecological systems, longer-term goals and targets (such as for 2050) are needed to guide policy and actions. Differences in inertia among drivers and among different components of biodiversity make it difficult to set goals or targets over a single time frame. For some drivers, such as the overharvest of particular species, lag times are rather short; for others, such as nutrient loading and climate change, lag times are much longer. Similarly, for some components of biodiversity, such as populations, lag times in the response of populations of many species

Figure 4. Trade-offs between Biodiversity and Human Well-being under the Four MA Scenarios

Loss of biodiversity is least in the two scenarios that feature a proactive approach to environmental management (*TechnoGarden* and *Adapting Mosaic*). The MA scenario with the worst impacts on biodiversity (high rates of habitat loss and species extinction) is also the one with the worst impacts on human well-being (*Order from Strength*). A scenario with relatively positive implications for human well-being (*Global Orchestration*) had the second worst implications for biodiversity.



to changes may be measured in years or decades, while for other components, such as the equilibrium number of species, lag times may be measured in hundreds of years. Thus, scenarios with short time frames may not capture the long-term benefits of biodiversity to human well-being. Further, while actions can be taken to reduce the drivers and their impacts on biodiversity, some change is inevitable, and adaptation to such change will become an increasingly important component of response measures.

Better prediction of the impacts of drivers on biodiversity, ecosystem functioning, and ecosystem services, together with improved measures of biodiversity, would aid decision-making at all levels. Models need to be developed and used to make better use of observational data for determining the trends and conditions of biodiversity. Additional effort is required to reduce critical uncertainties, including those associated with thresholds associated with changes in biodiversity, ecosystem functioning, and ecosystem services. Existing biodiversity indicators are helping to communicate trends in biodiversity and highlight its importance to human well-being. Additional measures, however, especially those that meet the needs of stakeholders, would assist in communication, setting achievable targets, addressing trade-offs between biodiversity conservation and other objectives, and finding ways to optimize responses. Given the multiple components of and values associated with biodiversity, no single measure is likely to be suitable for all needs.

A very wide array of possible futures for biodiversity remains within the control of people and decision-makers today, and these different futures have very different implications for the human well-being of current and future generations. The world in 2100 could have substantial remaining biodiversity or it could be relatively homogenized and contain relatively low levels of diversity. Science can help to inform people about the costs and benefits of these different futures and identify paths to achieve them (plus the risks and thresholds), and where there is insufficient information to predict the consequences of alternative actions, science can identify the range of possible outcomes. Science can thus help to ensure that social decisions are made with the best available information. But ultimately the choice of biodiversity levels must be determined by society.

Key Questions on Biodiversity in the Millennium Ecosystem Assessment

MARY L. FROST

1. *Biodiversity: What is it, where is it, and why is it important?*

■ **Biodiversity is the variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species, and of ecosystems.**

■ **Biodiversity forms the foundation of the vast array of ecosystem services that critically contribute to human well-being.**

■ **Biodiversity is important in human-managed as well as natural ecosystems.**

■ **Decisions humans make that influence biodiversity affect the well-being of themselves and others.**

What Is Biodiversity?

Biodiversity is the foundation of ecosystem services to which human well-being is intimately linked. No feature of Earth is more complex, dynamic, and varied than the layer of living organisms that occupy its surfaces and its seas, and no feature is experiencing more dramatic change at the hands of humans than this extraordinary, singularly unique feature of Earth. This layer of living organisms—the biosphere—through the collective metabolic activities of its innumerable plants, animals, and microbes physically and chemically unites the atmosphere, geosphere, and hydrosphere into one environmental system within which millions of species, including humans, have thrived. Breathable air, potable water, fertile soils, productive lands, bountiful seas, the equitable climate of Earth's recent history, and other ecosystem services (see Box 1.1 and Key Question 2) are manifestations of the workings of life. It follows that large-scale human influences over this biota have tremendous impacts on human well-being. It also follows that the nature of these impacts, good or bad, is within the power of humans to influence (CF2).

Defining Biodiversity

Biodiversity is defined as "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems." The importance of this definition is that it draws attention to the many dimensions of biodiversity. It explicitly recognizes that every biota can be characterized by its taxonomic, ecological, and genetic diversity and that the way these dimensions of diversity vary over space and time is a key feature of biodiversity. Thus only a multidimensional assessment of biodiversity can provide insights into the relationship between changes in biodiversity and changes in ecosystem functioning and ecosystem services (CF2).

Biodiversity includes all ecosystems—managed or unmanaged. Sometimes biodiversity is presumed to be a relevant feature of only unmanaged ecosystems, such as wildlands, nature preserves, or national parks. This is incorrect. Managed systems—be they plantations, farms, croplands, aquaculture sites, rangelands, or even urban parks and urban ecosystems—have their own biodiversity. Given that cultivated systems alone now account for more than 24% of Earth's terrestrial surface, it is critical that any decision concerning biodiversity or ecosystem services address the maintenance of biodiversity in these largely anthropogenic systems (C26.1).

Measuring Biodiversity: Species Richness and Indicators

In spite of many tools and data sources, biodiversity remains difficult to quantify precisely. But precise answers are seldom needed to devise an effective understanding of where biodiversity is, how it is changing over space and time, the drivers responsible for such change, the consequences of such change for ecosystem services and human well-being, and the response options available. Ideally, to assess the conditions and trends of biodiversity either globally or sub-globally, it is necessary to measure the abundance of all organisms over space and time, using taxonomy (such as the number of species), functional traits (for example, the ecological type such as nitrogen-fixing plants like legumes versus non-nitrogen-fixing plants), and the interactions among species that affect their dynamics and function (predation, parasitism, competition, and facilitation such as pollination, for instance, and how strongly such interactions affect ecosystems). Even more important would be to estimate turnover of biodiversity, not just point estimates in space or time. Currently, it is not possible to do this with much accuracy because the data are lacking. Even for the taxonomic component of biodiversity, where information is the best, considerable uncertainty remains about the true extent and changes in taxonomic diversity (C4).

There are many measures of biodiversity; species richness (the number of species in a given area) represents a single but important metric that is valuable as the common currency of the diversity of life—but it must be integrated with other metrics to fully capture biodiversity. Because the multidimensionality of biodiversity poses formidable challenges to its measurement, a variety of surrogate or proxy measures are often used. These include the species richness of specific taxa, the number of distinct plant functional types (such as grasses, forbs, bushes, or trees), or the diversity of distinct gene sequences in a sample of microbial DNA taken from the soil. Species- or other taxon-based measures of biodiversity, however, rarely capture key attributes such as variability, function, quantity, and distribution—all of which provide insight into the roles of biodiversity. (See Box 1.2.)

Ecological indicators are scientific constructs that use quantitative data to measure aspects of biodiversity, ecosystem condition, services, or drivers of change, but no single ecological indicator captures all the dimensions of biodiversity (C2.2.4). (See Box 1.3.) Ecological indicators form a critical component of monitoring, assessment, and decision-making and are designed to communicate information quickly and easily to policy-makers. In a similar manner, economic indicators such as GDP are highly influential and well understood by decision-makers. Some environmental indicators, such as global mean temperature and atmospheric CO_2 concentrations, are becoming widely accepted as measures of anthropogenic effects on global climate. Ecological indicators are founded on much the same principles and therefore carry with them similar pros and cons (C2.2.4). (See Box 1.4.)

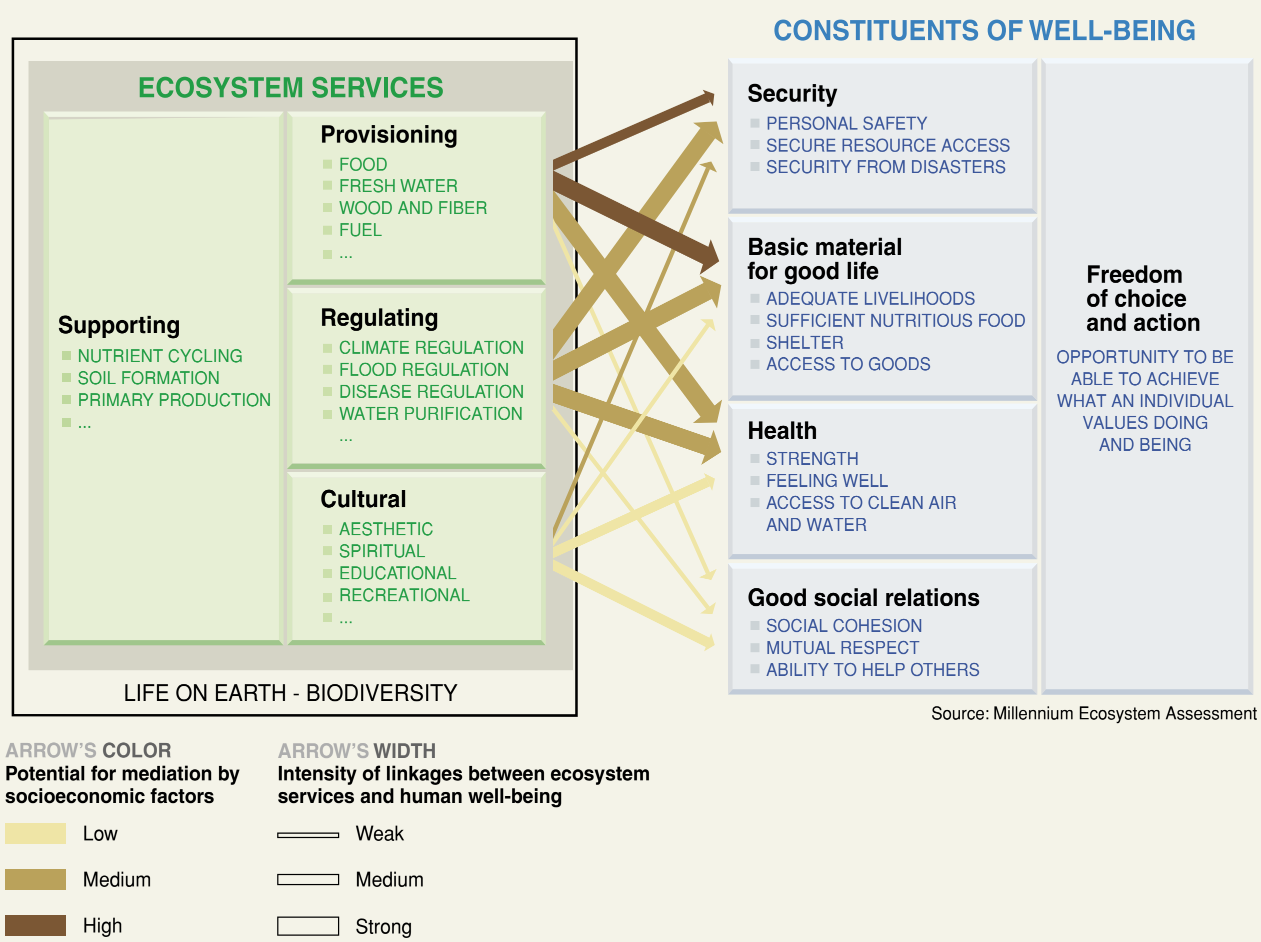
Where Is Biodiversity?

Biodiversity is essentially everywhere, ubiquitous on Earth's surface and in every drop of its bodies of water. The virtual omnipresence of life on Earth is seldom appreciated because most organisms are small (<5 centimeters); their presence is sparse, ephemeral, or cryptic, or, in the case of microbes, they are invisible to the unaided human eye (CF2).

Documenting spatial patterns in biodiversity is difficult because taxonomic, functional, trophic, genetic, and other dimensions of biodiversity have been relatively poorly quantified. Even knowledge of taxonomic diversity, the best known dimension of biodiversity, is incomplete and strongly biased toward the species level, megafauna, temperate systems, and components used by people. (See Figure 1.1.) This results in significant gaps in knowledge, especially regarding the status of tropical systems, marine and freshwater biota, plants, invertebrates, microorganisms, and subterranean biota. For these reasons, estimates of the total number of species on Earth range from 5 million to 30 million. Irrespective of actual global species richness, however, it is clear that the 1.7–2 million species that have been formally identified represent only a small portion of total species richness. More-complete biotic inventories are badly needed to correct for this deficiency (C4).

Box 1.1. Linkages among Biodiversity, Ecosystem Services, and Human Well-being

Biodiversity represents the foundation of ecosystems that, through the services they provide, affect human well-being. These include provisioning services such as food, water, timber, and fiber; regulating services such as the regulation of climate, floods, disease, wastes, and water quality; cultural services such as recreation, aesthetic enjoyment, and spiritual fulfillment; and supporting services such as soil formation, photosynthesis, and nutrient cycling (CF2). The MA considers human well-being to consist of five main components: the basic material needs for a good life, health, good social relations, security, and freedom of choice and action. Human well-being is the result of many factors, many directly or indirectly linked to biodiversity and ecosystem services while others are independent of these.



Spatial Patterns of Biodiversity: Hotspots, Biomes,[1] Biogeographic Realms, Ecosystems, and Ecoregions

While the data to hand are often insufficient to provide accurate pictures of the extent and distribution of all components of biodiversity, there are, nevertheless, many patterns and tools that decision-makers can use to derive useful approximations for both terrestrial and marine ecosystems. North-temperate regions often have usable data on spatial distributions of many taxa, and some groups (such as birds, mammals, reptiles, plants, butterflies, and dragonflies) are reasonably well documented globally. Biogeographic principles (such as gradients in species richness associated with latitude, temperature, salinity, and water depth) or the use of indicators can supplement available biotic inventories. Global and sub-global maps of species richness, several of which are provided in the MA reports *Current State and Trends* and *Scenarios*, provide valuable pictures of the distribution of biodiversity (C4, S10).

Most macroscopic organisms have small, often clustered geographical ranges, leading to centers of both high diversity and endemism, frequently concentrated in isolated or topographically variable regions (islands, mountains, peninsulas). A large proportion of the world's terrestrial biodiversity at the species level is concentrated in a small part of the world, mostly in the tropics. Even among the larger and more mobile species, such as terrestrial vertebrates, more than one third of all species have ranges of less than 1,000 square kilometers. In contrast, local and regional diversity of microorganisms tends to be more similar to large-scale and global diversity because of their large population

Box 1.2. Measuring and Estimating Biodiversity: More than Species Richness

Measurements of biodiversity seldom capture all its dimensions, and the most common measure—species richness—is no exception. While this can serve as a valuable surrogate measure for other dimensions that are difficult to quantify, there are several limitations associated with an emphasis on species. First, what constitutes a species is not often well defined. Second, although native species richness and ecosystem functioning correlate well, there is considerable variability surrounding this relationship. Third, species may be taxonomically similar (in the same genus) but ecologically quite distinct. Fourth, species vary extraordinarily in abundance; for most biological communities, only a few are dominant, while many are rare.

Simply counting the number of species in an ecosystem does not take into consideration how variable each species might be or its contribution to ecosystem properties. For every species, several properties other than its taxonomy are more valuable for assessment and monitoring. These properties include measures of genetic and ecological variability, distribution and its role in ecosystem processes, dynamics, trophic position, and functional traits.

In practice, however, variability, dynamics, trophic position, and functional attributes of many species are poorly known. Thus it is both necessary and useful to use surrogate, proxy, or indicator measures based on the taxonomy or genetic information.

Important attributes missed by species or taxon-based measures of diversity include:

- abundance—how much there is of any one type. For many provisioning services (such as food, fresh water, fiber), abundance matters more than the presence of a range of genetic varieties, species, or ecosystem types.
- variation—the number of different types over space and time. For understanding population persistence, the number of different varieties or races in a species or variation in genetic composition among individuals in a population provide more insight than species richness.
- distribution—where quantity or variation in biodiversity occurs. For many purposes, distribution and quantity are closely related and are therefore generally treated together under the heading of quantity. However, quantity may not always be sufficient for services: the location, and in particular its availability to the people that need it, will frequently be more critical than the absolute volume or biomass of a component of biodiversity.

Finally, the importance of variability and quantity varies, depending on the level of biodiversity measured. (See Table.)

Level	Importance of Variability	Importance of Quantity and Distribution
Genes	adaptive variability for production and resilience to environmental change, pathogens, and so on	local resistance and resilience
Populations	different populations retain local adaptation	local provisioning and regulating services, food, fresh water
Species	the ultimate reservoir of adaptive variability, representing option values	community and ecosystem interactions are enabled through the co-occurrence of species
Ecosystems	different ecosystems deliver a diversity of roles	the quantity and quality of service delivery depend on distribution and location

[1] Biomes represent broad habitat and vegetation types, span across biogeographic realms, and are useful units for assessing global biodiversity and ecosystem services because they stratify the globe into ecologically meaningful and contrasting classes. Throughout this report, and elsewhere in the MA, the 14 biomes of the WWF terrestrial biome classification are used, based on WWF terrestrial ecoregions (C4.2.2).

size, greater dispersal, larger range sizes, and lower levels of regional species clustering (C4.2.3).

Biomes and biogeographic realms provide broad pictures of the distribution of functional diversity. Functional diversity (the variety of different ecological functions in a community independent of its taxonomic diversity) shows patterns of associations (biota typical of wetlands, forests, grasslands, estuaries, and so forth) with geography and climate known as biomes (see Figure 1.2), with ecosystems and ecoregions being smaller divisions within biomes (see Figure 1.3). These can be used to provide first-order approximations of both expected functional diversity as well as possible changes in the distribution of these associations should environmental conditions change.

Box 1.3. Ecological Indicators and Biodiversity

The National Research Council in the United States identified three categories of ecological indicators, none of which adequately assesses the many dimensions of biodiversity:

- Ecosystem extent and status (such as land cover and land use) indicates the coverage of ecosystems and their ecological attributes.
- Ecological capital, further divided into biotic raw material (such as total species richness) and abiotic raw materials (such as soil nutrients), indicates the amount of resources available for providing services.
- Ecological functioning (such as lake trophic status) measures the performance of ecosystems.

Care must therefore be taken not to apply ecological indicators to uses they were not intended for, especially when assessing biodiversity. For example, biotic raw ecological capital measures the amount and variability of species within a defined area (C2.2.4). This may seem related to biodiversity, but it measures only taxonomic diversity. As such, this indicator does not necessarily capture many important aspects of biodiversity that are significant for the delivery of ecosystem services.

The most common ecological indicator, total species richness, is a case in point. TSR only partially captures ecosystem services. It does not differentiate among species in terms of sensitivity or resilience to change, nor does it distinguish between species that fulfill significant roles in the ecosystem (such as pollinators and decomposers) and those that play lesser roles. That is, all species are weighted equally, which can lead assigning equal values to areas that have quite different biota. Moreover, the value of TSR depends on the definition of the area over which it was measured and may scale neither to smaller nor to larger areas. Finally, TSR does not differentiate between native and non-native species, and the latter often include exotic, introduced, or invasive species that frequently disrupt key ecosystem services. Ecosystem degradation by human activities may temporarily increase species richness in the limited area of the impact due to an increase in exotic or weedy species, but this is not a relevant increase in biodiversity (C2.2.4).

Given the limitations of ecological indicators to serve as adequate indicators of biodiversity, work is urgently needed to develop a broader set of biodiversity indicators that are aligned against valued aspects of biodiversity. With the exception of diversity indices based on taxonomic or population measures, little attention has been paid to the development of indicators that capture all the dimensions of biodiversity (C4.5.1), although see Key Question 6 and C4.5.2 for more on indicators for the “2010 biodiversity target.”

Temporal Patterns of Biodiversity: Background Rates of Extinction and Biodiversity Loss

Knowledge of patterns of biodiversity over time allow for only very approximate estimates of background rates of extinction or of how fast species have become extinct over geological time. Except for the last 1,000 years, global biodiversity has been relatively constant over most of human history, but the history of life is characterized by considerable change. The estimated magnitude of background rates of extinction is roughly 0.1–1.0 extinctions per million species per year. Most measurements of this rate have come from assessing the length of species' lifetimes through the fossil record: these range over 0.5–13 million years, and possibly 0.2–16 million years. These data probably underestimate background extinction rates because they are necessarily largely derived from taxa that are abundant and widespread in the fossil record (C4.4.2). Current rates of extinction are discussed in Key Question 3.

A mismatch exists between the dynamics of changes in natural systems and human responses to those changes. This mismatch arises from the lags in ecological responses, the complex feedbacks between socioeconomic and ecological systems, and the difficulty of predicting thresholds. Multiple impacts (especially the addition of climate change to the mix of forcing functions) can cause thresholds, or rapid and dramatic changes in ecosystem function even though the increase in environmental

Box 1.4. Criteria for Effective Ecological Indicators

An effective ecological indicator should:

- Provide information about changes in important processes
- Be sensitive enough to detect important changes but not so sensitive that signals are masked by natural variability
- Be able to detect changes at the appropriate temporal and spatial scale without being overwhelmed by variability
- Be based on well-understood and generally accepted conceptual models of the system to which it is applied
- Be based on reliable data that are available to assess trends and are collected in a relatively straightforward process
- Be based on data for which monitoring systems are in place
- Be easily understood by policy-makers

stress has been small and constant over time. Understanding such thresholds requires having long-term records, but such records are usually lacking or monitoring has been too infrequent, of the wrong periodicity, or too localized to provide the necessary data to analyze and predict threshold behavior (C28, S3.3.1).

Shifts to different regimes may cause rapid substantial changes in biodiversity, ecosystem services, and human well-being. Regime shifts have been commonly documented in pelagic systems due to thresholds related to temperature regimes and overexploitation (C19.2.1, C18). Some regime shifts are essentially irreversible, such as coral reef ecosystems that undergo sudden shifts from coral-dominated to algal-dominated reefs (C19.5). The trigger for such phase shifts usually includes increased nutrient inputs leading to eutrophic conditions and removal of herbivorous fishes that maintain the balance between corals and algae. Once the thresholds (both an upper and a lower threshold) for the two ecological processes of nutrient loading and herbivory are passed, the phase shift occurs quickly (within months), and the resulting ecosystem—though stable—is less productive and less diverse. Consequently, human well-being is affected not only by reductions in food supply and decreased income from reef-related industries (diving and snorkeling, aquarium fish collecting, and so on), but also by increased costs due to diminished ability of reefs to protect shorelines. (Algal reefs are more prone to being broken up in storm events, leading to shoreline erosion and seawater breaches of land) (C19.3). Such phase shifts have been documented in Jamaica, elsewhere in the Caribbean, and in Indo-Pacific reefs (C19, S3.3.1).

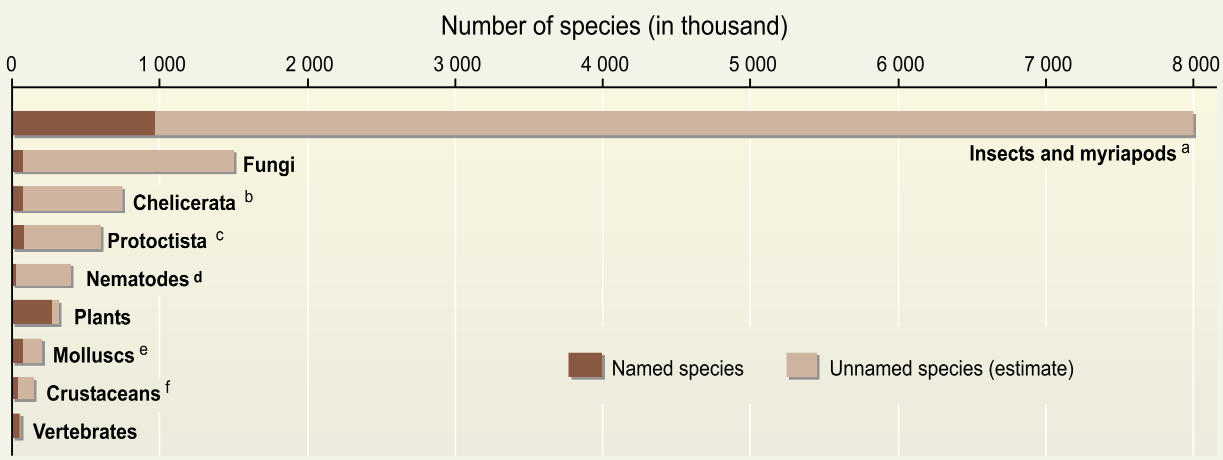
Introduced invasive species can act as a trigger for dramatic changes in ecosystem structure, function, and delivery of services. For example, the introduction of the carnivorous ctenophore *Mnemiopsis leidyi* (a jellyfish-like animal) in the Black Sea caused the loss of 26 major fisheries species and has been implicated (along with other factors) in the subsequent growth of the oxygen-deprived "dead" zone (C19.2.1).

Biodiversity and Its Link to Ecosystem Services

Biodiversity plays an important role in ecosystem functions that provide supporting, provisioning, regulating, and cultural services. These services are essential for human well-being. However, at present there are few studies that link changes in biodiversity with changes in ecosystem functioning to changes in human well-being. Protecting the Catskill watersheds that provide drinking water for New York City is one case where safeguarding ecosystem services paid a dividend of several billion dollars. Further work that demonstrates the links between biodiversity, regulating and supporting services, and human well-being is needed to show this vital but often unappreciated value of biodiversity (C4, C7, C11).

Species composition matters as much or more than species richness when it comes to ecosystem services. Ecosystem functioning, and hence ecosystem services, at any given moment in time is strongly influenced by the ecological characteristics of the most abundant species, not by the number of species. The relative importance of a species to ecosystem functioning is determined by its traits and its relative abundance. For example, the traits of the dominant or most abundant plant species—such as how long they live, how big they are, how fast they assimilate carbon and nutrients, how decomposable their leaves are, or how

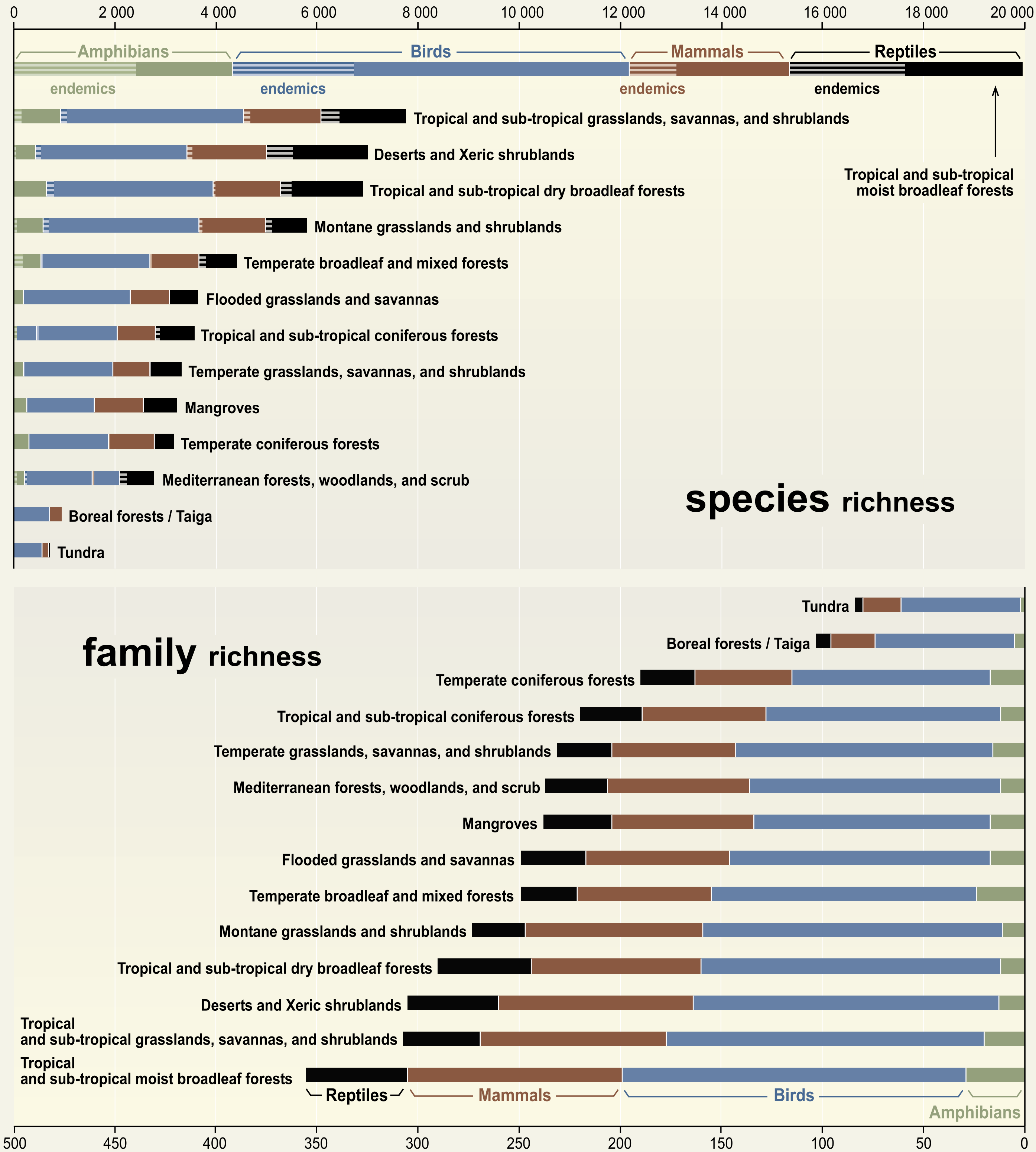
Figure 1.1. Estimates of Proportions and Numbers of Named Species in Groups of Eukaryote Species and Estimates of Proportions of the Total Number of Species in Groups of Eukaryotes (C4.2.3)



a Myriapods: centipedes and millipedes
b Arachnids
c Algae, slime mold, amoeboids, and other single-celled organisms (excluding bacteria)
d Roundworms
e Snails, clams, squids, octopuses, and kin
f Barnacles, copepods, crabs, lobsters, shrimps, krill, and kin

Source: Millennium Ecosystem Assessment

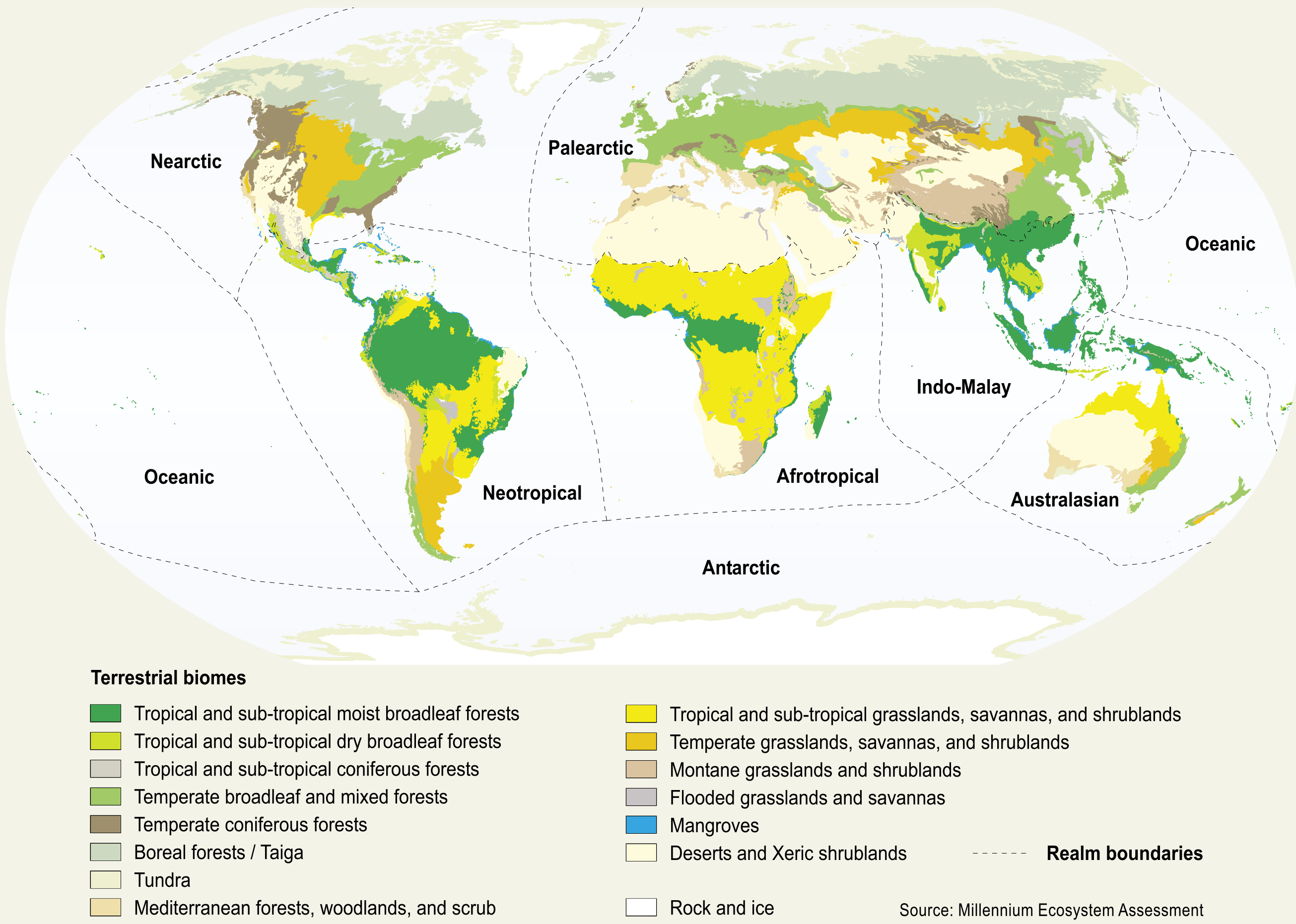
Figure 1.2. Comparisons for the 14 Terrestrial Biomes of the World in Terms of Species Richness, Family Richness, and Endemic Species (C4 Fig 4.7)



Source: Millennium Ecosystem Assessment

Figure 1.3. The 8 Biogeographical Realms and 14 Biomes Used in the MA (C4 Figure C4.3)

Biogeographic realms are large spatial regions within which ecosystems share a broadly similar biological evolutionary history. Eight terrestrial biogeographic realms are typically recognized, corresponding roughly to continents. Although similar ecosystems (such as tropical moist forests) share similar processes and major vegetation types wherever they are found, their species composition varies markedly depending on the biogeographic realm in which they are found. Assessing biodiversity at the level of biogeographic realms is important because the realms display substantial variation in the extent of change, they face different drivers of change, and there may be differences in the options for mitigating or managing the drivers. Terrestrial biogeographic realms reflect freshwater biodiversity patterns reasonably well, but marine biogeographic realms are poorly known and largely undefined (C4.2.1).



dense their wood is—are usually the key species drivers of an ecosystem's processing of matter and energy. Thus conserving or restoring the composition of biological communities, rather than simply maximizing species numbers, is critical to maintaining ecosystem services (C11.2.1, C11.3).

Local or functional extinction, or the reduction of populations to the point that they no longer contribute to ecosystem functioning, can have dramatic impacts on ecosystem services. Local extinctions (the loss of a species from a local area) and functional extinctions (the reduction of a species such that it no longer plays a significant role in ecosystem function) have received little attention compared with global extinctions (loss of all individuals of a species from its entire range). Loss of ecosystem functions, and the services derived from them, however, occurs long before global extinction. Often, when the functioning of a local ecosystem has been pushed beyond a certain limit by direct or indirect biodiversity alterations, the ecosystem-service losses may persist for a very long time (C11).

Changes in biotic interactions among species—predation, parasitism, competition, and facilitation—can lead to disproportionately large, irreversible, and often negative alterations of ecosystem processes. In addition to direct interactions, such as predation, parasitism, or facilitation, the maintenance of ecosystem processes depends on indirect interactions as well, such as a predator preying on a dominant competitor such that the dominant is suppressed, which permits subordinate species to coexist. Interactions with important consequences for ecosystem services include pollination; links between plants and soil communities, including mycorrhizal fungi and nitrogen-fixing microorganisms; links between plants and herbivores and seed dispersers; interactions involving organisms that modify habitat conditions (beavers that build ponds, for instance, or tussock grasses that increase fire frequency); and indirect interactions involving more than two species (such as top predators, parasites, or pathogens that control herbivores and thus avoid overgrazing of plants or algal communities) (C11.3.2).

Many changes in ecosystem services are brought about by the removal or introduction of organisms in ecosystems that disrupt biotic interactions or ecosystem processes. Because the network of interactions among species and the network of linkages among ecosystem processes are complex, the impacts of either the removal of existing species or the introduction of new species are difficult to anticipate (C11). (See Table 1.1.)

As in terrestrial and aquatic communities, the loss of individual species involved in key interactions in marine ecosystems can also influence ecosystem processes and the provisioning of ecological services. For example, coral reefs and the ecosystem services they provide are directly dependent on the maintenance of some key interactions between animals and algae. As one of the most species-rich communities on Earth, coral reefs are responsible for maintaining a vast storehouse of genetic and biological diversity. Substantial ecosystem services are provided by coral reefs—such as habitat construction, nurseries, and spawning grounds for fish; nutrient cycling and carbon and nitrogen fixing in nutrient-poor environments; and wave buffering and sediment stabilization. The total economic value of reefs and associated services is estimated as hundreds of millions of dollars. Yet all coral reefs are dependent on a single key biotic interaction: symbiosis with algae. The dramatic effects of climate change and variability (such as El Niño oscillations) on coral reefs are mediated by the disruption of this symbiosis (C11.4.2).

Supporting Services

Biodiversity affects key ecosystem processes in terrestrial ecosystems such as biomass production, nutrient and water cycling, and soil formation and retention—all of which govern and ensure supporting services (*high certainty*). The relationship between biodiversity and supporting ecosystem services depends on composition, relative abundance, functional diversity, and, to a lesser extent, taxonomic diversity. If multiple dimensions of biodiversity are driven to very low levels, especially trophic or functional diversity within an ecosystem, both the level and stability (for instance, biological insurance) of supportive services may decrease (CF2, C11). (See Figure 1.4.)

Region-to-region differences in ecosystem processes are driven mostly by climate, resource availability, disturbance, and other extrinsic factors and not by differences in species richness (*high certainty*). In natural ecosystems, the effects of abiotic and land use drivers on ecosystem services are usually more important than changes in species richness. Plant productivity, nutrient retention, and resistance to invasions and diseases sometimes grow with increasing species numbers in experimental ecosystems that have been reduced to low levels of biodiversity. In natural ecosystems, however, these direct effects of increasing species richness are usually overridden by the effects of climate, resource availability, or disturbance regime (C11.3).

Even if losses of biodiversity have small short-term impacts on ecosystem function, such losses may reduce the capacity of ecosystems for adjustment to changing environments (that is, ecosystem stability or resilience, resistance, and biological insurance) (*high certainty*). The loss of multiple components of biodiversity, especially functional and ecosystem diversity at the landscape level, will lead to lowered ecosystem stability (*high certainty*). Although the stability of an ecosystem depends to a large extent on the characteristics of the dominant species (such as life span, growth rate, or regeneration strategy), less abundant species also contribute to the long-term preservation of ecosystem functioning. There is evidence that a large number of resident species, including those that are rare, may act as "insurance" that buffers ecosystem processes in the face of changes in the physical and biological environment (such as changes in precipitation, temperature, pathogens) (C11.3.2). As tragically illustrated by social conflict and humanitarian crisis over droughts, floods, and other ecosystem collapses, stability of ecosystems underpins most components of human well-being, including health, security, satisfactory social relations, and freedom of choice and action (C6; see also Key Question 2).

Regulating Services

Invasion resistance

The preservation of the number, types, and relative abundance of resident species can enhance invasion resistance in a wide range of natural and semi-natural ecosystems (*medium certainty*). Although areas of high species richness (such as biodiversity hot spots) are more susceptible to invasion than species-poor areas, within a given habitat the preservation of its natural species pool appears to increase its resistance to invasions by non-native species. This is also supported by evidence from several marine ecosystems, where decreases in the richness of native taxa were correlated with increased survival and percent cover of invading species (C11.3.1, C11.4.1).

Pollination

Pollination is essential for the provision of plant-derived ecosystem services, yet there have been worldwide declines in pollinator diversity (*medium certainty*). Many fruits and vegetables require pollinators, thus pollination services are critical to the production of a considerable portion of the vitamins and minerals in the human diet. Although there is no assessment at the continental level, documented declines in more-restricted geographical areas include mammals (lemurs and bats, for example)

(*continued on page 29*)

Table 1.1. Ecological Surprises Caused by Complex Interactions

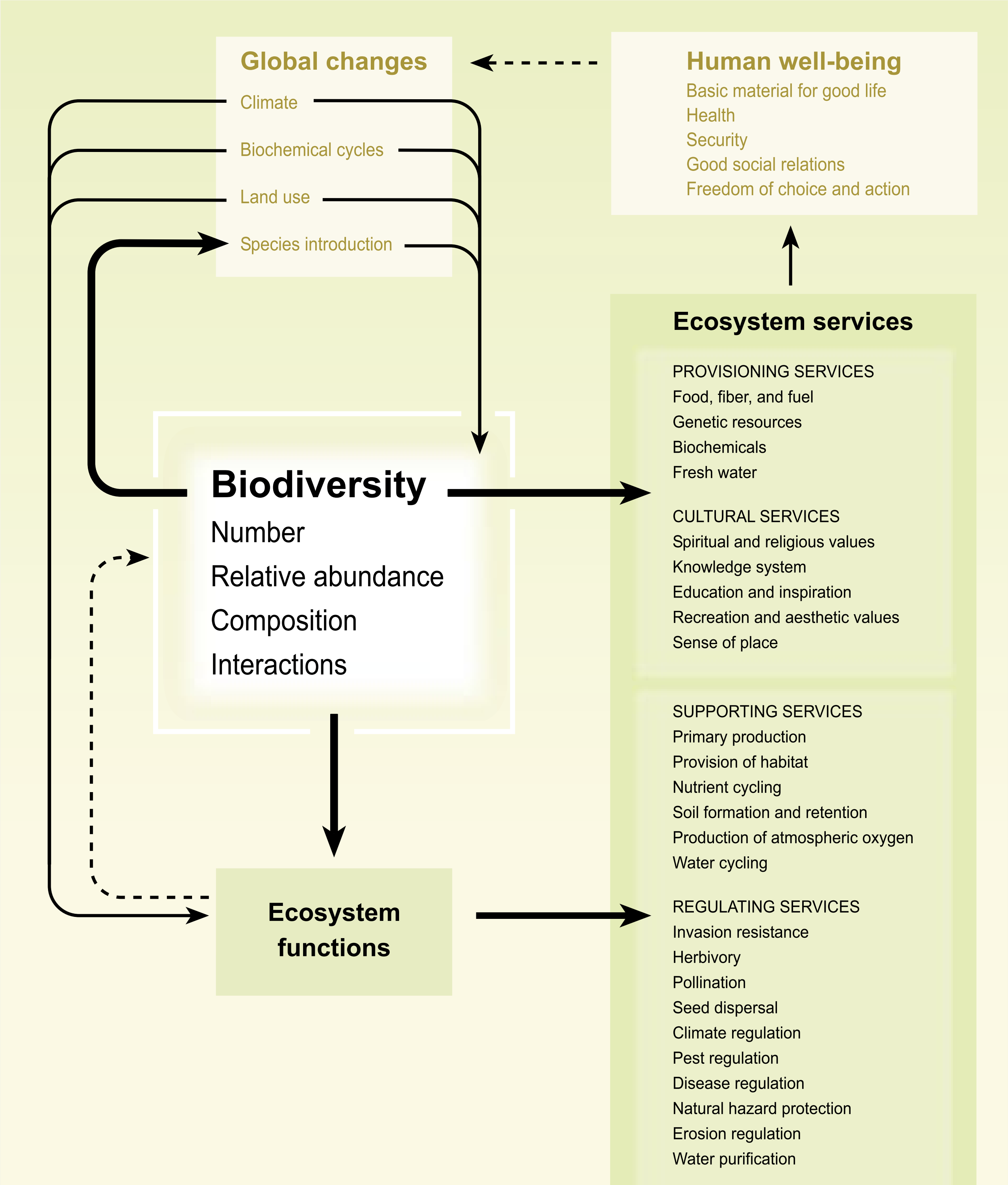
Voluntary or involuntary introductions or deletions of species often trigger unexpected alterations in the normal provision of ecosystem services by terrestrial, freshwater, and marine ecosystems. In all cases, the community and ecosystem alterations have been the consequence of indirect interactions among three or more species (C11, Table 11.2).

Study Case	Nature of the Interaction Involved	Ecosystem Service Consequences
Introductions		
Top predators		
Introduction of brown trout (*Salmo trutta*) in New Zealand for angling	trophic cascade, predator increased primary producers by decreasing herbivores	**negative—**increased eutrophication
Introduction of bass *(Cichla ocellaris)* in Gatun Lake, Panama	trophic cascade, top predator decreased control by predators of mosquito larvae	**negative—**decreased control of malaria vector
Introduction of pine marten (*Martes martes*) in the Balearic Islands, Spain	predator of frugivorous lizards (main seed dipersers)	**negative—**decreased diversity of frugivorous lizards due to extinction of native lizards on some islands; changes in dominant shrub (*Cneorum tricoccon*) distribution because marten replaced the frugivorous-dispersing role
Intraguild predators		
Egg parasitoid (*Anastatus kashmirensis*) to control gypsy moth (*Lymantria dispar*)	hyperparasitism (parasitoids that use parasitoids as hosts)	**negative—**disruption of biological control of pests; introduced parasitoid poses risk of hyperparasitism to other pest-regulating native parasitoids
Gambusia and *Lepomis* fish in rice fields to combat mosquitoes	intraguild predator (adult fish feed on juveniles as well as on mosquito larvae)	**opposed to goal—**decreased control of disease vector (mosquito)
Intraguild preys		
Opossum shrimp (*Mysis relicta*) in Canadian lakes to increase fish production	intraguild prey depletes shared zooplankton prey	**opposed to goal—**decreased salmonid fish production
Apparent competitors		
Rats (*Rattus* spp) and cats (*Felis catus*) in Steward Island, New Zealand	rats induced high cat densities and increased predation on endangered flightless parrot (*Strigops habroptilus)*	**negative—**reduced diversity
Herbivores		
Zebra mussel (*Dreissena polymorpha*) in Great Lakes, United States	zebra mussel reduced phytoplankton and outcompeted native bivalves	**negative—**reduced diversity **positive—**increased water quality
Mutualists		
Myna bird (*Acridotheres tristis*) for worm pest control in Hawaiian sugarcane plantations	myna engaged in the dispersal of the exotic woody weed *Lantana camara*	**negative—**increased invasion by *Lantana* produced impenetrable thorny thickets; reduced agricultural crops and pasture carrying capacity and sometimes increased fire risk; displaced habitat of native birds

Ecosystem engineers		
Earthworm (*Pontoscolex corethrurus*) in Amazonian tropical forests converted to pasture	dramatically reduces soil macroporosity and gas exchange capacity	**negative—**reduces soil macrofaunal diversity and increases soil methane emissions
C_4 perennial grasses *Schizachyrium condesatum, Melinis minutiflora* in Hawaii for pasture improvement	increased fuel loads, fuel distribution, and flammability	**negative—**increases fire frequency, affecting fire-sensitive plants; reduced plant diversity; positive feedback for further invasion of flammable exotic species on burned areas
Nitrogen-fixing firetree (*Myrica faya*) in Hawaii	increases soil nitrogen levels in newly formed nitrogen-poor volcanic soils	**negative—**increased fertility, increased invasion by other exotics, reduced regeneration of native *Metrosideros* tree, alteration of successional patterns
Deletions/Harvesting		
Top predators		
Selective harvesting of piscivorous fishes in Canadian lakes	piscivorus fishes promote *Daphnia* that effectively suppresses primary (algal) production	**negative—**shifts from net carbon sinks in piscivorous-dominated to equilibrium or net carbon sources in planktivorous-dominated lakes
Sea otter (*Enhydra lutris*) harvesting near extinction in southern California	cascading effects produced reductions of kelp forests and the kelp-dependent community	**negative—**loss of biodiversity of kelp habitat users
Pollution-induced reductions in predators of nematodes in forest soils	heavy metal bioaccumulation produced reductions nematophagous predators and increased herbivorous nematodes	**negative—**disruption of forest soil food webs; increases in belowground herbivory; decrease in forest productivity
Intraguild predators		
Declining populations of coyote (*Canis latrans*) in southern California	releases in raccoons (*Procyon lotor*) and feral house cats	**negative—**threat to native bird populations
Overhavesting of seals and sea lions in Alaska	diet shifts of killer whales increased predation on sea otters	**negative—**conflict with other restoration programs; failure of reintroduction of sea otters to restore kelp forest ecosystems
Keystone predators		
Harvesting of triggerfish (*Balistaphus*) in Kenyan coral reefs	triggerfish declines release sea urchins, which outcompete herbivorous fish	**negative—**increased bioerosion of coral substrates; reduced calcium carbonate deposition
Herbivores		
Voluntary removal of sheep and cattle in Santa Cruz Island, United States, for restoration	release of the exotic plant component from top-down control	**opposite to goal—**explosive increases in exotic herbs and forbs and little recovery of native plant species
Overfishing in the Caribbean reduced herbivorous and predatory fish and reduced fish biomass	lack of fish grazers allowed macroalgae to outcompete coral following disturbances	**negative—**coral cover was reduced from 52% to 3%, and macroalgae increased from 4% to 92%
Ecosystem engineers		
Voluntary removal of exotic tamarisk (*Tamariscus* sp.) for restoration of riparian habitats in Mediterranean deserts	long-established tamarisk has replaced riparian vegetation and serves as habitat to endangered birds	**opposite to goal—**reduction in biodiversity; structural changes in riparian habitats

Figure 1.4. Biodiversity, Ecosystem Functioning, and Ecosystem Services (C11 Fig 11.1)

Biodiversity is both a response variable affected by global change drivers and a factor modifying ecosystem processes and services and human well-being. Solid arrows indicate the links that are the focus of Chapter C11.



Source: Millennium Ecosystem Assessment

and birds (hummingbirds and sunbirds, for instance), bumblebees in Britain and Germany, honeybees in the United States and some European countries, and butterflies in Europe. The causes of these declines are multiple, but habitat destruction and the use of pesticide are especially important. Estimates of the global annual monetary value of pollination vary widely, but they are in the order of hundreds of billions of dollars (C11.3.2, Box C11.2).

Climate regulation

Biodiversity influences climate at local, regional, and global scales, thus changes in land use and land cover that affect biodiversity can affect climate. The important components of biodiversity include plant functional diversity and the type and distribution of habitats across landscapes. These influence the capacity of terrestrial ecosystems to sequester carbon, albedo (proportion of incoming radiation from the Sun that is reflected by the land surface back to space), evapotranspiration, temperature, and fire regime—all of which influence climate, especially at the landscape, ecosystem, or biome levels. For example, forests have higher evapotranspiration than other ecosystems, such as grasslands, because of their deeper roots and greater leaf area. Thus forests have a net moistening effect on the atmosphere and become a moisture source for downwind ecosystems. In the Amazon, for example, 60% of precipitation comes from water transpired by upwind ecosystems (C11.3.3).

In addition to biodiversity within habitats, the diversity of habitats in a landscape exerts additional impacts on climate across multiple scales. Landscape-level patches (>10 kilometers in diameter) that have lower albedo and higher surface temperature than neighboring patches create cells of rising warm air above the patch (convection). This air is replaced by cooler moister air that flows laterally from adjacent patches (advection). Climate models suggest that these landscape-level effects can substantially modify local-to-regional climate. In Western Australia, for example, the replacement of native heath vegetation by wheatlands increased regional albedo. As a result, air tended to rise over the dark (more solar-absorptive and therefore warmer) heathland, drawing moist air from the wheatlands to the heathlands. The net effect was a 10% increase in precipitation over heathlands and a 30% decrease in precipitation over croplands (C11.3.3).

Some components of biodiversity affect carbon sequestration and thus are important in carbon-based climate change mitigation when afforestation, reforestation, reduced deforestation, and biofuel plantations are involved (*high certainty*). Biodiversity affects carbon sequestration primarily through its effects on species characteristics, which determine how much carbon is taken up from the atmosphere (assimilation) and how much is released into it (decomposition, combustion). Particularly important are how fast plants can grow, which governs carbon inputs, and woodiness, which enhances carbon sequestration because woody plants tend to contain more carbon, live longer, and decompose more slowly than smaller herbaceous plants. Plant species also strongly influence carbon loss via decomposition and their effects on disturbance. Plant traits also influence the probability of disturbances such as fire, windthrow, and human harvest, which temporarily change forests from accumulating carbon to releasing it (C11.3.3).

The major importance of marine biodiversity in climate regulation appears to be via its effect on biogeochemical cycling and carbon sequestration. The ocean, through its sheer volume and links to the terrestrial biosphere, plays a huge role in cycling of almost every material involved in biotic processes. Of these, the anthropogenic effects on carbon and nitrogen cycling are especially prominent. Biodiversity influences the effectiveness of the biological pump that moves carbon from the surface ocean and sequesters it in deep waters and sediments. Some of the carbon that is absorbed by marine photosynthesis and transferred through food webs to grazers sinks to the deep ocean as fecal pellets and dead cells. The efficiency of this trophic transfer and therefore the extent of carbon sequestration is sensitive to the species richness and composition of the plankton community (C11.4.3).

Pest, disease, and pollution control

The maintenance of natural pest control services, which benefits food security, rural household incomes, and national incomes of many countries, is strongly dependent on biodiversity. Yields of desired products from agroecosystems may be reduced by attacks of animal herbivores and microbial pathogens, above and below ground, and by competition with weeds. Increasing associated biodiversity with low-diversity agroecosystems, however, can enhance biological control and reduce the dependency and costs associated with biocides. Moreover, high-biodiversity agriculture has cultural and aesthetic value and can reduce many of the externalized costs of irrigation, fertilizer, pesticide, and herbicide inputs associated with monoculture agriculture (C11.3.4, Boxes C11.3 and C11.4).

The marine microbial community provides critical detoxification services, but how biodiversity influences them is not well understood. There is very little information on how many species are necessary to provide detoxification services, but these services may critically depend on one or a few species. Some marine organisms provide the ecosystem service of filtering water and reducing effects of eutrophication. For example, American oysters in Chesapeake Bay were once abundant but have sharply declined—and with them, their filtering ecosystem services. Areas like the Chesapeake might have much clearer water if large populations of filtering oysters could be reintroduced. Some marine microbes can degrade toxic hydrocarbons, such as those in an oil spill, into carbon and water, using a process that requires oxygen. Thus this service is threatened by nutrient pollution, which generates oxygen deprivation (C11.4.4).

2. *Why is biodiversity loss a concern?*

■ **Biodiversity is essential for ecosystem services and hence for human well-being. Biodiversity goes beyond the provisioning for material welfare and livelihoods to include security, resiliency, social relations, health, and freedoms and choices. Some people have benefited over the last century from the conversion of natural ecosystems to human-dominated ecosystems and from the exploitation of biodiversity. At the same time, however, these losses in biodiversity and associated changes in ecosystem services have caused other people to experience declining well-being, with some social groups being pushed into poverty.**

Main Links among Biodiversity, Ecosystem Services, and Various Constituents of Human Well-being

The MA identifies biodiversity and the many ecosystem services that it provides as a key instrumental and constitutive factor determining human well-being. The MA findings support, with *high certainty*, that biodiversity loss and deteriorating ecosystem services contribute—directly or indirectly—to worsening health, higher food insecurity, increasing vulnerability, lower material wealth, worsening social relations, and less freedom for choice and action.

Food Security

Biological diversity is used by many rural communities directly as an insurance and coping mechanism to increase flexibility and spread or reduce risk in the face of increasing uncertainty, shocks, and surprises. The availability of this biological "safety net" has increased the security and resilience of some local communities to external economic and ecological perturbations, shocks, or surprises (C6.2.2, C8.2). In a world where fluctuating commodity prices are more the norm than the exception, economic entitlements of the poor are increasingly becoming precarious. The availability of an ecosystem-based food security net during times when economic entitlements are insufficient to purchase adequate nourishment in the market provides an important insurance program (C8.1, C6.7).

Coping mechanisms based on indigenous plants are particularly important for the most vulnerable people, who have little access to formal employment, land, or market opportunities (C6). For example, investigations of two dryland sites in Kenya and Tanzania report local communities using wild indigenous plants to provide alternative sources of food when harvests failed or when sudden expenses had to be met (such as a hospital bill). (See Table 2.1.)

Another pathway through which biodiversity can improve food security is the adoption of farming practices that maintain and make use of agricultural biodiversity. Biodiversity is important to maintaining agricultural production. Wild relatives of domestic crops provide genetic variability that can be crucial for overcoming outbreaks of pests and pathogens and new environmental stresses. Many agricultural communities consider increased local diversity a critical factor for the long-term productivity and viability of their agricultural systems. For example, interweaving multiple varieties of rice in the same paddy has been shown to increase productivity by lowering the loss from pests and pathogens.

Vulnerability

The world is experiencing an increase in human suffering and economic losses from natural disasters over the past several decades. Mangrove forests and coral reefs—a rich source of biodiversity—are excellent natural buffers against floods and storms. Their loss or reduction in coverage has increased the severity of flooding on coastal communities. Floods affect more people (140 million per year on average) than all other natural or technological disasters put together. Over the past four decades, the number of "great" disasters has increased by a factor of four, while economic losses have increased by a factor of ten. During the 1990s, countries low on the Human Development Index experienced about 20% of the hazard events and reported over 50% of the deaths and just 5% of economic losses. Those with high rankings on the index accounted for over 50% of the total economic losses and less than 2% of the deaths (C6, R11, C16).

A common finding from the various sub-global assessments was that many people living in rural areas cherish and promote ecosystem variability and diversity as a risk management strategy against shocks and surprises (SG11). They maintain a diversity of ecosystem services and are skeptical about solutions that reduce their options. The sub-global assessments found that diversity of species, food, and landscapes serve as "savings banks" that rural communities use to cope with change and ensure sustainable livelihoods (see Peruvian, Portuguese, Costa Rican, and India sub-global assessments).

Table 2.1. Percentage of Households Dependent on Indigenous Plant–based Coping Mechanisms at Kenyan and Tanzanian Site (C6 Table 6.4)

Activities that Involve Use of Indigenous Plants	Share of Households, Kenya site	Share of Households, Tanzania site
	(percent)	(percent)
All use	94	94
Food use	69	54
Non-food use	40	42

Health

An important component of health is a balanced diet. About 7,000 species of plants and several hundred species of animals have been used for human food consumption at one time or another. Some indigenous and traditional communities currently consume 200 or more species. Wild sources of food remain particularly important for the poor and landless to provide a somewhat balanced diet (C6, C8.2.2). Overexploitation of marine fisheries worldwide, and of bushmeat in many areas of the tropics, has lead to a reduction in the availability of wild-caught animal protein, with serious consequences in many countries for human health (C4.3.4).

Human health, particularly risk of exposure to many infectious diseases, may depend on the maintenance of biodiversity in natural ecosystems. On the one hand, a greater diversity of wildlife species might be expected to sustain a greater diversity of pathogens that can infect humans. However, evidence is accumulating that greater wildlife diversity may decrease the spread of many wildlife pathogens to humans. The spread of Lyme disease, the best-studied case, seems to be decreased by the maintenance of the biotic integrity of natural ecosystems (C11, C14).

Energy Security

Wood fuel provides more than half the energy used in developing countries. Even in industrial countries such as Sweden and the United States, wood supplies 17% and 3% of total energy consumption respectively. In some African countries, such as Tanzania, Uganda, and Rwanda, wood fuel accounts for 80% of total energy consumption (SG-SAfMA). In rural areas, 95% is consumed in the form of firewood, while in urban areas 85% is in the form of charcoal. Shortage of wood fuel occurs in areas with high population density without access to alternative and affordable energy sources. In some provinces of Zambia where population densities exceed the national average of 13.7 persons per square kilometer, the demand for wood has already surpassed local supply. In such areas, people are vulnerable to illness and malnutrition because of the lack of resources to heat homes, cook food, and boil water. Women and children in rural poor communities are the ones most affected by wood fuel scarcity. They must walk long distances searching for firewood and therefore have less time for tending crops and school (C9.4).

Provision of Clean Water

The continued loss of cloud forests and the destruction of watersheds reduce the quality and availability of water supplied to household use and agriculture. The availability of clean drinking water is a concern in dozens of the world's largest cities (C27). In one of the best documented cases, New York City took steps to protect the integrity of watersheds in the Catskills to ensure continued provision of clean drinking water to 9 million people. Protecting the ecosystem was shown to be far more cost-effective than building and operating a water filtration plant. New York City avoided $6–8 billion in expenses by protecting its watersheds (C7, R17).

Social Relations

Many cultures attach spiritual and religious values to ecosystems or their components such as a tree, hill, river, or grove (C17). Thus loss or damage to these components can harm social relations—for example, by impeding religious and social ceremonies that normally bind people. (See Box 2.1.) Damage to ecosystems, highly valued for their aesthetic, recreational, or spiritual values can damage social relations, both by reducing the bonding value of shared experience as well as by causing resentment toward groups that profit from their damage (S11, SG10).

Box 2.1. Social Consequences of Biodiversity Degradation (SG-SAfMA)

The basic needs of the AmaXhosa people in South Africa are met by ecosystem services, including fuelwood, medicinal plants, building materials, cultural species, food supplements, and species of economic value. When asked by researchers about their relationship with the natural environment, a local responded "I am entirely dependent on the environment. Everything that I need comes from this environment" and "[the environment] will be important forever because if you have something from the environment it does encourage you to love the environment."

Respondents often described positive emotional and physical symptoms when the environment is healthy: "When the environment is healthy, my body and spirit is also happy." And when describing people's feelings toward a healthy environment, a respondent stated that "people love such an environment. They really adore it. Such an environment makes them feel free." In addition, respondents described the feelings of peace when walking in the bush and how they would go into the natural environment to pray.

The beliefs and traditions of the AmaXhosa play an important role in guiding resource use and management and encouraging values to be place-centered. The ancestors are central to this cosmology, where the very identity of a Xhosa person is based on performing traditions and rituals for ancestors. The majority of respondents stated that practicing traditions and thus communicating with ancestors is what is of value to a Xhosa person.

A number of sites and species are fundamental to the performance of rituals and maintaining a relationship with the ancestors. When respondents were asked what would happen if these sites were to be destroyed, they replied "It means that the ancestors would be homeless." "That can't happen here at this village because our health depends entirely on these sites," and "it means that our culture is dead."

Freedom of Choice and Action

Freedom of choice and action within the MA context refers to individuals having control over what happens and being able to achieve what they value (CF3). Loss of biodiversity often means a loss of choices. Local fishers depend on mangroves as breeding grounds for local fish populations. Loss of mangroves translates to a loss in control over the local fish stock and a livelihood they have been pursuing for many generations and that they value. Another example is high-diversity agricultural systems. These systems normally produce less cash than monoculture cash crops, but farmers have some control over their entitlements because of spreading risk through diversity. High diversity of genotypes, populations, species, functional types, and spatial patches decreases the negative effects of pests and pathogens on crops and keeps open possibilities for agrarian communities to develop crops suited to future environmental challenges and to increase their resilience to climate variability and market fluctuations (C11).

Another dimension of choices relates to the future. The loss of biodiversity in some instances is irreversible, and the value individuals place on keeping biodiversity for future generations—the option value—can be significant (CF6, C2). The notion of having choices available irrespective of whether any of them will be actually picked is an essential constituent of the freedom aspect of well-being. However, putting a monetary figure on option values is notoriously difficult. We can only postulate on the needs and desires of future generations, some of which can be very different from today's aspirations.

Basic Materials for a Good Life and Sustainable Livelihoods

Biodiversity offers directly the various goods—often plants, animals, and fungi—that individuals need in order to earn an income and secure sustainable livelihoods. In addition, it also contributes to livelihoods through the support it provides for ecosystem services: the agricultural labor force currently contains approximately 22% of the world's population and accounts for 46% of its total labor force (C26.5.1). For example, apples are a major cash crop in the Himalayan region in India, accounting for 60–80% of total household income (SG3). The region is also rich in honeybee diversity, which played a significant role in pollinating field crops and wild plants, thereby increasing productivity and sustaining ecosystem functions. In the early 1980s, market demand for particular types of apples led farmers to uproot pollinated varieties and plant new, sterile cultivars. The pollinator populations were also negatively affected by excessive use of pesticides. The result was a reduction in overall apple productivity and the extinction of many natural pollinator species (SG3).

Nature-based tourism ("ecotourism")—one of the fastest-growing segments of tourism worldwide—is a particularly important economic sector in a number of countries and a potential income source for many rural communities (C17.2.6). The aggregate revenue generated by nature-based tourism in Southern Africa was estimated to be $3.6 billion in 2000, roughly 50% of total tourism revenue (SG-SAfMA). Botswana, Kenya, Namibia, South Africa, Tanzania, Uganda, and Zimbabwe each generated over $100 million in revenue annually from nature-based tourism in 2000. In Tanzania, tourism contributed 30% of the total GDP of the country.

Biodiversity also contributes to a range of other industries, including pharmaceuticals, cosmetics, and horticulture. Market trends vary widely according to the industry and country involved but many bioprospecting activities and revenues are expected to increase over the next decades (C10). The current economic climate suggests that pharmaceutical bioprospecting will increase, especially as new methods use evolutionary and ecological knowledge.

Losses of biodiversity can impose substantial costs at local and national scales. For example, the collapse of the Newfoundland cod fishery in the early 1990s cost tens of thousands of jobs, as well as at least $2 billion in income support and retraining. Recent evidence suggests that the preservation of the integrity of local biological communities, both in terms of the identity and the number of species, is important for the maintenance of plant and animal productivity, soil fertility, and their stability in the face of a changing environment (C11). Recent estimates from the MA Portugal sub-global assessment indicate that environmental expenses in that country are increasing at a rate of 3% a year and are presently 0.7% of GDP (SG-Portugal).

Trade-offs among Biodiversity, Ecosystem Services, and Human Well-being

When society has multiple goals, many of which depend on biodiversity, ecosystem services, and the many constituents of well-being, difficult decisions involving trade-offs among competing goals have to be made. The value of ecosystem services lost to human society, in the long term, may greatly exceed the short-term economic benefits that are gained from transformative activities. In Sri Lanka, for example, the clearing of tropical forest for agriculture initially reduced the habitat for forest-adapted anopheline mosquito vectors of malaria. But in due course, other vector species occupied the changed habitat, contributing to the resurgence of malaria (SG3).

Many of the changes in biodiversity and ecosystems have been made to enhance the production of specific ecosystem services such as food production. But only 4 of the 24 ecosystem services examined in this assessment have been enhanced: crops, livestock, aquaculture, and (in recent decades) carbon sequestration, while 15 services have been degraded. (See Table 2.2.) The degraded services include capture fisheries, timber production, water supply, waste treatment

(*continued on page 37*)

Table 2.2. Trends in the Human Use of Ecosystem Services and Enhancement or Degradation of the Service around the Year 2000 (See page 37 for legend.)

Service	Sub-category	Human Use[a]	Enhanced or Degraded[b]	Notes	MA Chapter
Provisioning Services					
Food	Crops	▲	▲	Food provision has grown faster than overall population growth. Primary source of growth from increase in production per unit area but also significant expansion in cropland. Still persistent areas of low productivity and more rapid area expansion, e.g., sub-Saharan Africa and parts of Latin America.	C8.2
	Livestock	▲	▲	Significant increase in area devoted to livestock in some regions, but major source of growth has been more intensive, confined production of chicken, pigs, and cattle.	C7
	Capture fisheries	▼	▼	Marine fish harvest increased until the late 1980s and has been declining since then. Currently, one quarter of marine fish stocks are overexploited or significantly depleted. Freshwater capture fisheries have also declined. Human use of capture fisheries as declined because of the reduced supply, not because of reduced demand.	C18 C8.2.2 C19
	Aquaculture	▲	▲	Aquaculture has become a globally significant source of food in the last 50 years and, in 2000, contributed 27% of total fish production. Use of fish feed for carnivorous aquaculture species places an additional burden on capture fisheries.	C8 Table 8.4
	Wild plant and animal products	NA	▼	Provision of these food sources is generally declining as natural habitats worldwide are under increasing pressure and as wild populations are exploited for food, particularly by the poor, at unsustainable levels.	8.3.1
Fiber	Timber	▲	+/–	Global timber production has increased by 60% in the last four decades. Plantations provide an increasing volume of harvested roundwood, amounting to 35% of the global harvest in 2000. Roughly 40% of forest area has been lost during the industrial era, and forests continue to be lost in many regions (thus the service is degraded in those regions), although forest is now recovering in some temperate countries and thus this service has been enhanced (from this lower baseline) in these regions in recent decades.	C9.ES C21.1
	Cotton, hemp, silk	+/–	+/–	Cotton and silk production have doubled and tripled respectively in the last four decades. Production of other agricultural fibers has declined.	C9.ES
	Wood fuel	+/–	▼	Global consumption of fuelwood appears to have peaked in the 1990s and is now believed to be slowly declining but remains the dominant source of domestic fuel in some regions.	C9.ES
Genetic resources		▲	▼	Traditional crop breeding has relied on a relatively narrow range of germplasm for the major crop species, although molecular genetics and biotechnology provide new tools to quantify and expand genetic diversity in these crops. Use of genetic resources also is growing in connection with new industries based on biotechnology. Genetic resources have been lost through the loss of traditional cultivars of crop species (due in part to the adoption of modern farming practices and varieties) and through species extinctions.	C26.2.1

(*continued on page 34*)

Table 2.2. Trends in the Human Use of Ecosystem Services and Enhancement or Degradation of the Service around the Year 2000 (See page 37 for legend.) *(continued)*

Service	Sub-category	Human Use[a]	Enhanced or Degraded[b]	Notes	MA Chapter
Biochemicals, natural medicines, and pharmaceuticals		▲	▼	Demand for biochemicals and new pharmaceuticals is growing, but new synthetic technologies compete with natural products to meet the demand. For many other natural products (cosmetics, personal care, bioremediation, biomonitoring, ecological restoration), use is growing. Species extinction and overharvesting of medicinal plants is diminishing the availability of these resources.	C10
Ornamental resources		NA	NA		
Fresh water		▲	▼	Human modification of ecosystems (e.g., reservoir creation) has stabilized a substantial fraction of continental river flow, making more fresh water available to people but in dry regions reducing river flows through open water evaporation and support to irrigation that also loses substantial quantities of water. Watershed management and vegetation changes have also had an impact on seasonal river flows. From 5% to possibly 25% of global freshwater use exceeds long-term accessible supplies and requires supplies either through engineered water transfers or overdraft of groundwater supplies. Between 15% and 35% of irrigation withdrawals exceed supply rates. Fresh water flowing in rivers also provides a service in the form of energy that is exploited through hydropower. The construction of dams has not changed the amount of energy, but it has made the energy more available to people. The installed hydroelectric capacity doubled between 1960 and 2000. Pollution and biodiversity loss are defining features of modern inland water systems in many populated parts of the world.	C7
Regulating Services					
Air quality regulation		▲	▼	The ability of the atmosphere to cleanse itself of pollutants has declined slightly since preindustrial times but likely not by more than 10%. The net contribution of ecosystems to this change is not known. Ecosystems are also a sink for tropospheric ozone, ammonia, NO_X, SO_2, particulates, and CH_4, but changes in these sinks were not assessed.	C13.ES
Climate regulation	Global	▲	▲	Terrestrial ecosystems were on average a net source of CO_2 during the nineteenth and early twentieth century and became a net sink sometime around the middle of the last century. The biophysical effect of historical land cover changes (1750 to present) is net cooling on a global scale due to increased albedo, partially offsetting the warming effect of associated carbon emissions from land cover change over much of that period.	C13.ES
	Regional and local	▲	▼	Changes in land cover have affected regional and local climates both positively and negatively, but there is a preponderance of negative impacts. For example, tropical deforestation and desertification have tended to reduce local rainfall.	C13.3 C11.3
Water regulation		▲	+/–	The effect of ecosystem change on the timing and magnitude of runoff, flooding, and aquifer recharge depends on the ecosystem involved and on the specific modifications made to the ecosystem.	C7.4.4

Service	Sub-category	Human Use[a]	Enhanced or Degraded[b]	Notes	MA Chapter
Erosion regulation		▲	▼	Land use and crop/soil management practices have exacerbated soil degradation and erosion, although appropriate soil conservation practices that reduce erosion, such as minimum tillage, are increasingly being adopted by farmers in North America and Latin America.	C26
Water purification and waste treatment		▲	▼	Globally, water quality is declining, although in most industrial countries pathogen and organic pollution of surface waters has decreased over the last 20 years. Nitrate concentration has grown rapidly in the last 30 years. The capacity of ecosystems to purify such wastes is limited, as evidenced by widespread reports of inland waterway pollution. Loss of wetlands has further decreased the ability of ecosystems to filter and decompose wastes.	C7.2.5 C19
Disease regulation		▲	+/–	Ecosystem modifications associated with development have often increased the local incidence of infectious diseases, although major changes in habitats can both increase or decrease the risk of particular infectious diseases.	C14
Pest regulation		▲	▼	In many agricultural areas, pest control provided by natural enemies has been replaced by the use of pesticides. Such pesticide use has itself degraded the capacity of agroecosystems to provide pest control. In other systems, pest control provided by natural enemies is being used and enhanced through integrated pest management. Crops containing pest-resistant genes can also reduce the need for application of toxic synthetic pesticides.	C11.3
Pollination		▲	▼[c]	There is *established but incomplete* evidence of a global decline in the abundance of pollinators. Pollinator declines have been reported in at least one region or country on every continent except Antarctica, which has no pollinators. Declines in abundance of pollinators have rarely resulted in complete failure to produce seed or fruit, but more frequently resulted in fewer seeds or in fruit of reduced viability or quantity. Losses in populations of specialized pollinators have directly affected the reproductive ability of some rare plants.	C11 Box 11.2
Natural hazard regulation		▲	▼	People are increasingly occupying regions and localities that are exposed to extreme events, thereby exacerbating human vulnerability to natural hazards. This trend, along with the decline in the capacity of ecosystems to buffer from extreme events, has led to continuing high loss of life globally and rapidly rising economic losses from natural disasters.	C16 C19
Cultural Services					
Cultural diversity		NA	NA		

(*continued on page 36*)

Table 2.2. Trends in the Human Use of Ecosystem Services and Enhancement or Degradation of the Service around the Year 2000 (See page 37 for legend.) *(continued)*

Service	Sub-category	Human Use[a]	Enhanced or Degraded[b]	Notes	MA Chapter
Cultural Services *(continued)*					
Spiritual and religious values		▲	▼	There has been a decline in the numbers of sacred groves and other such protected areas. The loss of particular ecosystem attributes (sacred species or sacred forests), combined with social and economic changes, can sometimes weaken the spiritual benefits people obtain from ecosystems. On the other hand, under some circumstances (e.g., where ecosystem attributes are causing significant threats to people), the loss of some attributes may enhance spiritual appreciation for what remains.	C17.2.3
Knowledge systems		NA	NA		
Educational values		NA	NA		
Inspiration		NA	NA		
Aesthetic values		▲	▼	The demand for aesthetically pleasing natural landscapes has increased in accordance with increased urbanization. There has been a decline in quantity and quality of areas to meet this demand. A reduction in the availability of and access to natural areas for urban residents may have important detrimental effects on public health and economies.	C17.2.5
Social relations		NA	NA		
Sense of place		NA	NA		
Cultural heritage values		NA	NA		
Recreation and ecotourism		▲	+/–	The demand for recreational use of landscapes is increasing, and areas are increasingly being managed to cater for this use, to reflect changing cultural values and perceptions. However, many naturally occurring features of the landscape (e.g., coral reefs) have been degraded as resources for recreation.	C17.2.6 C19
Supporting Services					
Soil formation		†	†		
Photosynthesis		†	†		
Primary production		†	†	Several global MA systems, including dryland, forest, and cultivated systems, show a trend of NPP increase for the period 1981 to 2000. However, high seasonal and inter-annual variations associated with climate variability occur within this trend on the global scale	C22.2.1

Service	Sub-category	Human Use[a]	Enhanced or Degraded[b]	Notes	MA Chapter
Supporting Services *(continued)*					
Nutrient cycling		†	†	There have been large-scale changes in nutrient cycles in recent decades, mainly due to additional inputs from fertilizers, livestock waste, human wastes, and biomass burning. Inland water and coastal systems have been increasingly affected by eutrophication due to transfer of nutrients from terrestrial to aquatic systems as biological buffers that limit these transfers have been significantly impaired.	C12 S7
Water cycling		†	†	Humans have made major changes to water cycles through structural changes to rivers, extraction of water from rivers, and, more recently, climate change.	C7

[a] For provisioning services, human use increases if the human consumption of the service increases (e.g., greater food consumption); for regulating and cultural services, human use increases if the number of people affected by the service increases. The time frame is in general the past 50 years, although if the trend has changed within that time frame, the indicator shows the most recent trend.

[b] For provisioning services, we define enhancement to mean increased production of the service through changes in area over which the service is provided (e.g., spread of agriculture) or increased production per unit area. We judge the production to be degraded if the current use exceeds sustainable levels. For regulating and supporting services, enhancement refers to a change in the service that leads to greater benefits for people (e.g., the service of disease regulation could be improved by eradication of a vector known to transmit a disease to people). Degradation of a regulating and supporting services means a reduction in the benefits obtained from the service, either through a change in the service (e.g., mangrove loss reducing the storm protection benefits of an ecosystem) or through human pressures on the service exceeding its limits (e.g., excessive pollution exceeding the capability of ecosystems to maintain water quality). For cultural services, degradation refers to a change in the ecosystem features that decreases the cultural (recreational, aesthetic, spiritual, etc.) benefits provided by the ecosystem. The time frame is in general the past 50 years, although if the trend has changed within that time frame the indicator shows the most recent trend.

[c] *Low to medium certainty*. All other trends are *medium to high certainty*.

Legend:

▲ = Increasing (for human use column) or enhanced (for enhanced or degraded column)

▼ = Decreasing (for human use column) or degraded (for enhanced or degraded column)

+/– = Mixed (trend increases and decreases over past 50 years or some components/regions increase while others decrease)

NA = Not assessed within the MA. In some cases, the service was not addressed at all in the MA (such as ornamental resources), while in other cases the service was included but the information and data available did not allow an assessment of the pattern of human use of the service or the status of the service.

† = The categories of "human use" and "enhanced or degraded" do not apply for supporting services since, by definition, these services are not directly used by people. (Their costs or benefits would be double-counted if the indirect effects were included.) Changes in supporting services influence the supply of provisioning, cultural, or regulating services that are then used by people and may be enhanced or degraded.

and detoxification, water purification, natural hazard protection, regulation of air quality, regulation of regional and local climate, regulation of erosion, and many cultural services (the spiritual, aesthetic, recreational, and other benefits of ecosystems). Modifications of ecosystems to enhance one service generally have come at a cost to other services that the ecosystem provided. For example, while the expansion of agriculture and its increased productivity are a success story of enhanced production of one key ecosystem service, this success has come at high and growing costs in terms of trade-offs with other ecosystem services, both through the direct impact of land cover change and as a result of water withdrawals for irrigation and release of nutrients into rivers. Globally, roughly 15–35% of irrigation withdrawals are estimated to be unsustainable (*low to medium uncertainty*).The impacts of these trade-offs among ecosystem services affect people in different ways. An aquaculture farmer, for instance, may gain material welfare from management practices that increase soil salinization and thereby reduce rice yields and threaten food security for nearby subsistence farmers.

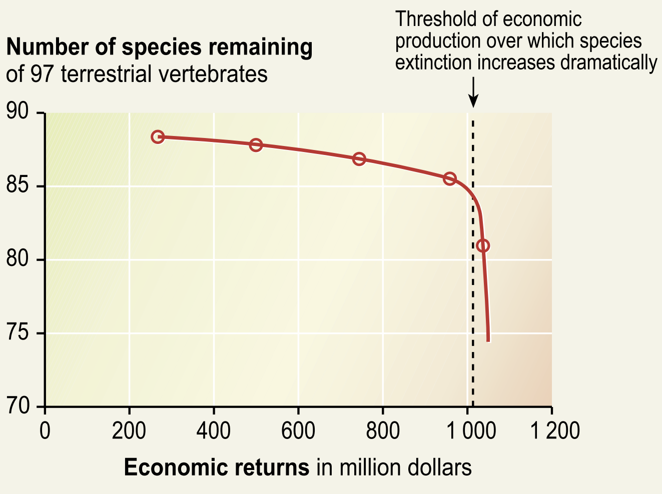
Trade-off analysis aided by qualitative and quantitative values for biodiversity and ecosystem services can help decision-makers make intelligent decisions among competing goals (R17). (See Figure 2.1.) Such analysis can identify management strategies that generate efficient outcomes in which it is not possible to increase one objective without decreasing another. Second, it can show the extent to which current decisions are inefficient and help identify opportunities for improving the status quo. Third, it illustrates the nature of the trade-offs between goals once the efficiency frontier has been reached.

Values of Biodiversity and Ecosystem Services for Human Well-being

The importance of biodiversity and natural processes in producing ecosystem services that people depend on is not captured in financial markets. Unlike goods bought and sold in markets, many ecosystem services do not have markets or readily observable prices. However, lack of a price does not mean lack of value. A substantial body of research on nonmarket valuation is now available for some ecosystem services, including clean drinking water, recreation, or commercially harvested species. Existence value of species and other "non-use" values pose a greater challenge to those who would try to measure the complete value of conserving biodiversity and natural processes. The fact that ecosystems are dynamic and complex, as well as the fact that human preferences change through time, also present difficulties for attempts to value natural systems. Combinations of irreversible actions, such as species extinction, and uncertainty give rise to option value (such as the value of maintaining flexibility, keeping options open, until uncertainty is resolved). Though clear in theory, getting reasonable estimates of option value is difficult in practice (C2.3). Better quantification of the benefits derived from ecosystems would provide greater impetus for biodiversity protection and create a more transparent picture of the equitability of the distribution of benefits.

Figure 2.1. Efficiency Frontier Analysis of Species Persistence and Economic Returns

The production possibility shows feasible combinations of species persistence and economic returns for a sample landscape based on the Willamette Basin in Oregon in the United States. The Figure shows results for 97 terrestrial vertebrates found in the basin and economic returns from agriculture and forestry production. Each land parcel can be put into a biological reserve, agriculture, or forestry. The land use pattern determines the value of economic returns from agriculture and forestry production and the pattern of habitat. For each species, persistence depends on the extent and pattern of suitable habitat (R17).



Source: Millennium Ecosystem Assessment

Private and social values of conserving biodiversity and natural systems often differ widely. The private use value of biodiversity and ecosystem services by individuals will typically ignore the "external" benefits of conservation that accrue to society in general. For example, a farmer may benefit from intensive use of the land but generally does not bear all the consequences caused by leaching of excess nutrients and pesticides into ground or surface water, or the consequences of loss of habitat for native species. If private decision-makers are not given the incentives to value the larger social benefits of conservation, their decisions will often result in inadequate conservation (C5.4).

The indirect values of biodiversity conservation can be highly significant in comparison with the direct economic values derived from a particular area. (See Box 2.2.) In existing economic studies of changes to biodiversity in specific locations (such as the conversion of mangrove forests, degradation of coral reefs, and clear-felling of forests), the costs of ecosystem conversion are often found to be significant and sometimes exceed the benefits of the habitat conversion. Despite this, in a number of these cases conversion was promoted because the value of the lost ecosystem services—the indirect value of biodiversity conservation—was not internalized. In other instances, subsidies distorted the relative costs and benefits and provided the incentives to destroy biodiversity (C5).

The depletion and degradation of many ecosystem services represents the loss of a capital asset that is poorly reflected in conventional indicators of economic growth or growth in human well-being (C2.3.5). A country could cut its forests and deplete its fisheries, and this would show only as a positive gain to GDP, despite the loss of the capital asset. (GDP measures the flow of economic benefits from the use of these resources, but the depletion of the capital asset is not reflected.) Moreover, many ecosystem services are available freely to those who use them (fresh water in aquifers, for instance, and the use of the atmosphere as a sink for pollutants) and so again their degradation is

Box 2.2. Economic Costs and Benefits of Ecosystem Conversion (C5 Box 5.2)

Relatively few studies have compared the total economic value of ecosystems under alternate management regimes. The results of several that attempted to do so are shown in the Figure. In each case where the total economic value of sustainable management practices was compared with management regimes involving conversion of the ecosystem or unsustainable practices, the benefit of managing the ecosystem more sustainably exceeded that of the converted ecosystem even though the private benefits—that is, the actual monetary benefits captured from the services entering the market—would favor conversion or unsustainable management. These studies are consistent with the understanding that market failures associated with ecosystem services lead to greater conversion of ecosystems than is economically justified. However, this finding would not hold at all locations. For example, the value of conversion of an ecosystem in areas of prime agricultural land or in urban regions often exceeds the total economic value of the intact ecosystem (although even in dense urban areas, the TEV of maintaining some "green space" can be greater than development of these sites) (C5).

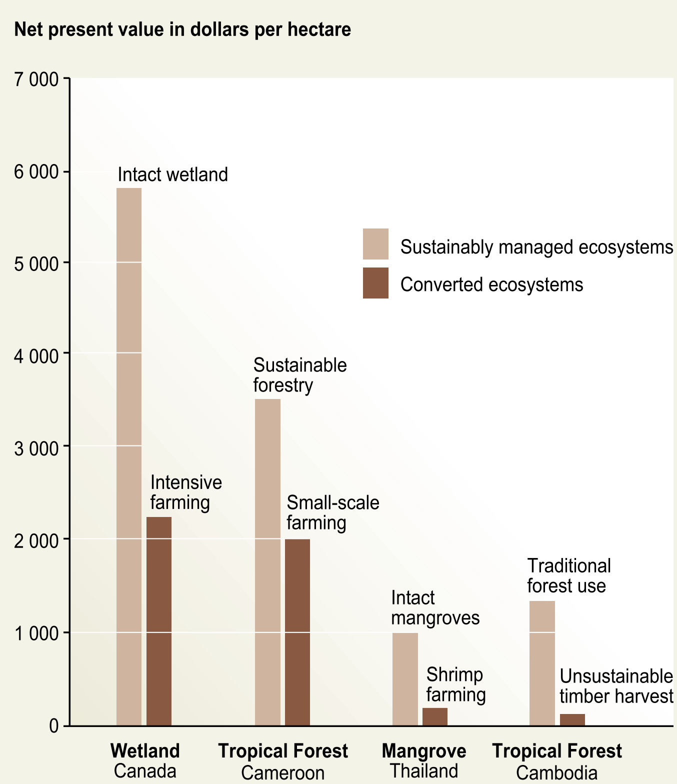
- *Conversion of tropical forest to small-scale agriculture or plantations (Mount Cameroon, Cameroon).* Maintenance of the forest with low-impact logging provided social benefits (NWFPs, sedimentation control, and flood prevention) and global benefits (carbon storage plus option, bequest, and existence values) across the five study sites totaling some $3,400 per hectare. Conversion to small-scale agriculture yielded the greatest private benefits (food production), of about $2,000 per hectare. Across four of the sites, conversion to oil palm and rubber plantations resulted in average net costs (negative benefits) of $1,000 per hectare. Private benefits from cash crops were only realized in this case because of market distortions.

- *Conversion of a mangrove system to aquaculture (Thailand).* Although conversion for aquaculture made sense in terms of short-term private benefits, it did not once external costs were factored in. The global benefits of carbon sequestration were considered to be similar in intact and degraded systems. However, the substantial social benefits associated with the original mangrove cover—from timber, charcoal, NWFPs, offshore fisheries, and storm protection—fell to almost zero following conversion. Summing all measured goods and services, the TEV of intact mangroves was a minimum of $1,000 and possibly as high as $36,000 per hectare, compared with the TEV of shrimp farming, which was about $200 per hectare.

- *Draining freshwater marshes for agriculture (Canada).* Draining freshwater marshes in one of Canada's most productive agricultural areas yielded net private benefits in large part because of substantial drainage subsidies. However, the social benefits of retaining wetlands arising from sustainable hunting, angling, and trapping greatly exceeded agricultural gains. Consequently, for all three marsh types considered, TEV was on average $5,800 per hectare, compared with $2,400 per hectare for converted wetlands.

- *Use of forests for commercial timber extraction (Cambodia).* Use of forest areas for swidden agriculture and extraction of non-wood forest products (including fuelwood, rattan and bamboo, wildlife, malva nuts, and medicine) as well as ecological and environmental functions such as watershed, biodiversity, and carbon storage provided a TEV ranging of $1,300–4,500 per hectare (environmental services accounted for $590 of that while NWFPs provided $700–3,900 per hectare). However, the private benefits associated with unsustainable timber harvest practices exceeded private benefits of NWFP collection. Private benefits for timber harvest ranged from $400 to $1,700 per hectare, but after accounting for lost services the total benefits were from $150 to $1,100 per hectare, significantly less than the TEV of more sustainable uses.

Economic Benefits under Alternate Management Practices



Source: Millennium Ecosystem Assessment

not reflected in standard economic measures. When changes to these natural capital assets are factored into measures of the inclusive wealth of nations, they significantly change the balance sheet for countries with economies largely dependent on natural resources. Some countries that appeared to have positive growth in the 1970s and 1980s, for example, actually experienced a net loss of capital assets, effectively undermining the sustainability of any gains they may have achieved.

The Distributional Impacts of Biodiversity Loss and Ecosystem Change

Biodiversity use, change, and loss have improved well-being for many social groups and individuals. But people with low resilience to ecosystem changes—mainly the disadvantaged—have been the biggest losers and witnessed the biggest increase in not only monetary poverty but also relative, temporary poverty and the depth of poverty (C5, C6, R17). See Box 2.3 for a description of various types of poverty.

Box 2.3. Concepts and Measures of Poverty

Relative poverty is the state of deprivation defined by social standards. It is fixed by a contrast with others in the society who are not considered poor. Poverty is then seen as lack of equal opportunities. It is based on subjective measures of poverty.

Depth of poverty is a measure of the average income gap of the poor in relation to a certain threshold. It defines how poor the poor are. It gives the amount of resources needed to bring all poor people to the poverty-line level.

Temporary poverty is characterized by a short-term deprivation, usually seasonal, of water or food.

Monetary poverty is an insufficiency of income or monetary resources. Most indicators like the U.S. dollar a day indicator or national poverty lines are defined in those terms.

Multidimensional poverty is conceived as a group of irreducible deprivations that cannot be adequately expressed as income insufficiency. It combines basic constituents of well-being in a composite measure, such as the Human Poverty Index.

Other characteristics of poverty commonly used in the literature include rural and urban poverty, extreme poverty (or destitution), female poverty (to indicate gender discrimination), and food-ratio poverty lines (with calorie-income elasticities). Other indices such as the FGT (Foster, Greer, and Thorbecke) or the Sen Index, which combine both dimensions of incidence and depth of poverty, are also widely used. The type of poverty experienced by individuals will therefore differ for different rates and levels of biodiversity and ecosystem services loss and if the loss is transitory or permanent.

Many communities depend on a range of biological products for their material welfare. In addition, the transfer of ownership or use rights to ecosystem services like timber, fishing, and mining to privileged groups by governments have also excluded local communities from the use of these ecosystem services (R8). Provisions for ensuring the equitable distribution of monetary benefits from the use of biological products are an issue of major concern. Even in cases where equitable provisioning has been made, implementation is being impaired by weak and ineffective institutions (C10).

Poor people have historically disproportionately lost access to biological products and ecosystem services as demand for those services has grown. Coastal habitats are often converted to other uses, frequently for aquaculture ponds or cage culturing of highly valued species such as shrimp and salmon. Despite the fact that the area is still used for food production, local residents are often displaced from their fishing grounds, and the fish produced are usually not for local consumption but for export. Coastal residents often no longer have access to cheap protein or sources of income (C18). The development of shrimp aquaculture has displaced local fishers who are not able to enter the capital- and technology-intensive shrimp fisheries (SG3). Food security and overall well-being is much better in situations where local communities—with particular focus on the poor and the disadvantaged—were involved and made partners in the access, use, and management of biodiversity.

Changes in the equity structure of societies can have impacts on ecosystem services. Differential access to resources may also help to explain why some people living in environmental resource-rich areas nevertheless rank low in measures of human well-being. For example, economic liberalization in Viet Nam resulted in the development of a class of entrepreneurs with markedly greater access to capital. The poorer fishers were unable to enter the capital and technology-intensive shrimp fishery that developed. Furthermore, the ecological changes precipitated by the expansion of shrimp aquaculture reduced the capacity of the ecosystem to support the traditional fish stocks, further exacerbating the inequity (SG3.7).

The increase in international trade of biological products has improved the well-being for many social groups and individuals, especially in countries with well-developed markets and trade rules and among people in developing countries who have access to the biological products. However, many groups have not benefited from such trade. Some people who live near and are dependent on biodiversity-rich areas have experienced a drop in their well-being rather than an increase. Examples include the many indigenous groups and local communities who have relied on these products and the ecosystem services they support for many of the constituents of well-being. Weak and inefficient institutional structures that oversee the equitable distribution of benefits are key reasons for the inequitable distribution of benefits at the national and local levels. In addition, structural adjustment programs played a key role in pushing the poor further into destitution and forcing many to have no choice but to further stress ecosystem services (R17).

Conflicts between competing social groups or individuals over access to and use of biological products and ecosystem services have contributed to declines in well-being for some groups and improvements for others. Sometimes different social groups have a conflict over how a given bundle of ecosystem services or biological products ought to be used and shared. Although many such conflicts have been managed cooperatively, it is also common for one group to impose its preferred outcome on the others, leading to an improvement in well-being for one group at the expense of others. For example, if mountain communities convert forests into agricultural lands, they may reduce downstream water quality. When ecosystem change is linked to well-being change through this highly complex structure of interdependencies, there are both winners and losers. Some groups improve and other groups decline (C6). Box 2.4 describes some conflicts that emerged in Chile over the mining industry and local communities.

One of the main reasons some countries, social groups, or individuals—especially the disadvantaged—are more severely affected by biodiversity and ecosystem changes is limited access to substitutes or alternatives. When the quality of water deteriorates, the rich have the resources to buy personal water filters or imported bottled water that the poor can ill afford. Similarly, urban populations in developing countries have easier access to clean energy sources because of easy access to the electrical grid, while rural communities have fewer choices. Poor farmers often do not have the option of substituting modern methods for services provided by biodiversity because they cannot afford the alternatives. And, substitution of some services may not be sustainable, and may have negative environmental and human health effects. For example, the reliance on toxic and persistent pesticides to control certain pests can have negative effects on the provision of services by the cultivated system and other ecosystems connected to the cultivated system (C.26.2). Many industrial countries maintain seed banks in response to the rapid rate of loss of crop genetic diversity and to make existing genetic diversity more readily available to plant breeders. Apart from the network of seed banks maintained in developing countries by the Consultative Group on International Agricultural Research, for many developing countries creating such banks could pose a problem when electricity supplies are unreliable, fuel is costly, and there is a lack of human capacity (R17).

Place-based or micro-level data and not macro-level or aggregated data provide more useful information to identify disadvantaged communities being affected by biodiversity and ecosystem changes. Most poverty statistics are only available at an aggregate level. These tend to hide pockets of poverty existing sometimes within traditionally defined "wealthy" regions or provinces. Therefore, using aggregate data to understand and establish links between biodiversity loss, ecosystem changes, and well-being can be quite misleading (C5).

Box 2.4. Conflicts Between the Mining Sector and Local Communities in Chile

The Salar de Atacama, Chile, is a salty wetland within the driest desert in the world. Surface water is limited. The present major concern is over groundwater usage and the extent to which the exploitation is sustainable. The economic activities in this region include mining, agriculture, and tourism, all of which depend on the quantity and quality of available water. The Salar de Atacama holds over 40% of world lithium reserves; mining provides 12% of local employment and two thirds of the regional GDP. It also consumes 65% of the water used in the region. Tourism is the second largest source of employment and income, and tourist facilities need fresh water. Local communities rely on water for subsistence agriculture and livestock raising. Most subsistence farmers do not have enough resources to buy water rights when bidding against the mining companies. Hence the shortage of water is generating major conflicts over access and ownership rights among competing users (SG.SDM).

3. *What are the current trends and drivers of biodiversity loss?*

■ **Across the range of biodiversity measures, current rates of loss exceed those of the historical past by several orders of magnitude and show no indication of slowing.**

■ **Biodiversity is declining rapidly due to land use change, climate change, invasive species, overexploitation, and pollution. These result from demographic, economic, sociopolitical, cultural, technological, and other indirect drivers.**

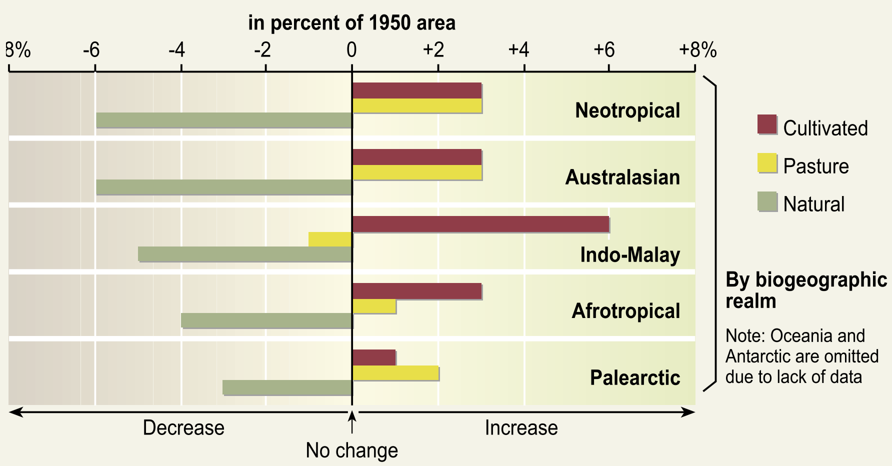
■ **While these drivers vary in their importance among ecosystems and regions, current trends indicate a continuing loss of biodiversity.**

Recent and Current Trends in Biodiversity

Across the range of biodiversity measures, current rates of change and loss exceed those of the historical past by several orders of magnitude and show no indication of slowing. At large scales, across biogeographic realms and ecosystems (biomes), declines in biodiversity are recorded in all parts of the habitable world. Among well-studied groups of species, extinction rates of organisms are high and increasing (*medium certainty*), and at local levels both populations and habitats are most commonly found to be in decline. (C4)

Figure 3.1. Percentage Change 1950–90 in Land Area of Biogeographic Realms Remaining in Natural Condition or under Cultivation and Pasture

Two biogeographic realms are omitted due to lack of data: Oceania and Antarctic. In the Nearctic, the amount of land under cultivation and pasture has stabilized, with no net change in cover since 1950.



Source: Millennium Ecosystem Assessment

Virtually all of Earth's ecosystems have now been dramatically transformed through human actions. More land was converted to cropland in the 30 years after 1950 than in the 150 years between 1700 and 1850 (C26). Between 1960 and 2000, reservoir storage capacity quadrupled (C7.2.4) and, as a result, the amount of water stored behind large dams is estimated to be three to six times the amount held by rivers (C7.3.2). Some 35% of mangroves have been lost in the last two decades in countries where adequate data are available (encompassing about half of the total mangrove area) (C19.2.1). Roughly 20% of the world's coral reefs have been destroyed and an additional 20% have been degraded (C19.2.1). Although the most rapid changes in ecosystems are now taking place in developing countries, industrial countries historically experienced comparable changes.

The biomes with the highest rates of conversion in the last half of the 20th century were temperate, tropical, and flooded grasslands and tropical dry forests (more than 14% lost between 1950 and 1990) (C4.4.3). Areas of particularly rapid change in terrestrial ecosystems over the past two decades include (C28.2):

- the Amazon basin and Southeast Asia (deforestation and expansion of croplands);
- Asia (land degradation in drylands); and
- Bangladesh, Indus Valley, parts of Middle East and Central Asia, and the Great Lakes region of Eastern Africa.

Habitat conversion to agricultural use has affected all biogeographical realms. In all realms (except Oceania and Antarctica), at least a quarter of the area had been converted to other land uses by 1950 (C4.4.4), and in the Indo-Malayan realm almost half of the natural habitat cover had been converted. In the 40 years from 1950 to 1990, habitat conversion has continued in nearly all realms. (See Figure 3.1.) The temperate northern realms of the Nearctic and Palearctic are currently extensively cultivated and urbanized; however, the amount of land under cultivation and pasture seems to have stabilized in the Nearctic, with only small increases in the Palearctic in the last 40 years. The decrease in extensification of land under agricultural use in these areas is counterbalanced by intensification of agricultural practices in order to ensure continued food production for expanding human populations

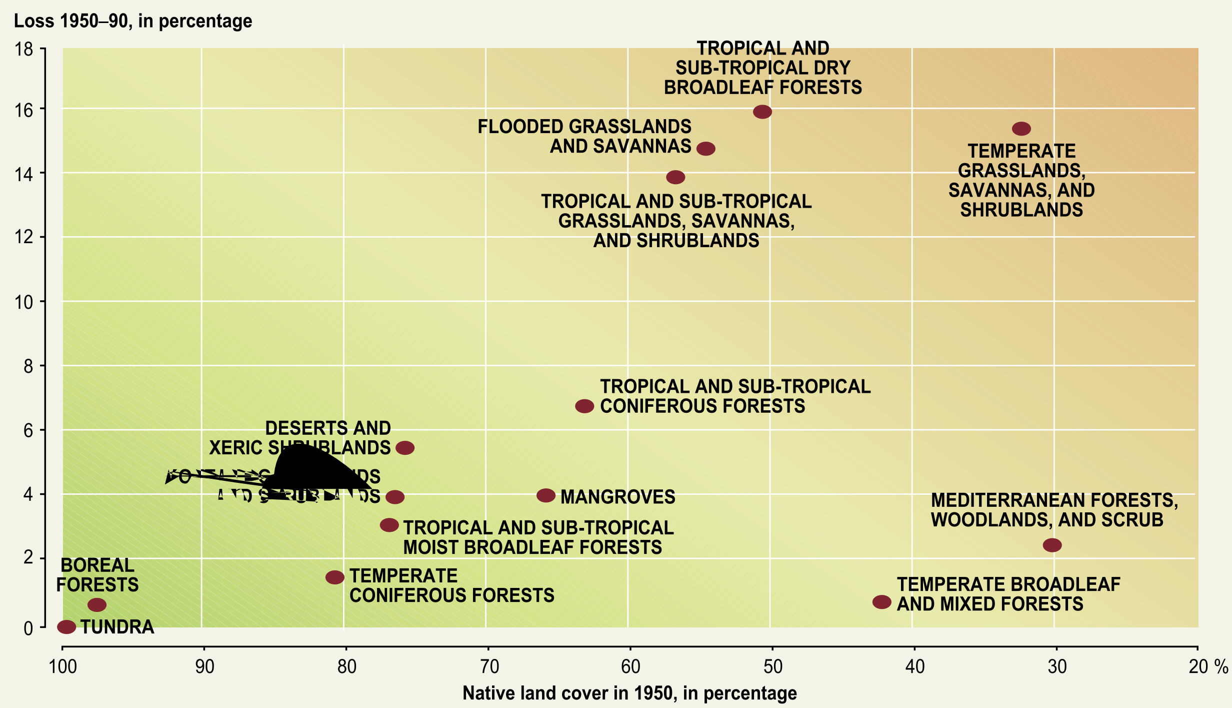
(C8, C26). Within the tropics, rates of land conversion to agricultural use range from very high in the Indo-Malayan realm to moderate in the Neotropics and the Afrotropics, where large increases in cropland area have taken place since the 1950s. Australasia has relatively low levels of cultivation and urbanization, but these have also increased in the last 40 years at a similar rate to those of the Neotropics.

The majority of biomes have been greatly modified. Between 20% and 50% of 9 out of 14 global biomes have been transformed to croplands. Tropical dry forests were the most affected by cultivation between 1950 and 1990, although temperate grasslands, temperate broadleaf forests, and Mediterranean forests each experienced 55% or more conversion prior to 1950. Biomes least affected by cultivation include boreal forests and tundra. (See Figure 3.2.) While cultivated lands provide many provisioning services (such as grains, fruits, and meat), habitat conversion to agriculture typically leads to reductions in local native biodiversity (C4.4.3).

Rates of human conversion among biomes have remained similar over at least the last century. For example, boreal forests had lost very little native habitat cover up to 1950 and have lost only a small additional percentage since then. In contrast, the temperate grasslands biome had lost nearly 70% of its native cover by 1950 and lost an additional 15.4% since then. Two biomes appear to be exceptions to this pattern: Mediterranean forests and temperate broadleaf forests. Both had lost the majority of their native habitats by 1950 but since then have lost less than 2.5% additional habitat. These biomes contain many of the world's most established cities and most extensive surrounding agricultural development (Europe, the United States, the Mediterranean basin, and China). It is possible that in these biomes the most suitable land for agriculture had already been converted by 1950 (C4.4.3).

Over the past few hundred years, humans have increased the species extinction rate by as much as three orders of magnitude (*medium certainty*). This estimate is only of *medium certainty* because the extent of extinctions of undescribed taxa is unknown, the status of many described species is poorly known, it is difficult to document the final disappearance of very rare species, and there are extinction lags between the impact of a threatening process and the resulting extinction. However, the most definite information, based on recorded extinctions of known species over the past 100 years, indicates extinction rates are around 100 times greater than rates characteristic of species in the fossil record (C4.4.2). Other less direct estimates, some of which model extinctions hundreds of years into the future, estimate extinction rates 1,000 to 10,000 times higher than rates recorded among fossil lineages. (See Figure 3.3.)

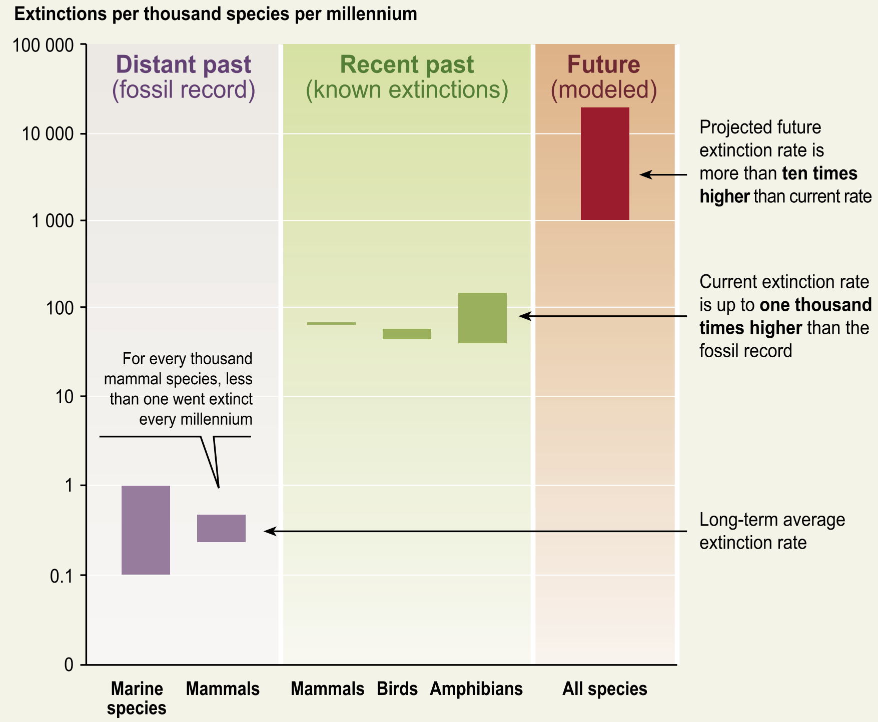
Figure 3.2. Relationship between Native Habitat Loss by 1950 and Additional Losses between 1950 and 1990 (C4 Fig 4.26)



Source: Millennium Ecosystem Assessment

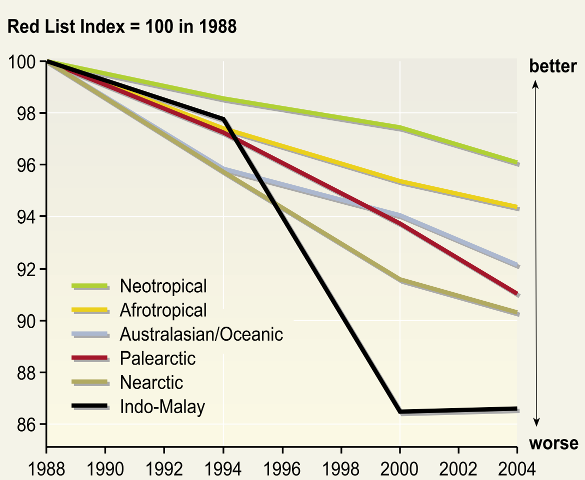
Figure 3.3. Species Extinction Rates (Adapted from C4 Fig 4.22)

"Distant past" refers to average extinction rates as calculated from the fossil record. "Recent past" refers to extinction rates calculated from known extinctions of species (lower estimate) or known extinctions plus "possibly extinct" species (upper bound). A species is considered to be "possibly extinct" if it is believed to be extinct by experts, but extensive surveys have not yet been undertaken to confirm its disappearance. "Future" extinctions are model-derived estimates using a variety of techniques, including species-area models, rates at which species are shifting to increasingly more threatened categories, extinction probabilities associated with the IUCN categories of threat, impacts of projected habitat loss on species currently threatened with habitat loss, and correlation of species loss with energy consumption. The time frame and species groups involved differ among the "future" estimates, but in general refer to either future loss of species based on the level of threat that exists today, or current and future loss of species as a result of habitat changes taking place over the period of roughly 1970 to 2050. Estimates based on the fossil record are *low certainty*. The lower bound estimates for known extinctions are *high certainty*, while the upper bound estimates are *medium certainty*; lower bound estimates for modeled extinctions are *low certainty*, and upper bound estimates are *speculative*.



Source: Millennium Ecosystem Assessment

Figure 3.4. Red List Indices for Birds, 1988–2004, in Different Biogeographic Realms (C4)



The Red List Index illustrates the relative rate at which sets of species change in overall threat status (i.e., projected relative extinction risk), based on population, range size, and trends as quantified by categories on the IUCN Red List.

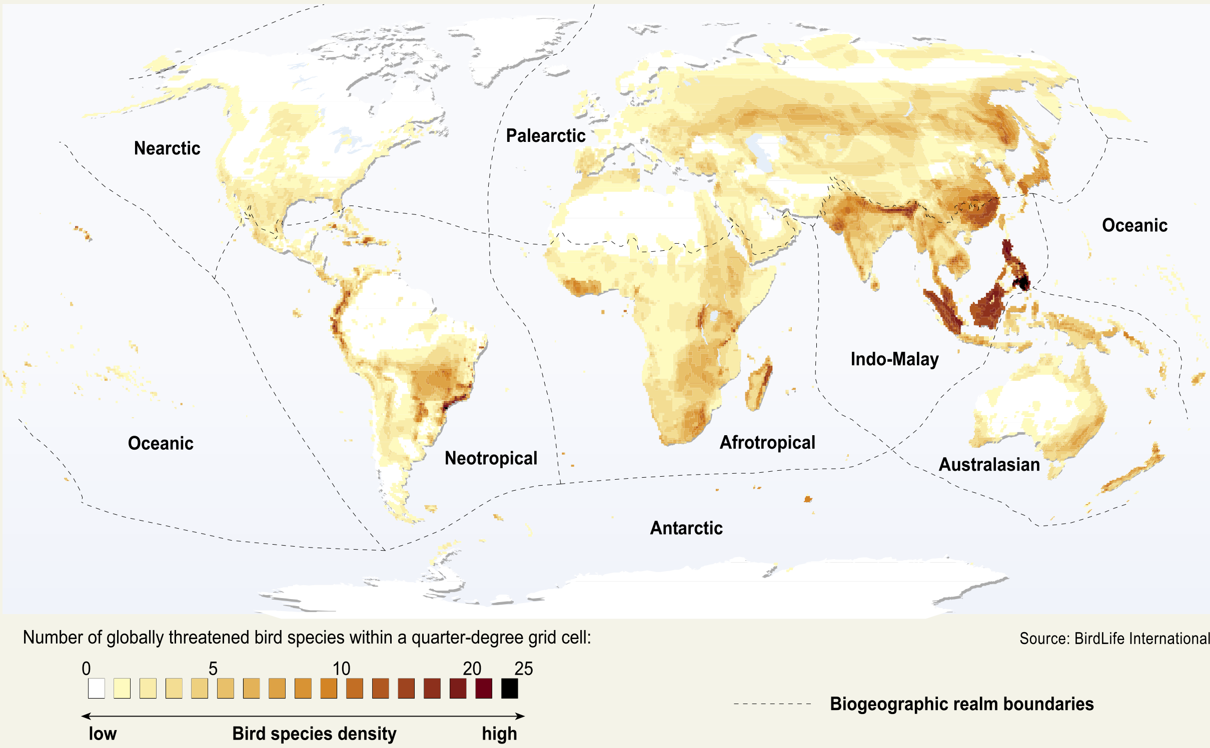
Source: Butchart et al. 2005

Between 12% and 52% of species within well-studied higher taxa are threatened with extinction, according to the IUCN Red List. Less than 10% of named species have been assessed in terms of their conservation status. Of those that have, birds have the lowest percentage of threatened species, at 12%. The patterns of threat are broadly similar for mammals and conifers, which have 23% and 25% of species threatened, respectively. The situation with amphibians looks similar, with 32% threatened, but information is more limited, so this may be an underestimate. Cycads have a much higher proportion of threatened species, with 52% globally threatened. In regional assessments, taxonomic groups with the highest proportion of threatened species tended to be those that rely on freshwater habitats (C4.4). Threatened species show continuing declines in conservation status, and species threat rates tend to be highest in the realms with highest species richness (C4.4). (See Figures 3.4 and 3.5.)

Threatened vertebrates are most numerous in the biomes with intermediate levels of habitat conversion. Low-diversity biomes (such as boreal forest and tundra) have low species richness and

Figure 3.5. Density Distribution Map of Globally Threatened Bird Species Mapped at a Resolution of Quarter-degree Grid Cell (C4 Fig 4.25)

Dark orange colors correspond to higher richness, dark blue to lowest. (n=1,213)

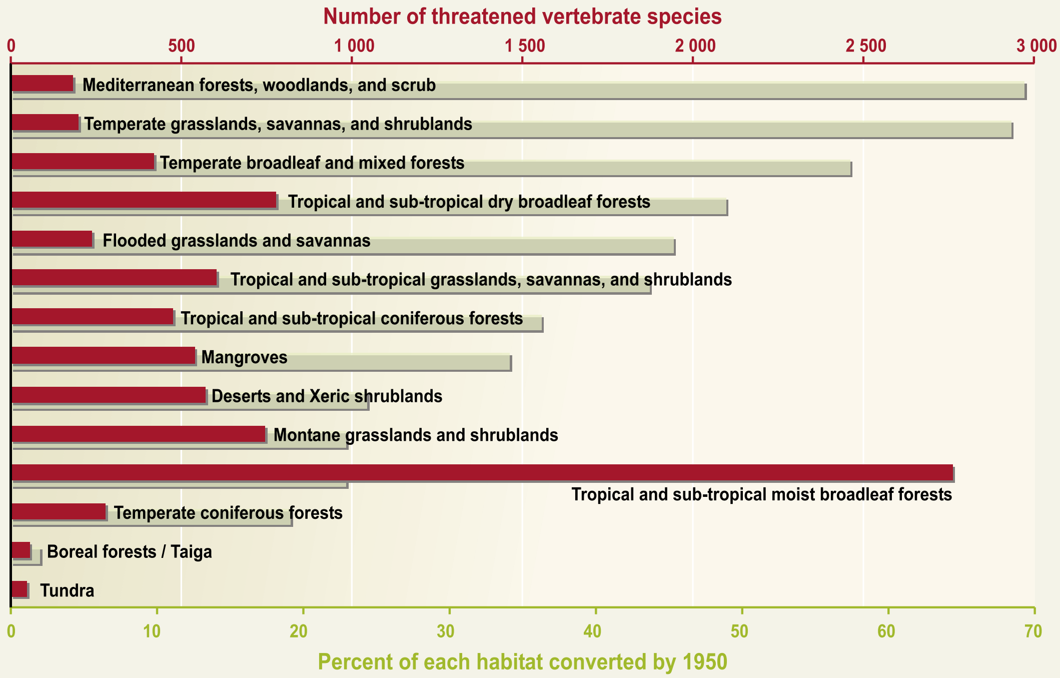


low threat rates and have experienced little conversion. Very highly converted habitats in the temperate zone had lower richness than tropical biomes, and many species vulnerable to conversion may have gone extinct already. It is in the high-diversity, moderately converted tropical biomes that the greatest number of threatened vertebrates are found (C4.4.3). (See Figure 3.6.)

Among a range of higher taxa, the majority of species are currently in decline. Studies of amphibians globally, African mammals, birds in agricultural lands, British butterflies, Caribbean corals, waterbirds, and fishery species show the majority of species to be declining in range or number. Increasing trends in species can almost always be attributed to management interventions, such as protection in reserves, or to elimination of threats such as overexploitation, or they are species that tend to thrive in human-dominated landscapes (C4.4.1). An aggregate indicator of trends in species populations—the Living Planet Index—uses published data on trends in natural populations of a variety of wild species to identify overall trends in species abundance. Although more balanced sampling would enhance its reliability, the trends are all declining, with the highest rate in freshwater habitats. (See Figure 3.7.)

Genetic diversity has declined globally, particularly among domesticated species (C26.2.1). In cultivated systems, since 1960 there has been a fundamental shift in the pattern of intra-species diversity in farmers' fields and farming systems as a result of the Green Revolution. Intensification of agricultural systems coupled with specialization by plant breeders and the harmonizing effects of globalization have led to a substantial reduction in the genetic diversity of domesticated plants and animals in agricultural systems. The on-farm losses of genetic diversity of crops have been partially offset by the maintenance of genetic diversity in gene banks. A third of the 6,500 breeds of domesticated animals are threatened with extinction due to their very small population sizes (C.26.2). In addition to cultivated systems, the extinction of species and loss of unique populations that has taken place has resulted in the loss of unique genetic diversity contained in those species and populations. This loss reduces overall fitness and adaptive potential, and it limits the prospects for recovery of species whose populations are reduced to low levels (C4.4).

Figure 3.6. Threatened Vertebrates in the 14 Biomes, Ranked by the Amount of Their Habitat Converted by 1950 (C4)



Source: Millennium Ecosystem Assessment

Globally, the net rate of conversion of some ecosystems has begun to slow, and in some regions ecosystems are returning to more natural states largely due to reductions in the rate of expansion of cultivated land, though in some instances such trends reflect the fact that little habitat remains for further conversion. Generally, opportunities for further expansion of cultivation are diminishing in many regions of the world as the finite proportion of land suitable for intensive agriculture continues to decline (C26.ES). Increased agricultural productivity is also lowering pressures for agricultural expansion. Since 1950, cropland areas in North America, Europe, and China have stabilized, and even decreased in Europe and China (C26.1.1). Cropland areas in the former Soviet Union have decreased since 1960 (C26.1.1). Within temperate and boreal zones, forest cover increased by approximately 3 million hectares per year in the 1990s, although about half of this increase consisted of forest plantations (C21.4.2).

Translating biodiversity loss between different measures is not simple: rates of change in one biodiversity measure may underestimate or overestimate rates of change in another. The scaling of biodiversity between measures is not simple, and this is especially significant in the relationship between habitat area and species richness. Loss of habitat initially leads to less species loss than might be expected, but depending on how much habitat remains, rates of loss of habitat can underestimate rates of loss of species (C2.2.4, C4.5.1).

Biotic homogenization, defined as the process whereby species assemblages become increasingly dominated by a small number of widespread species, represents further losses in biodiversity that are often missed when only considering changes in absolute numbers of species. Human activities have both negative and positive impacts on species. The many species that are declining as a result of human activities tend to be replaced by a much smaller number of expanding species that thrive in human-altered environments. The outcome is a more homogenized biosphere with lower species diversity at a global scale. One effect is that in some regions where diversity has been low because of isolation, the species diversity may actually increase—a result of invasions of non-native forms (this is true in continental areas such as the Netherlands as well as on oceanic islands). Recent data also indicate that the many losers and few winners tend to be non-randomly distributed among higher taxa and ecological groups, enhancing homogenization (C4.4).

While biodiversity loss has been a natural part of the history of Earth's biota, it has always been countered by origination and, except for rare events, has occurred at extremely slow rates. Currently, however, loss far exceeds origination, and rates are orders of magnitude higher than average rates in the past. Recall that biodiversity loss is not just global extinction, such as that faced by many threatened and endangered species, but declines in genetic, ecosystem, and landscape diversity are considered biodiversity loss as well. Even if every native species were retained in an ecological preserve, if the majority of the landscape has been converted to high-intensity monoculture cropland systems, then biodiversity has declined significantly. Landscape homogenization is linked to biotic homogenization (C4).

The patterns of threat and extinction are not evenly distributed among species but tend to be concentrated in particular ecological or taxonomic groups. Ecological traits shared by species facing high extinction risk include high trophic level, low population density, long lifespan, low reproductive rate, and small geographical range size (C4.4.2). The degree of extinction risk also tends to be similar among related species, leading to the likelihood that entire evolutionary radiations can and have been lost. The majority of recorded species extinctions since 1500 have occurred on islands. However, predictions of increasing numbers of future extinctions suggest a significant shift from island to continental areas (C4.4.2).

Drivers of Biodiversity Change and Their Trends

Biodiversity change is caused by a range of drivers. A driver is any natural or human-induced factor that directly or indirectly causes a change in an ecosystem. A direct driver unequivocally influences ecosystem processes. An indirect driver operates more diffusely, by altering one or more direct drivers. Important direct drivers affecting biodiversity are habitat change, climate change, invasive species, overexploitation, and pollution (CF4, C3, C4.3, S7).

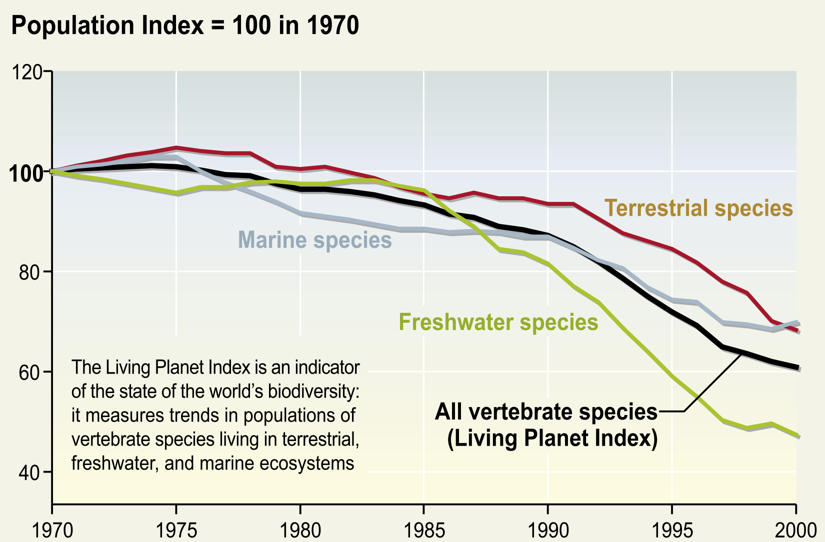
No single measure or indicator represents the totality of the various drivers. Some direct drivers of change have relatively straightforward indicators, such as fertilizer usage, water consumption, irrigation, and harvests. Indicators for other drivers, including invasion by non-native species, climate change, land cover conversion, and landscape fragmentation, are not as well developed, and data to measure them are not as readily available (S7).

Changes in biodiversity and in ecosystems are almost always caused by multiple, interacting drivers. Changes are driven by combinations of drivers that work over time (such as population and income growth interacting with technological advances that lead to climate change) or level of organization (such as local zoning laws versus international environmental treaties) and that happen intermittently (such as droughts, wars, and economic crises). Reviews of case studies of deforestation and desertification reveal that the most common type of interaction is synergetic factor combinations: combined effects of multiple drivers that are amplified by reciprocal action and feedbacks (S7.4).

Drivers interact across spatial, temporal, and organizational scales, and any specific ecosystem change is driven by a network of interactions among different drivers. Though some of the elements of these networks are global, the actual set of interactions that brings about an ecosystem change is more or less specific to a particular place. For example, a link between increasing producer prices and the extension of production can be found in many places throughout the world. The strength of this effect, however, is determined by a range of location-specific factors including production conditions, the availability of resources and knowledge, and the economic situation of the farmer (S7.4). No single conceptual framework captures the broad range of case study evidence about the interactions among drivers. Based on the findings of the sub-global assessments of the MA and recent literature, some examples of causal linkages for ecosystem change can be given (SG-Portugal, SG-SAfMA). (See Figures 3.8 and 3.9 and Box 3.1.)

Figure 3.7. The Living Planet Index, 1970–2000

The index currently incorporates data on the abundance of 555 terrestrial species, 323 freshwater species, and 267 marine species around the world. While the index fell by some 40% between 1970 and 2000, the terrestrial index fell by about 30%, the freshwater index by about 50%, and the marine index by around 30% over the same period.



Source: WWF, UNEP-WCMC

Figure 3.8. Illustration of Feedbacks and Interaction between Drivers in Portugal Sub-global Assessment

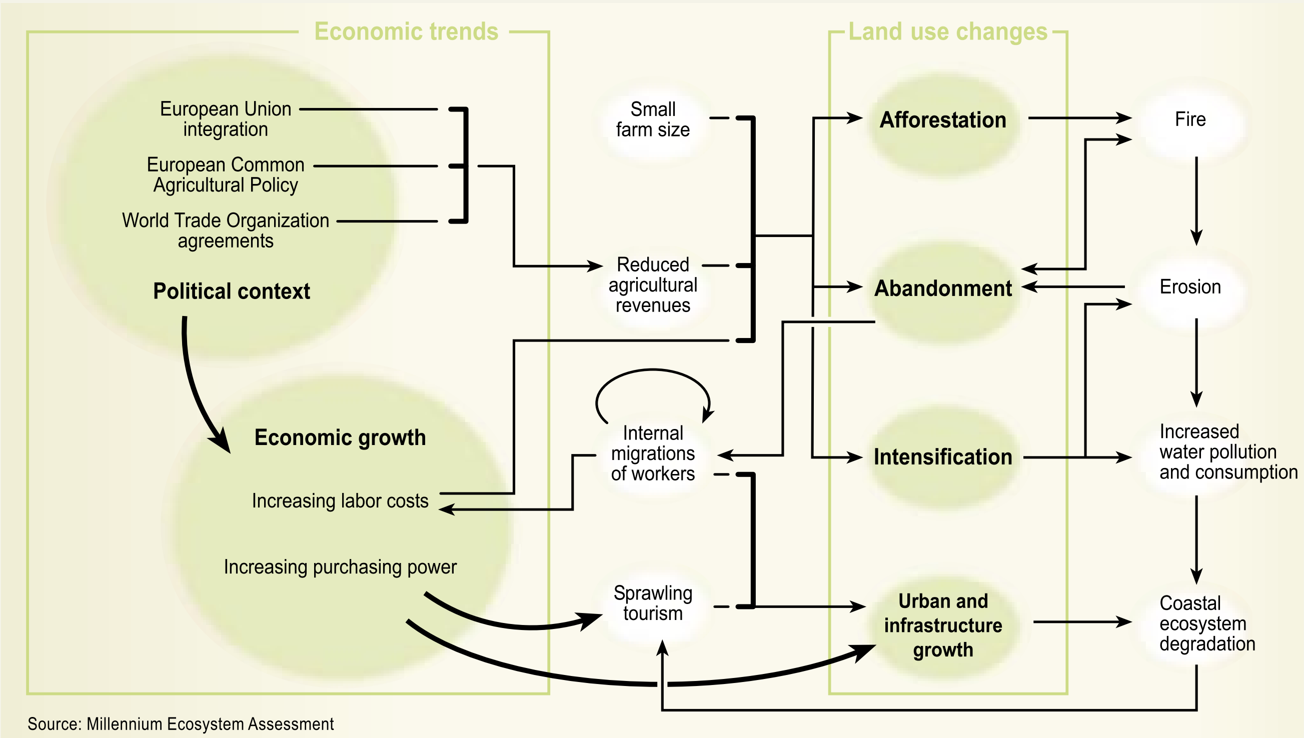
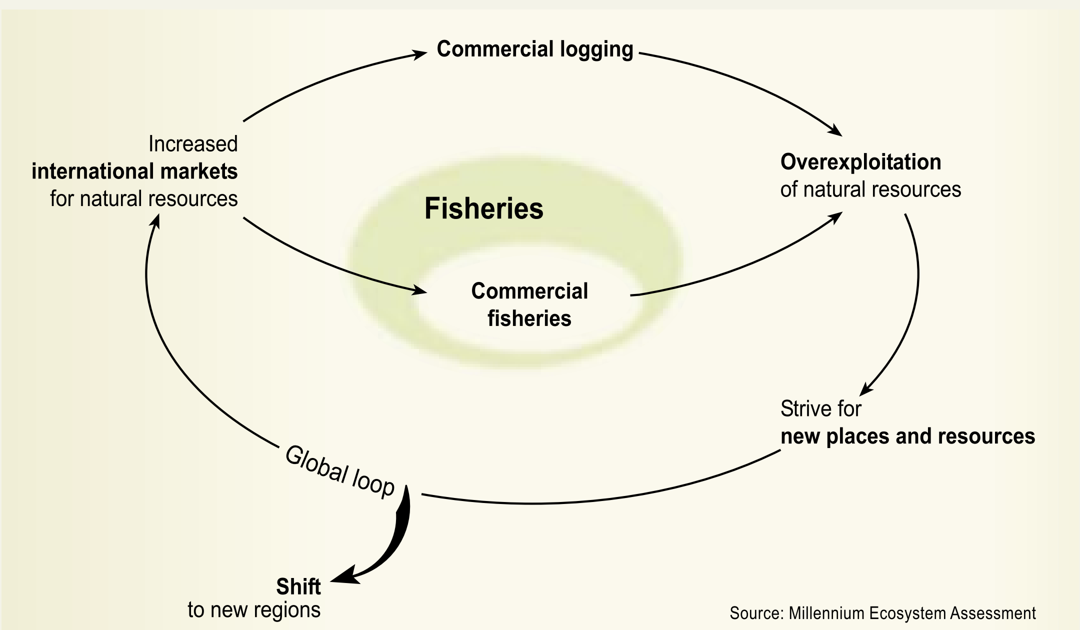


Figure 3.9. Summary of Interactions among Drivers Associated with the Overexploitation of Natural Resources (Adapted from SG7 Fig 7.7)



Box 3.1. Direct Drivers: Example from Southern African Sub-global Assessment (SG-SAfMA)

The direct drivers of biodiversity loss in southern Africa include the impacts of land use change, alien invasives, overgrazing, and overharvesting—all of which have already had a large impact on the region's biodiversity, ecosystem services, and human well-being, and all of which are likely to spread in the absence of interventions.

The dominant direct driver of ecosystem change in southern Africa is considered to be widespread land use change that in some cases has led to degradation. Forests and woodlands are being converted to croplands and pastures at a rate somewhat slower than in Southeast Asia and the Amazon during the 1990s, but nevertheless sufficiently fast to endanger ecosystem services at a local scale. Half of the region consists of drylands, where overgrazing is the main cause of desertification.

In the first half of the twenty-first century, climate change is a real threat to water supplies, human health, and biodiversity in southern Africa. The threats arise partly because the projected warming may, over large areas, be accompanied by a drying trend, and partly because of the low state of human welfare and weak governance, which increases vulnerability of humans to climate change. Although some of these threats have slowed in some regions (afforestation with monocultures of alien species in South Africa has decreased, for example), some have accelerated elsewhere (afforestation with alien species in Mozambique has increased, for instance, due to favorable growing conditions and weak regulation). Thus, the region's biodiversity remains vulnerable to land use change. In addition, the more subtle problem of land degradation is considered a bigger threat in the region.

Several studies indicate that the biodiversity of southern Africa is at risk. There is now evidence, for example, that it is declining in the northern part of its range, but stable in the southern part, as predicted by the global change models. In addition, there is experimental evidence that the recorded expansion of woody invasions into grasslands and savannas may be driven by rising global CO_2 concentrations. The ability of species to disperse and survive these pressures will be hampered by a fragmented landscape made inhospitable by human activities. The Assessments of Impacts and Adaptations to Climate Change in Multiple Regions and Sectors project is currently analyzing response options that may conserve biodiversity under future climate and land cover scenarios in southern Africa.

Indirect Drivers

Biodiversity change is most clearly a consequence of the direct drivers. However, these reflect changes in indirect drivers—the root causes of changes in ecosystems. These can be classified into the following broad categories: change in economic activity, demographic change, sociopolitical factors, cultural and religious factors, and scientific and technological change.

- Global economic activity increased nearly sevenfold between 1950 and 2000 (S7.SDM), and in the MA scenarios it is projected to grow a further three- to sixfold by 2050. The many processes of globalization have amplified some driving forces of changes in ecosystem services and attenuated other forces by removing regional barriers, weakening national connections, and increasing the interdependence among people and between nations (S7.2.2).
- Global population doubled in the past 40 years, reaching 6 billion in 2000 (S7.2.1). It is projected to grow to 8.1–9.6 billion by 2050, depending on the scenario. Urbanization influences consumption, generally increasing the demand for food and energy and thereby increasing pressures on ecosystems globally.
- Over the past 50 years, there have been significant changes in sociopolitical drivers, including a declining trend in centralized authoritarian governments and a rise in elected democracies, which allows for new forms of management, in particular adaptive management, of environmental resources (S7.2.3).

Culture conditions individuals' perceptions of the world, and by influencing what they consider important, it has implications for conservation and consumer preferences and suggests courses of action that are appropriate and inappropriate. The development and diffusion of scientific knowledge and technologies can on the one hand allow for increased efficiency in resource use and on the other hand can provide the means to increase exploitation of resources (S7.2.4, S7.2.5).

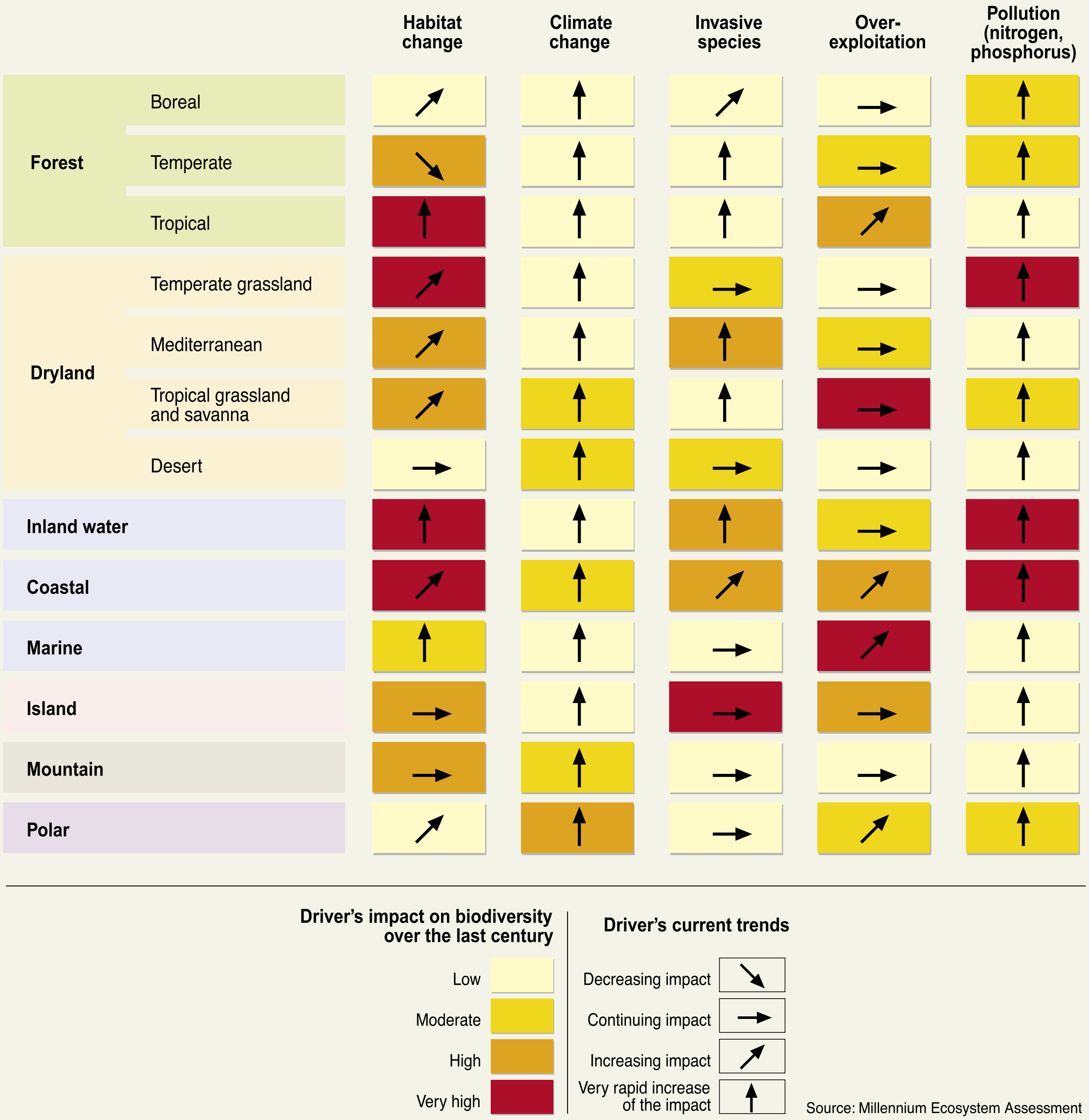
Direct Drivers

Direct drivers vary in their importance within and among systems and in the extent to which they are increasing their impact. Historically, habitat and land use change have had the biggest impact on biodiversity across biomes. Climate change is projected to increasingly affect all aspects of biodiversity, from individual organisms, through populations and species, to ecosystem composition and function. Pollution, especially the deposition of nitrogen and phosphorus, but also including the impact of other contaminants, is also expected to have an increasing impact, leading to declining biodiversity across biomes. Overexploitation and invasive species have been important as well and continue to be major drivers of changes in biodiversity (C4.3). (See Figure 3.10.)

For terrestrial ecosystems, the most important direct driver of change in the past 50 years has been land cover change (C4.3, SG7). Only biomes relatively unsuited to crop plants, such as deserts, boreal forests, and tundra, are relatively intact (C4). Deforestation and forest degradation are currently more extensive in the tropics than in the rest of the world, although data on boreal forests are especially limited (C21). Approximately 10–20% of drylands are considered degraded (*medium certainty*),

Figure 3.10. Main Direct Drivers

The cell color indicates the impact to date of each driver on biodiversity in each biome over the past 50–100 years. The arrows indicate the trend in the impact of the driver on biodiversity. Horizontal arrows indicate a continuation of the current level of impact; diagonal and vertical arrows indicate progressively increasing trends in impact. This Figure is based on expert opinion consistent with and based on the analysis of drivers of change in various chapters of the assessment report of the Condition and Trends Working Group. This Figure presents global impacts and trends that may be different from those in specific regions.



with the majority of these areas in Asia (C22). A study of the southern African biota shows how degradation of habitats led to loss of biodiversity across all taxa. (See Figure 3.11.)

Cultivated systems (defined in the MA to be areas in which at least 30% of the landscape is in croplands, shifting cultivation, confined livestock production, or freshwater aquaculture in any particular year) cover 24% of Earth's surface. (See Figure 3.12.) In 1990, around 40% of the cropland is located in Asia; Europe accounts for 16%, and Africa, North America, and South America each account for 13% (S7).

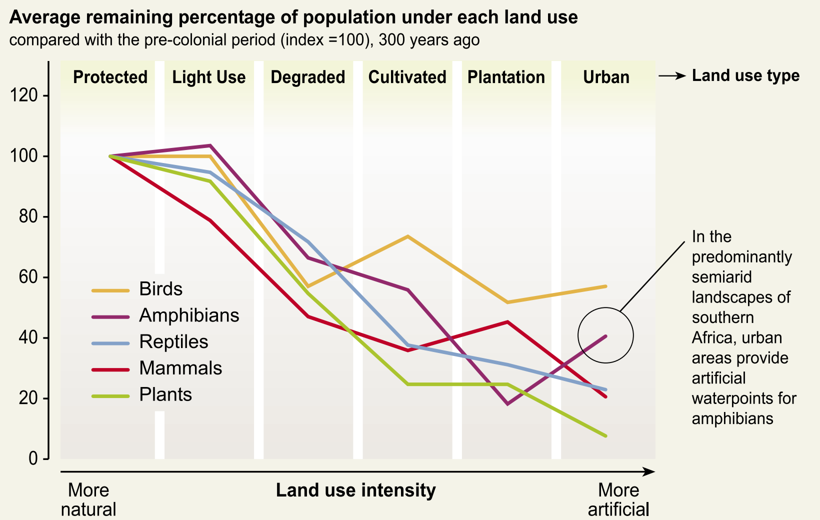
For marine ecosystems, the most important direct driver of change in the past 50 years, in the aggregate, has been fishing. Fishing is the major direct anthropogenic force affecting the structure, function, and biodiversity of the oceans (C18). Fishing pressure is so strong in some marine systems that over much of the world the biomass of fish targeted in fisheries (including that of both the target species and those caught incidentally) has been reduced by 90% relative to levels prior to the onset of industrial fishing. In these areas a number of targeted stocks in all oceans have collapsed—having been overfished or fished above their maximum sustainable levels. Recent studies have demonstrated that global fisheries landings peaked in the late 1980s and are now declining despite increasing effort and fishing power, with little evidence of this trend reversing under current practices (C18.3). In addition to the landings, the average trophic level of global landings is declining, which implies that we are increasingly relying on fish that originate from the lower part of marine food webs (C18.3). (See Figures 3.13 and 3.14.) Destructive fishing is also a factor in shallower waters; bottom trawling homogenizes three-dimensional benthic habitats and dramatically reduces biodiversity.

For freshwater ecosystems, depending on the region, the most important direct drivers of change in the past 50 years include physical changes, modification of water regimes, invasive species, and pollution. The loss of wetlands worldwide has been *speculated* to be 50% of those that existed in 1900. However, the accuracy of this figure has not been established due to an absence of reliable data (C20.3.1). Massive changes have been made in water regimes. In Asia, 78% of the total reservoir volume was constructed in the last decade, and in South America almost 60% of all reservoirs were built since the 1980s (C20.4.2). Water withdrawals from rivers and lakes for irrigation or urban or industrial use increased sixfold since 1900 (C7.2.2). Globally, humans now use roughly 10% of the available renewable freshwater supply, although in some regions, such as the Middle East and North Africa, humans use 120% of renewable supplies—the excess is obtained through mining groundwater (C7.2.3). The introduction of non-native invasive species is now a major cause of species extinction in freshwater systems. It is *well established* that the increased discharge of nutrients causes intensive eutrophication and potentially high levels of nitrate in drinking water and that pollution from point sources such as mining has had devastating impacts on the biota of inland waters (C20.4).

Apparently stable areas of habitat may suffer from fragmentation, with significant impacts on their biodiversity (C4.3.1). Fragmentation is caused by natural disturbance (such as fires or wind) or by land use change and habitat loss, such as the clearing of natural vegetation for agriculture or road construction, which divides previously continuous habitats. Larger remnants, and

Figure 3.11. Effect of Increasing Land Use Intensity on the Fraction of Inferred Population 300 Years Ago of Different Taxa that Remain

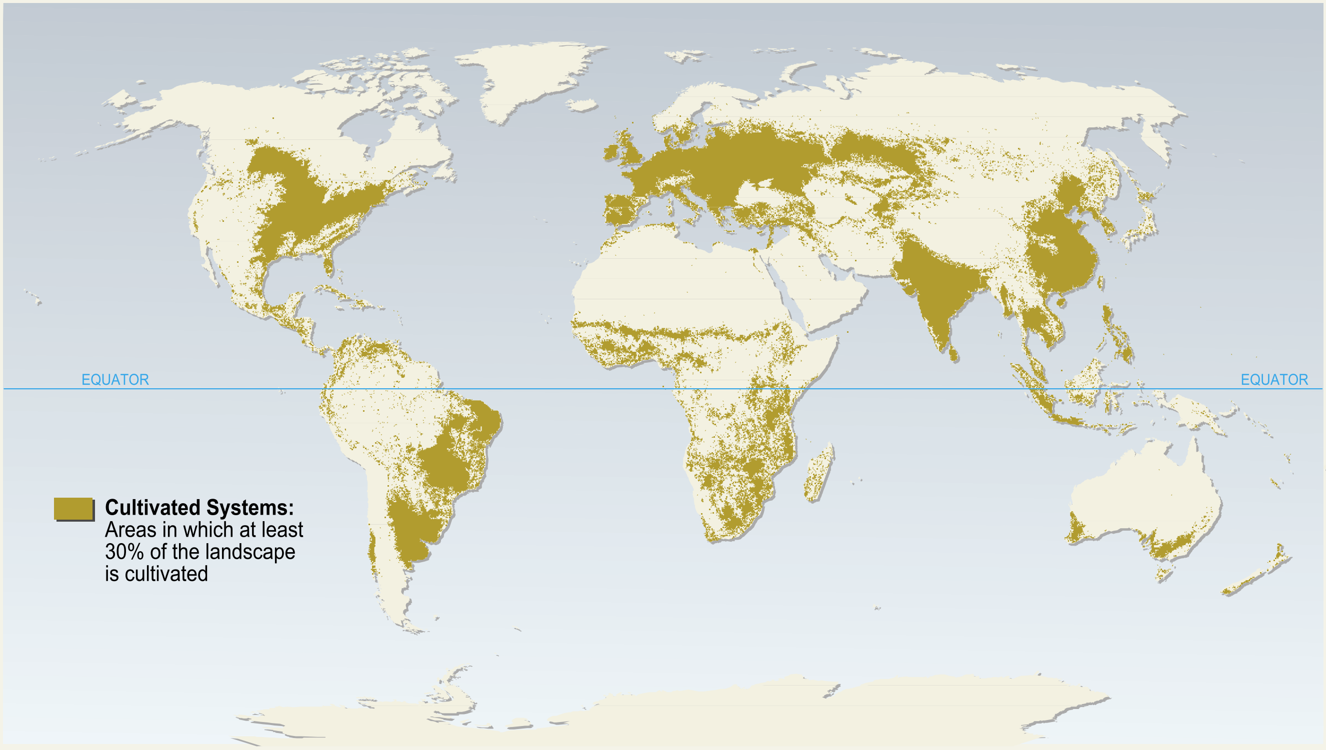
The vertical axis percentages refer to the share of southern Africa under the respective land uses. Human landscape modifications can also lead to increases of populations under conditions of light use (see amphibians).



Protected areas: assumed to have intact biodiversity and therefore used as a reference
Light use: natural vegetation productively used (e.g., for grazing) within the limits of sustainability
Degraded: natural vegetation where intensity of use exceeds the natural productive capacity
Cultivated: cropland and planted pastures
Plantation: monocultures of exotic trees, mainly eucalyptus and pine species
Urban: built-up urban and high-impact mining landscapes

Source: Scholes and Biggs 2004

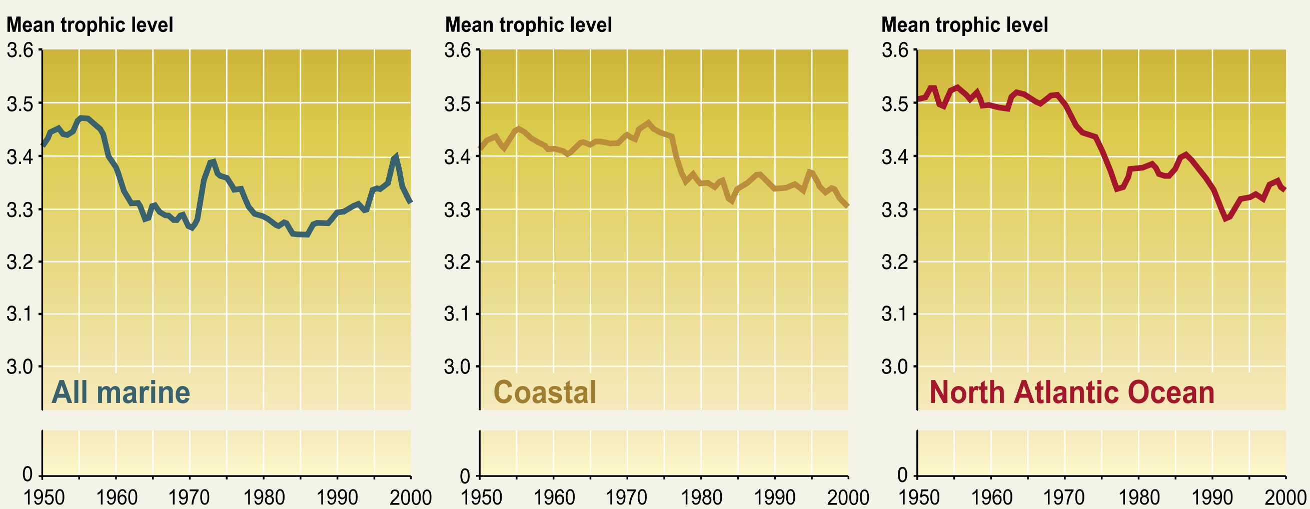
Figure 3.12. Extent of Cultivated Systems, 2000 (C26)



Source: Millennium Ecosystem Assessment

Figure 3.13. Decline in Trophic Level of Fisheries Catch since 1950 (C18)

A trophic level of an organism is its position in a food chain. Levels are numbered according to how far particular organisms are along the chain from the primary producers (level 1), to herbivores (level 2), to predators (level 3), to carnivores or top carnivores (level 4 or 5). Fish at higher trophic levels are typically of higher economic value. The decline in the trophic level harvested is largely a result of the overharvest of fish at higher trophic levels.



Source: Millennium Ecosystem Assessment

remnants that are close to other remnants, are less affected by fragmentation. Small fragments of habitat can only support small populations, which tend to be more vulnerable to extinction. Moreover, habitat along the edge of a fragment has a different climate and favors different species to the interior. Small fragments are therefore unfavorable for those species that require interior habitat, and they may lead to the extinction of those species. Species that are specialized to particular habitats and those whose dispersal abilities are weak suffer from fragmentation more than generalist species with good dispersal ability (C4.3.1). Fragmentation affects all biomes, but especially forests (see Figure 3.15) and major freshwater systems (see Figure 3.16).

Invasive alien species have been a major cause of extinction, especially on islands and in freshwater habitats, and they continue to be a problem in many areas. In freshwater habitats, the introduction of alien species is the second leading cause of species extinction, and on islands it is the main cause of extinction over the past 20 years, along with habitat destruction. Awareness about the importance of stemming the tide of invasive alien species is increasing, but effective implementation of preventative measures is lacking. The rate of introductions continues to be extremely high; for example, in New Zealand plant introductions alone have occurred at a rate of 11 species per year since European settlement in 1840 (C4.3.2).

Overexploitation remains a serious threat to many species and populations. Among the most commonly overexploited species or groups of species are marine fish and invertebrates, trees, and animals hunted for meat. Most industrial fisheries are either fully or overexploited, and the impacts of overharvesting are coupled to destructive fishing techniques that destroy habitat, as well as associated ecosystems such as estuaries and wetlands. Even recreational and subsistence fishing has contributed to what is known as the "shifting baselines" phenomenon, in which what we consider the norm today is dramatically different from preexploitation conditions.

Many of the current concerns with overexploitation of bushmeat (wild meat taken from the forests by local people for income or subsistence) are similar to those of fisheries, where sustainable levels of exploitation remain poorly understood and where the offtake is difficult to manage effectively. Although the true extent of exploitation is poorly known, it is clear that rates of offtake are extremely high in tropical forests. The trade in wild plants and animals and their derivatives is poorly documented but is estimated at nearly $160 billion annually. It ranges from live animals for the food and pet trade to ornamental plants and timber. Because the trade in wild animals and plants crosses national borders, the effort to regulate it requires international cooperation to safeguard certain species from overexploitation (C4.3.4).

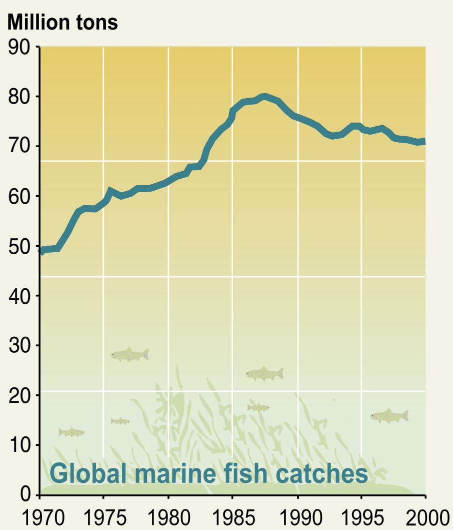
Over the past four decades, nutrient loading has emerged as one of the most important drivers of ecosystem change in terrestrial, freshwater, and coastal ecosystems. While the introduction of nutrients into ecosystems can have both beneficial and adverse effects, the beneficial effects will eventually reach a plateau as more nutrients are added (for example, additional inputs will not lead to further increases in crop yield), while the harmful effects will continue to grow. Synthetic production of nitrogen fertilizer has been the key driver for the remarkable increase in food production of the past 50 years (S7.3). (See Figure 3.17.) The total amount of reactive, or biologically available, nitrogen created by human activities increased ninefold between 1890 and 1990, with most of that increase taking place in the second half of the century in association with increased use of fertilizers (C7.3.2).

More than half of all the synthetic nitrogen fertilizers ever used on Earth have been used since 1985 (R9.2). Humans now produce more reactive nitrogen than is produced by all natural pathways combined (R9.ES). Nitrogen application has increased fivefold since 1960, but as much as 50% of the nitrogen fertilizer applied may be lost to the environment. Phosphorus application has increased threefold since 1960, with steady increase until 1990, followed by leveling off at a level about equal to applications in 1980. (See Figure 3.18.) These changes are mirrored by phosphorus accumulation in soils, which can serve as an indicator of eutrophication potential for freshwater lakes and phosphorus-sensitive estuaries. Potential consequences include eutrophication of freshwater ecosystems, hypoxia in coastal marine ecosystems, nitrous oxide emissions contributing to global

(*continued on page 56*)

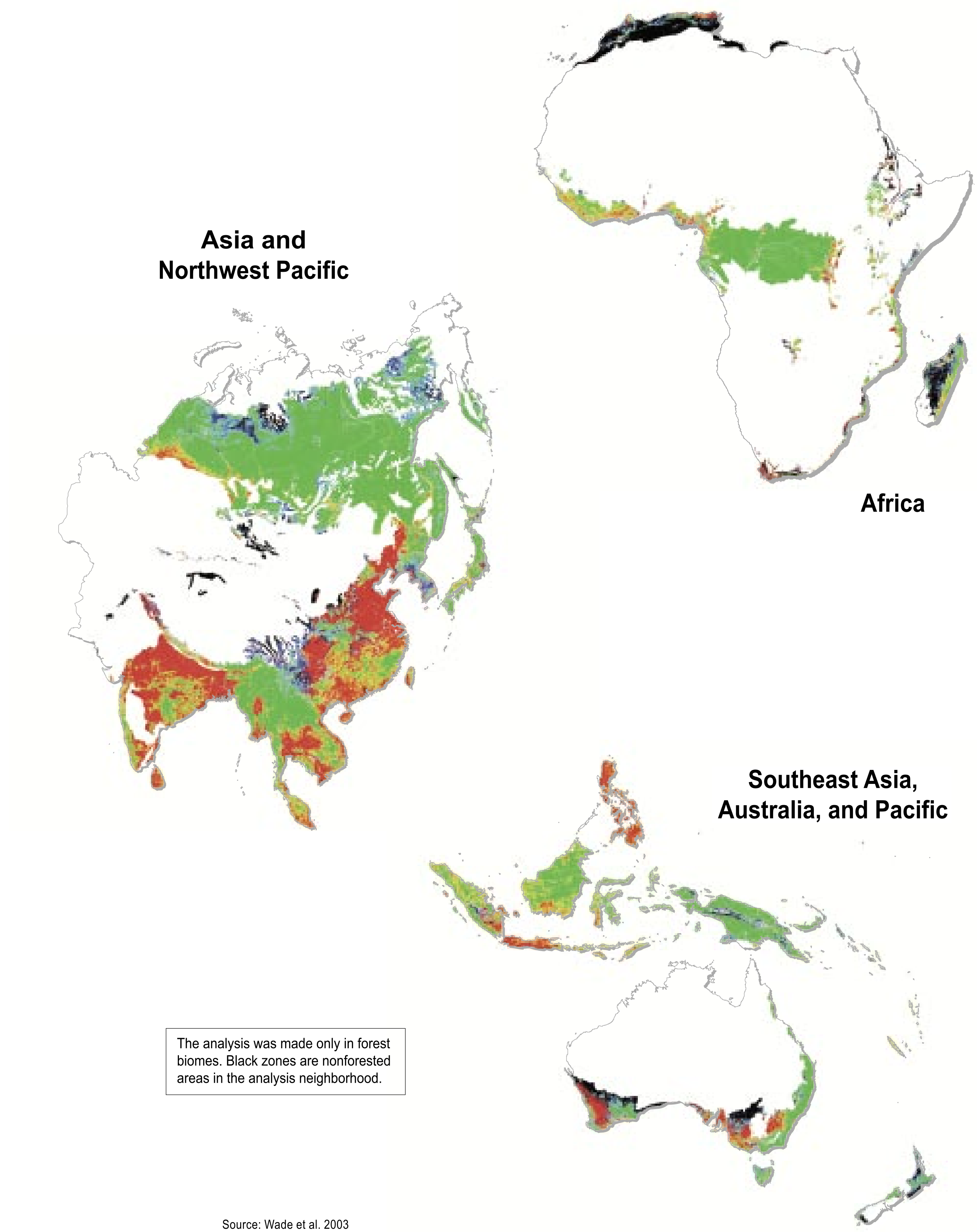
Figure 3.14. Estimated Global Marine Fish Catch, 1950–2001 (C18 Fig 18.3)

In this Figure, the catch reported by governments is in some cases adjusted to correct for likely errors in data.



Source: Millennium Ecosystem Assessment

Figure 3.15. Estimates of Forest Fragmentation due to Anthropogenic Causes (C4)



Source: Wade et al. 2003

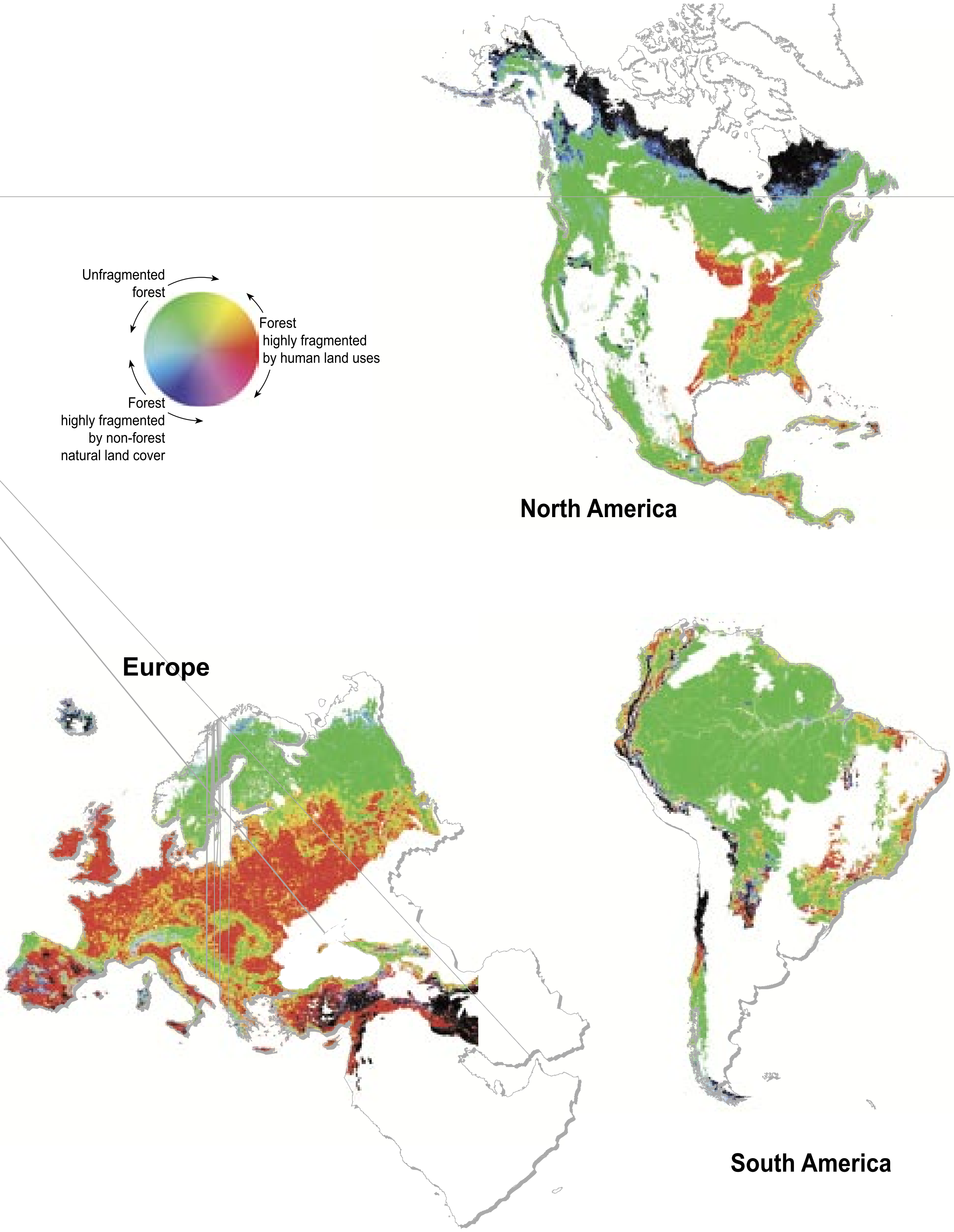
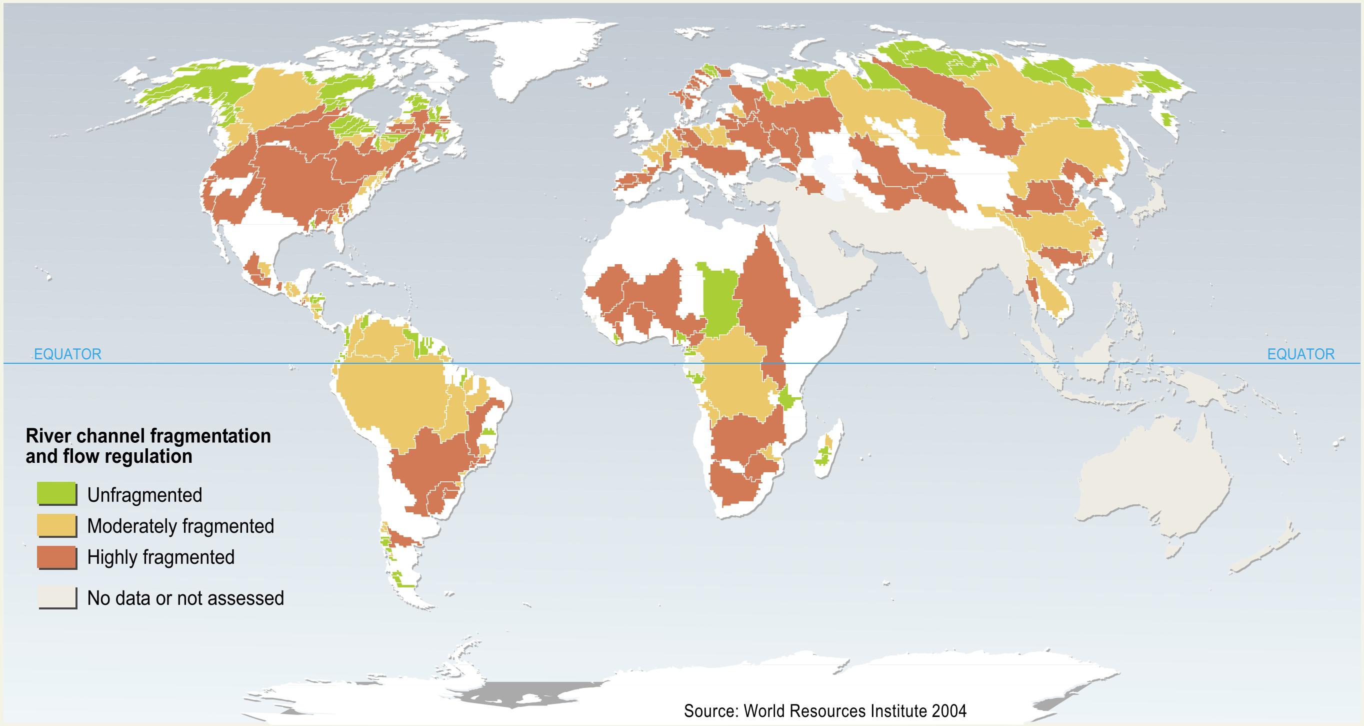

Unfragmented forest
Forest highly fragmented by human land uses
Forest highly fragmented by non-forest natural land cover
North America
Europe
South America

Figure 3.16. Fragmentation and Flow in Major Rivers (C20)



climate change, and air pollution by NO_x in urban areas. Occurrence of such problems varies widely in different regions (S7.3). (See Figure 3.19.)

Climate change in the past century has already had a measurable impact on biodiversity. Observed recent changes in climate, especially warmer regional temperatures, have already had significant impacts on biodiversity and ecosystems, including causing changes in species distributions, population sizes, the timing of reproduction or migration events, and an increase in the frequency of pest and disease outbreaks. Many coral reefs have undergone major, although often partially reversible, bleaching episodes when local sea surface temperatures have increased during one month by 0.5–1° Celsius above the average of the hottest months (R13.1.3). Precipitation patterns have changed spatially and temporally, and global average sea level rose 0.1–0.2 meters (S7.ES). By the end of the century, climate change and its impacts may be the dominant direct driver of biodiversity loss and changes in ecosystem services globally.

Recent studies, using the climate envelope/species-area technique, estimated that the projected changes in climate by 2050 could lead to an eventual extinction of 15–52% of the subset of 1,103 endemic species (mammals, birds, frogs, reptiles, butterflies, and plants) analyzed (R13.1.3). While the growing season in Europe has lengthened over the last 30 years, in some regions of Africa the combination of regional climate changes and anthropogenic stresses has led to decreased cereal crop production since 1970. Changes in fish populations have been linked to large-scale climate oscillations; El Niño events, for instance, have affected fisheries off the coasts of South America and Africa, and decadal oscillations in the Pacific have affected fisheries off the west coast of North America (R13.1.3).

The scenarios developed by the Intergovernmental Panel on Climate Change project an increase in global mean surface temperature of 2.0–6.4° Celsius above preindustrial levels by 2100, increased incidence of floods and droughts, and a rise in sea level of an additional 8–88 centimeters between 1990 and 2100. (See Figure 3.20.)

Harm to biodiversity will grow worldwide with increasing rates of change in climate and increasing absolute amounts of change. In contrast, some ecosystem services in some regions may initially be enhanced by projected changes in climate (such as increases in temperature or precipitation), and thus these regions may experience net benefits at low levels of climate change. As climate change becomes more severe, however, the harmful impacts on ecosystem services outweigh the benefits in most regions of the world. The balance of scientific evidence suggests that there will be a significant net harmful impact on ecosystem services worldwide if global mean surface temperature increases more than 2º Celsius above preindustrial levels or at rates greater than 0.2º Celsius per decade (*medium certainty*).Climate change is projected to further adversely affect key development challenges, including providing clean water, energy services, and food; maintaining a healthy environment; and conserving ecological systems and their biodiversity and associated ecological goods and services (R13.1.3).

- Climate change is projected to exacerbate the loss of biodiversity and increase the risk of extinction for many species, especially those already at risk due to factors such as low population numbers, restricted or patchy habitats, and limited climatic ranges (*medium to high certainty*).
- Water availability and quality are projected to decrease in many arid and semiarid regions (*high certainty*).
- The risk of floods and droughts is projected to increase (*high certainty*).
- The reliability of hydropower and biomass production is projected to decrease in some regions (*high certainty*).
- The incidence of vector-borne diseases such as malaria and dengue and of waterborne diseases such as cholera is projected to increase in many regions (*medium to high certainty*), and so too are heat stress mortality and threats of decreased nutrition in other regions, along with severe weather traumatic injury and death (*high certainty*).
- Agricultural productivity is projected to decrease in the tropics and sub-tropics for almost any amount of warming (*low to medium certainty*), and there are projected adverse effects on fisheries.
- Projected changes in climate during the twenty-first century are very likely to be without precedent during at least the past 10,000 years and, combined with land use change and the spread of exotic or alien species, are likely to limit both the capability of species to migrate and the ability of species to persist in fragmented habitats.

Present-day threats are often multiple and of greater intensity than historical threats. The susceptibility of an ecological community to a given threat will depend on the events of the past that have shaped the current biota. If the current threats are novel, they will have dramatic effects on populations, since species will lack adaptations. Even if drivers are similar to past drivers (climate, for example, has always been variable to some degree), the intensity of some current-day drivers is unprecedented (such as the rates and extent of habitat change). Furthermore, today's drivers of extinction are often multiple—land use change, emerging disease, and invasive species are all occurring together, for instance. Because exposure to one threat type often makes a species more susceptible to a second, exposure to a second makes a species more susceptible to a third, and so on, consecutive, multiple threats to species may have unexpectedly dramatic impacts on biodiversity (S7.4, C4.3).

Figure 3.17. Trends in Global Use of Nitrogen Fertilizer, 1961–2001 (million tons) (S7 Fig 7.16)

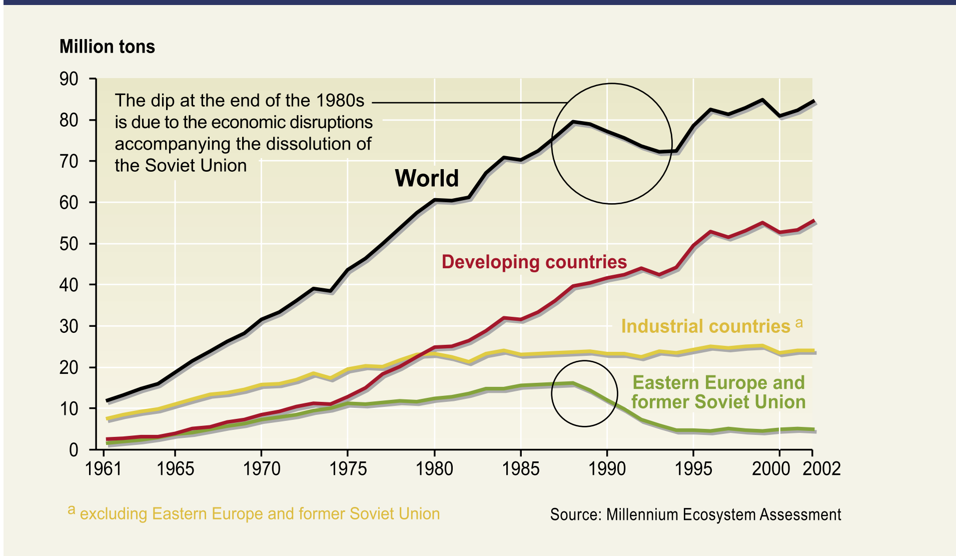


Figure 3.18. World Phosphate Fertilizer Use, 1961–2000 (million tons) (S7 Fig 7.18)

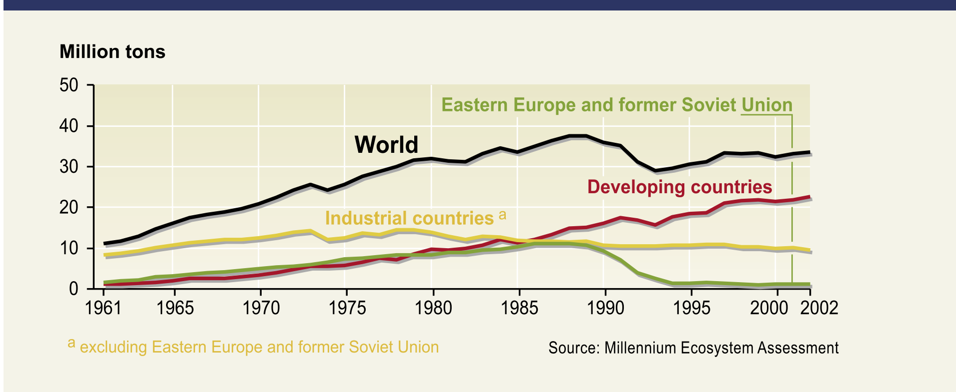
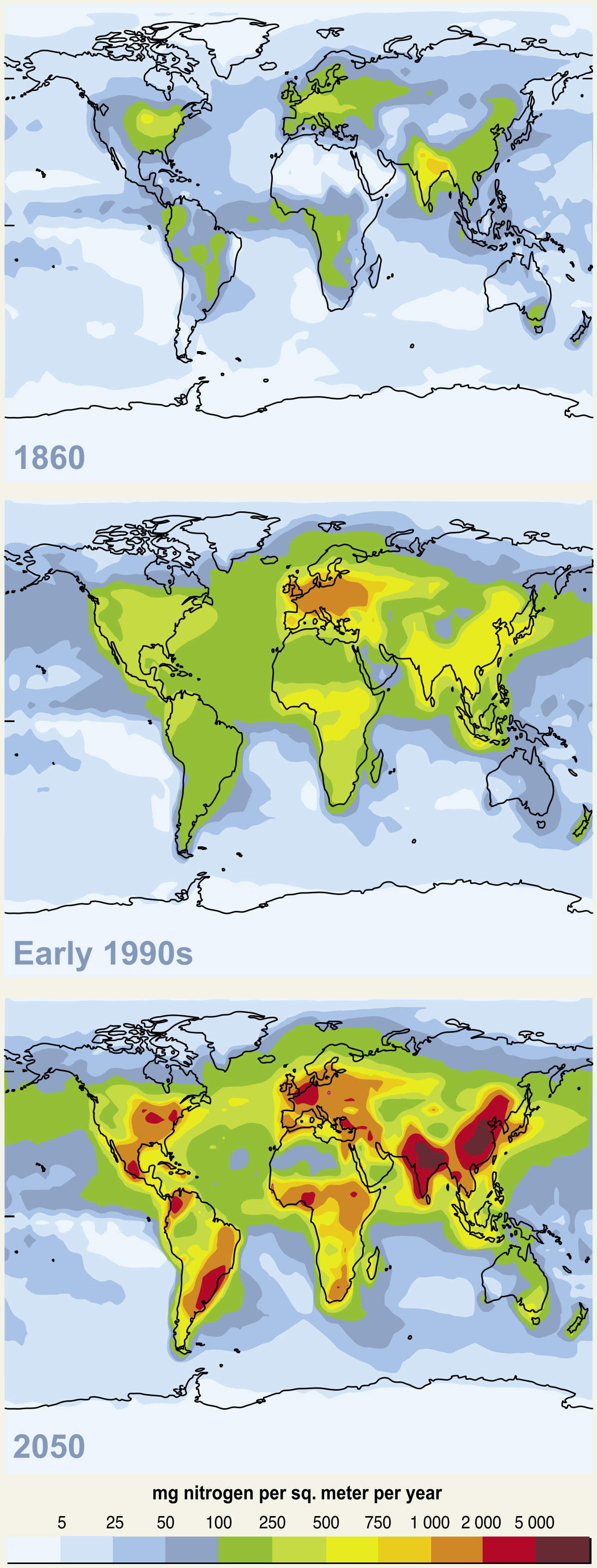


Figure 3.19. Estimated Total Reactive Nitrogen Deposition from the Atmosphere (Wet and Dry) in 1860, Early 1990s, and Projected for 2050 (milligrams of nitrogen per square meter per year) (R9 Fig 9.2)

Atmospheric deposition currently accounts for roughly 12% of the reactive nitrogen entering terrestrial and coastal marine ecosystems globally, although in some regions, atmospheric deposition accounts for a higher percentage (about 33% in the United States). (Note: the projection was included in the original study and is not based on MA scenarios.)



Source: Galloway et al. 2004

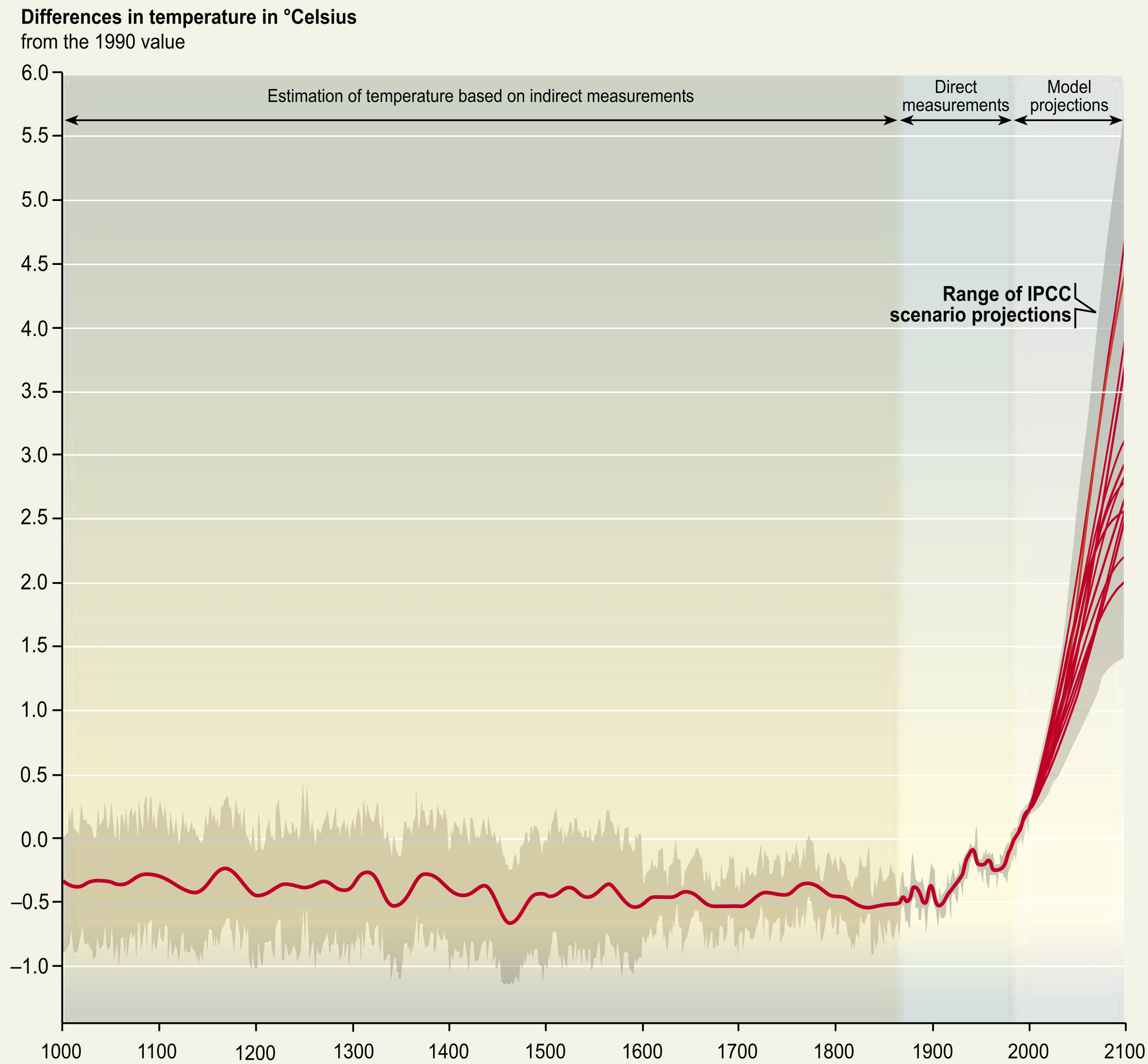
Each driver has a characteristic spatial and temporal scale at which it affects ecosystem services and human well-being. Climate change may operate on a spatial scale of a large region; political change may operate at the scale of a nation or a municipal district. Sociocultural change typically occurs slowly, on a time scale of decades, while economic forces tend to occur more rapidly. Because of the variability in ecosystems, their services, and human well-being in space and time, there may be mismatches or lags between the scale of the driver and the scale of its effects on ecosystem services (S7, SG7.3.5).

The fate of declining species and habitats will depend on sources of inertia and the speed of their response to management interventions. Natural sources of inertia correspond to the time scales inherent to natural systems; for example, recovery of a population cannot proceed more quickly than the average turnover or generation time, and established recovery will often take several generations. On top of this is anthropogenic inertia resulting from the time scales inherent in human institutions for decision-making and implementation. For most systems, these two sources of inertia will lead to delays of years, and more often decades, in slowing and reversing a declining biodiversity trend. This analysis assumes that the drivers of change could indeed be halted or reversed in the near term. Yet currently there is little evidence that any of the direct or indirect drivers are slowing or that any are well controlled at the large to global scale. More significantly, we have net yet seen all of the consequences of changes that occurred in the past (C4, R5, S7, S10).

The delay between a driver affecting a system and its consequences for biodiversity change can be highly variable. In the relatively well studied case of species extinctions, habitat loss is known to be a driver with particularly long lag times. In studies of tropical forest bird species the time from habitat fragmentation to species extinction has been estimated to have a half-life of decades to hundreds of years. Overall, these results suggest that about half of the species losses may occur over a period of 100 to 1,000 years. Therefore, humans have the opportunity to deploy active habitat restoration practices that may rescue some of the species that otherwise would have been in a trajectory toward extinction. Notwithstanding this, habitat restoration measures will not be likely to save the most sensitive species, which will become extinct soon after habitat loss (C4.5.2).

Figure 3.20. Historical and Projected Variations in Earth's Surface Temperature

Estimated global temperature averages for the past 1,000 years, with projections to 2100 depending on various plausible scenarios for future human behavior.



Source: Intergovernmental Panel on Climate Change 2002

4. *What is the future for biodiversity and ecosystem services under plausible scenarios?*

■ In the range of plausible scenarios explored by the MA, biodiversity will continue to be lost at extremely high rates over the next 50 years. Given inertia in the indirect drivers and in ecosystems, this loss cannot be halted over this time period. Nonetheless, opportunities exist to reduce the rate of loss of biodiversity and associated ecosystem services if society places an emphasis on ecosystem protection, restoration, and management.

Statements of certainty in the following conclusions are conditional statements in that they refer to level of certainty or uncertainty in the particular projection should that scenario and its associated changes in drivers unfold.

Global Scenarios and Ecosystem Change

The scenarios developed by the MA project continued loss of biodiversity, with attendant changes in ecosystems services and declines in human well-being in some regions and populations. The MA scenarios address the consequences of different plausible futures for ecosystem services and human well-being (S5). (See Box 4.1.) These futures were selected to explore a wide range of contexts under which development will be pursued, as well as a wide range of approaches to development. Two basic contrasts are explored, one in which the world becomes increasingly globalized and the other in which it becomes increasingly regionalized. In the first case we see a focus on global markets and policies and on supranational institutions fostering international cooperation, while in the regionalized world there is an emphasis on local and national institutions and on regional markets, and little attention is paid to the global commons.

In terms of approaches, the scenarios focus either on a reactive attitude toward environmental problems or on futures that emphasize proactive management of ecosystems and their services. In the reactive approach, the environmental problems that threaten human well-being are dealt with only after they become apparent, and, in general, people believe that the necessary knowledge and technology to address environmental challenges will emerge or can be developed as needed. The proactive ecosystem management approach focuses on ecosystem engineering or adaptive management to maximize the delivery of ecosystem services while reducing the impact of human activities and to enhance ecosystem resilience.

Habitat loss caused by land use change will lead, *with high certainty*, to continuing decline in the local and global diversity of some taxa, especially vascular plants, in all four scenarios (S10.2). Habitat conversion between 1970 and 2050 ranges from 13% to 20% (see Figure 4.1) as projected by the IMAGE model, leading to local and global extinctions as populations approach equilibrium with the remnant habitat. Analysis using the *well-established* species-area relationship indicates that the number of

Box 4.1. An Outline of the Four MA Scenarios

It is important to remember that no scenario will match the future as it actually occurs. None of the scenarios represents a "best" path or a "worst" path. There could be combinations of policies and practices that produce significantly better or worse outcomes than any of these scenarios. The future will represent a mix of approaches and consequences described in the scenarios, as well as events and innovations that could not be imagined at the time of writing (S5).

The focus on alternative approaches to sustaining ecosystem services distinguishes the MA scenarios from previous global scenario exercises. The four approaches were developed based on interviews with leaders in NGOs, governments, and business on five continents, on scenario literature, and on policy documents addressing linkages between ecosystem change and human well-being. The approach to scenario development used in the MA consists of a combination of qualitative storyline development and quantitative modeling based on assumptions about the evolution of indirect drivers such as economic and population growth (S6).

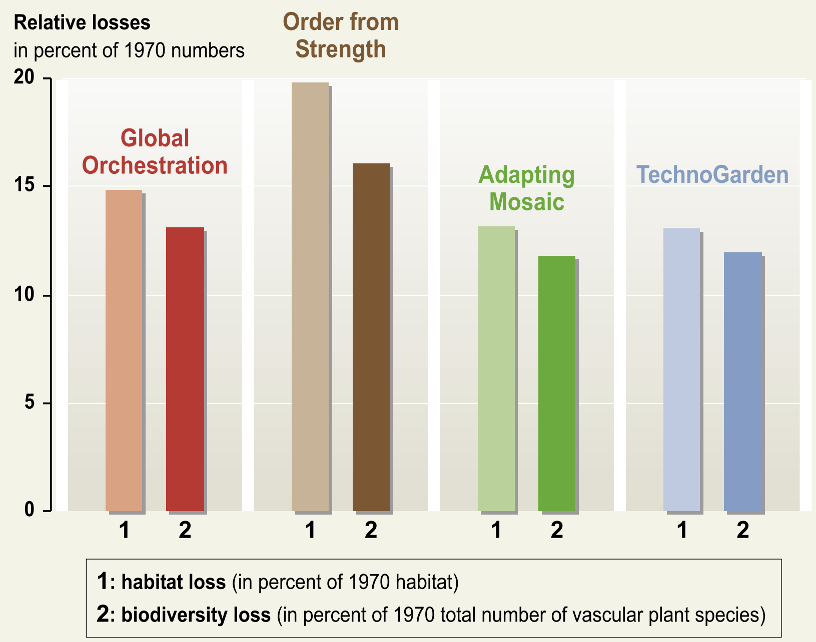
The *Global Orchestration* scenario explores the possibilities of a world in which global economic and social policies are the primary approach to sustainability. The recognition that many of the most pressing global problems seem to have roots in poverty and inequality evokes fair policies to improve the well-being of those in poorer countries by removing trade barriers and subsidies. Environmental problems are dealt with in an ad-hoc reactive manner, as it is assumed that improved economic well-being will eventually create demand for and the means to achieve environmental protection. Nations also make progress on global environmental problems, such as greenhouse gas emissions and the depletion of pelagic marine fisheries. However, some local and regional environmental problems are exacerbated. The results for ecosystem services are mixed. Human well-being is improved in many of the poorest countries (and in some rich countries), but a number of ecosystem services deteriorate by 2050, placing at risk the long-term sustainability of the well-being improvements.

The *Order from Strength* scenario examines the outcomes of a world in which protection through boundaries becomes paramount. The policies enacted in this scenario lead to a world in which the species lost at equilibrium (that is, the number of species that can be supported by the habitat remaining by 2050) is likely to be approximately 10–15% of the species present in 1970 (*low certainty*), and other factors such as overharvesting, invasive species, pollution, and climate change will further increase the rate of extinction. The two scenarios that take a more proactive approach to the environment (*TechnoGarden* and *Adapting Mosaic*) have more success in reducing terrestrial biodiversity loss in the near future than the two scenarios that take a reactive approach to environmental issues (S10.2). The scenario with a focus on security through boundaries (*Order from Strength*) has the highest rate of biodiversity loss. It is important to note that all the projected extinctions will not have occurred by 2050.

Habitat and vascular plant populations are projected to be lost in the MA scenarios at the fastest rate in warm mixed forests, savannas, scrub, tropical forests, and tropical woodlands (*high certainty*) (S10.2). In a few biomes, expected changes post-1990 are greater that those seen in the past half-century. Regions that will lose species at the lowest rate include those with low human impact as well as those where major land use changes and human intervention have already occurred, such as the Palearctic (S10.2). (See Figures 4.2 and 4.3.) Tropical

Figure 4.1. Losses of Habitat as a Result of Land Use Change between 1970 and 2050 and Reduction in the Equilibrium Number of Vascular Plant Species under the MA Scenarios (S10.2)

Extinctions of vascular plants will occur between now and sometime after 2050, when populations reach equilibrium with the remaining habitat.



Source: Millennium Ecosystem Assessment

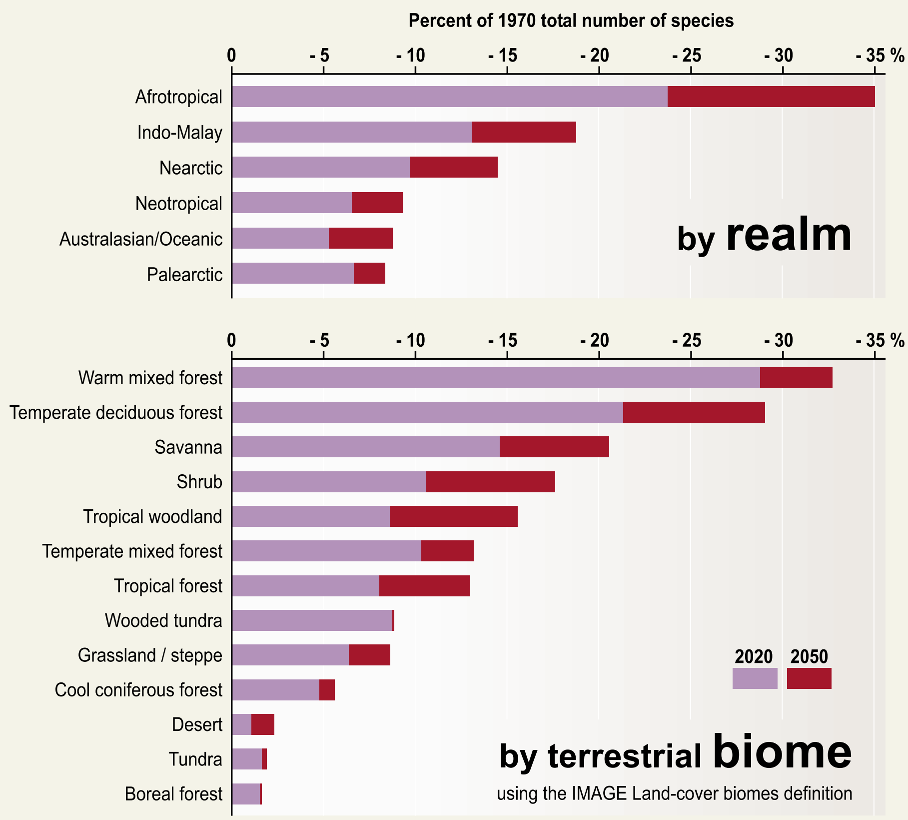
rich protect their borders, attempting to confine poverty, conflict, environmental degradation, and deterioration of ecosystem services to areas outside the borders. These problems often cross borders, however, impinging on the well-being of those within.

The *Adapting Mosaic* scenario explores the benefits and risks of environmentally proactive local and regional management as the primary approach to sustainability. In this scenario, lack of faith in global institutions, combined with increased understanding of the importance of resilience and local flexibility, leads to approaches that favor experimentation and local control of ecosystem management. The results are mixed, as some regions do a good job managing ecosystems but others do not. High levels of communication and interest in learning leads regions to compare experiences and learn from one another. Gradually the number of successful experiments begins to grow. While global problems are ignored initially, later in the scenario they are approached with flexible strategies based on successful experiences with locally adaptive management. However, some systems suffer long-lasting degradation.

The *TechnoGarden* scenario explores the potential role of technology in providing or improving the provision of ecosystem services. The use of technology and the focus on ecosystem services is driven by a system of property rights and valuation of ecosystem services. In this scenario, people push ecosystems to their limits of producing the optimum amount of ecosystem services for humans through the use of technology. Often, the technologies they use are more flexible than today's environmental engineering, and they allow multiple needs to be met from the same ecosystem. Provision of ecosystem services in this scenario is high worldwide, but flexibility is low due to high dependence on a narrow set of optimal approaches. In some cases, unexpected problems created by technology and erosion of ecological resilience lead to vulnerable ecosystem services, which may breakdown. In addition, the success in increasing the production of ecosystem services often undercuts the ability of ecosystems to support themselves, leading to surprising interruptions of some ecosystem services. These interruptions and collapses sometimes have serious consequences for human well-being.

Figure 4.2. Relative Loss of Biodiversity of Vascular Plants between 1970 and 2050 as a Result of Land Use Change for Different Biomes and Realms in the Order from Strength Scenario (S10.2)

Extinctions will occur between now and sometime after 2050, when populations reach equilibrium with remaining habitat. Note that the biomes in this Figure are from the IMAGE model (see Figure 4.3) and are slightly different from the biomes mentioned elsewhere in this report.



Source: Millennium Ecosystem Assessment

Land use changes causing habitat loss are associated primarily with further expansion of agriculture and, secondarily, with the expansion of cities and infrastructure (S9.8). This expansion is caused by increases in population, economic growth, and changing consumption patterns. By 2050, global population increases (*medium to high certainty*) to 8.1–9.6 billion, depending on the scenario. At the same time, per capita GDP expands by a factor of 1.9–4.4 depending on the scenario (*low to medium certainty*). Demand is dampened by increasing efficiency in the use of resources. The expansion of agricultural land occurs mainly in developing countries and arid regions, whereas in industrial countries, agricultural area declines. (See Figure 4.5.) The reverse pattern occurs in terms of forest cover, with some forest being regained in industrial countries but with 30% of the forest in the developing world being lost from 1970 to 2050, resulting in a global net loss of forest. The two scenarios with a proactive approach to the environment (*TechnoGarden* and *Adapting Mosaic*) are the most land-conserving ones because of increasingly efficient agricultural production, lower meat consumption, and lower population increases. Existing wetlands and the services they provide (such as water purification) are at increasing risk in some areas due to reduced runoff or intensified land use.

Africa is the region that will lose the most vascular plant species, mainly as a result of rapid population growth and strong increases in per capita food production in the region, much of which continues to rely on expansion of cultivated area. The Indo-Malayan region loses the second-most biodiversity. Past and projected future trends in habitat change indicate that the biomes that have already suffered the greatest change (Mediterranean forests and temperate grasslands) show the highest recoveries over the next 50 years, while the biomes that suffered intermediate changes in the past have the highest rates of change in the near future. (See Figure 4.4.) Finally, biomes at higher latitudes that had not been converted to agriculture in the past will continue to be relatively unchanged.

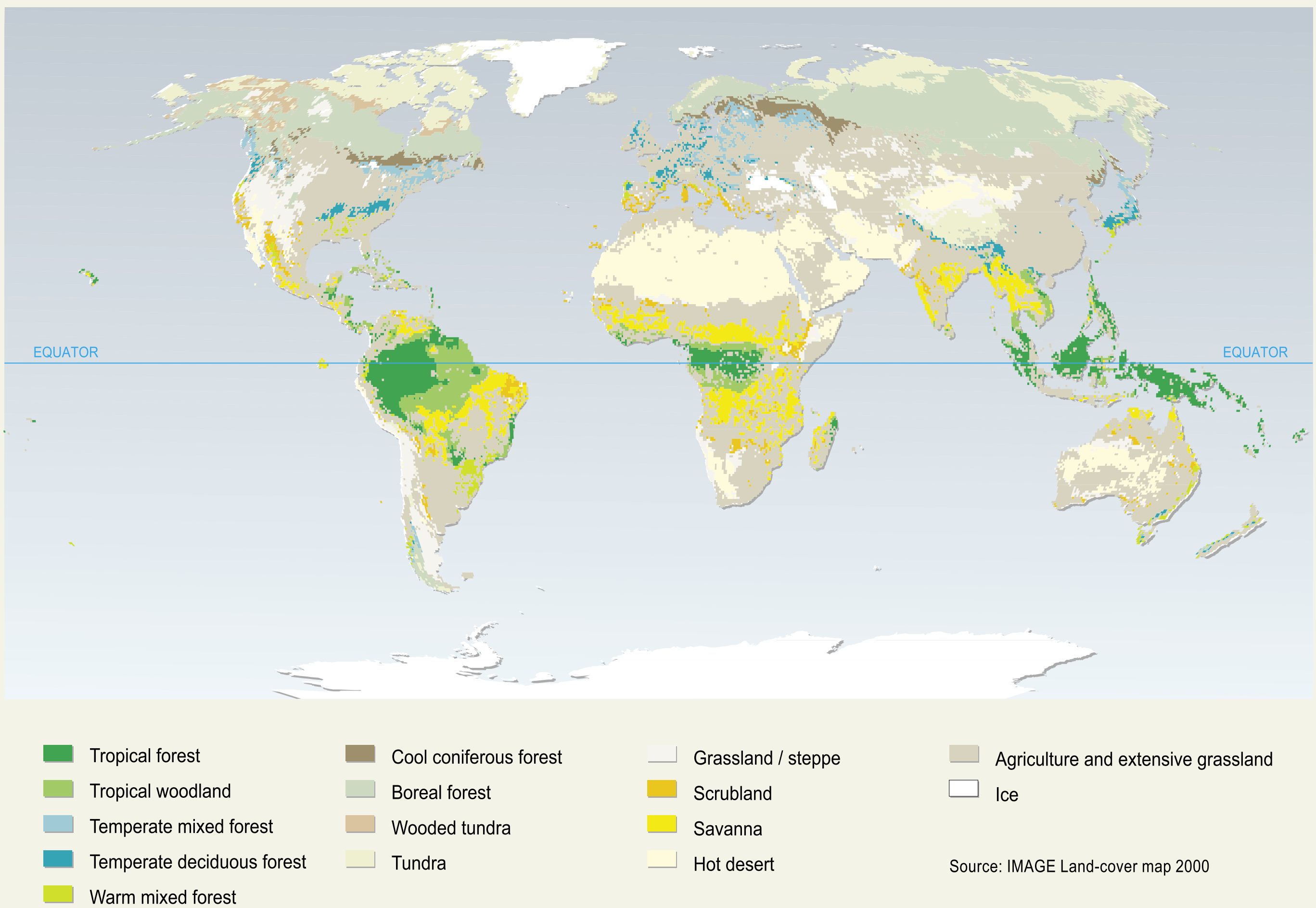
For the three drivers tested across scenarios regarding terrestrial systems, land use change is projected to be the dominant driver of biodiversity loss, followed by changes in climate and nitrogen deposition. But there are differences between biomes (*medium certainty*) (S10.2). For example, climate change will be the dominant driver of biodiversity change in tundra, boreal forest, cool conifer forest, savanna, and deserts. Nitrogen deposition will be an important driver in warm mixed forests and temperate deciduous forest. These two ecosystems are sensitive to nitrogen deposition and include densely populated areas. Considering these three drivers together, the total loss of vascular plant diversity from 1970 to 2050 ranges from 13% to 19%, depending on the scenario (*low certainty*). The impact of other important drivers, such as overexploitation and invasive species, could not be assessed as fully, suggesting that terrestrial biodiversity loss may be larger than the above projection.

Vast changes are expected in world freshwater resources and hence in their provisioning of ecosystem services (S9.4.5). (See Figure 4.6.) Under the two scenarios with a reactive approach to the environment (*Order from Strength* and *Global Orchestration*), massive increases in water withdrawals in developing countries are projected to lead to an increase in untreated wastewater discharges, causing a deterioration of freshwater quality. Climate change leads to both increasing and declining river runoff, depending on the region. The combination of huge increases in water withdrawals, decreasing water quality, and decreasing runoff in some areas leads to an intensification of water stress over wide areas. In sum, a deterioration of the services provided by freshwater resources (such as aquatic habitat, fish production, and water supply for households, industry and agriculture) is expected under the two scenarios with a reactive approach to the environment, with a less severe decline under the other two scenarios (*medium certainty*).

Fish populations are projected to be lost from some river basins under all scenarios due to the combined effects of climate change and water withdrawals. Under all scenarios, water availability decreases in 30% of the modeled river basins from the combined effects of climate change and water withdrawal, as projected by the WaterGAP model (S10.3). Based on *established but incomplete* scientific understanding of fish species-discharge relationships, the decreased water discharge will result in eventual losses of up to 65% (by 2100) of fish species from these basins (*low certainty*).

Climate change rather than water withdrawal is the major driver for the species losses from most basins, with projected losses from climate change alone of up to 65% by 2100. Rivers that are projected to lose the most fish species are concentrated in poor tropical and sub-tropical countries, where the needs for human adaptation are most likely to exceed governmental and societal capacity to cope (S10.3). Many rivers and lakes also experience increased temperatures, eutrophication, acidification, and increased invasions by nonindigenous species, leading to loss of native biodiversity. No algorithms exist for estimating the numbers of species lost due to these drivers, but recent experience suggests that they cause losses greater than those caused by climate change and water withdrawal.

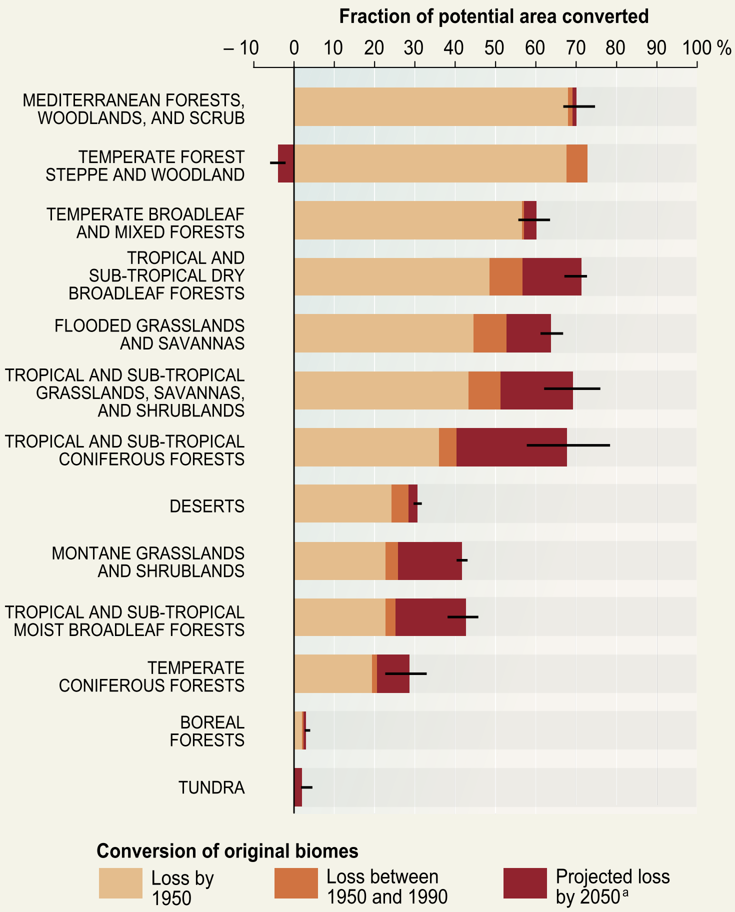
Figure 4.3. IMAGE Land-cover Map for the Year 2000 (S6)



Source: IMAGE Land-cover map 2000

Figure 4.4. Conversion of Terrestrial Biomes (Adapted from C4, S10)

It is not possible to estimate accurately the extent of different biomes prior to significant human impact, but it is possible to determine the "potential" area of biomes based on soil and climatic conditions. This Figure shows how much of that potential area is estimated to have been converted by 1950 (*medium certainty*), how much was converted between 1950 and 1990 (*medium certainty*), and how much would be converted under the four MA scenarios (*low certainty*) between 1990 and 2050. Mangroves are not included here because the area was too small to be accurately assessed. Most of the conversion of these biomes is to cultivated systems.



[a] According to the four MA scenarios. For 2050 projections, the average value of the projections under the four scenarios is plotted and the error bars (black lines) represent the range of values from the different scenarios.

Source: Millennium Ecosystem Assessment

Demand for fish as food expands under all scenarios, and the result will be an increasing risk of a major long-lasting collapse of regional marine fisheries (*low to medium certainty*). The demand for fish from both freshwater and marine sources, as well as from aquaculture, increases across all scenarios because of increasing human population, income growth, and growing preferences for fish (S9.4.2). Increasing demand raises the pressure on marine fisheries, most of which are already above or near their maximum sustainable yield and could cause a long-term collapse in their productivity. The production of fish via aquaculture adds to the risk of collapse of marine fisheries, as aquaculture continues to depend on marine fish as a feed source.

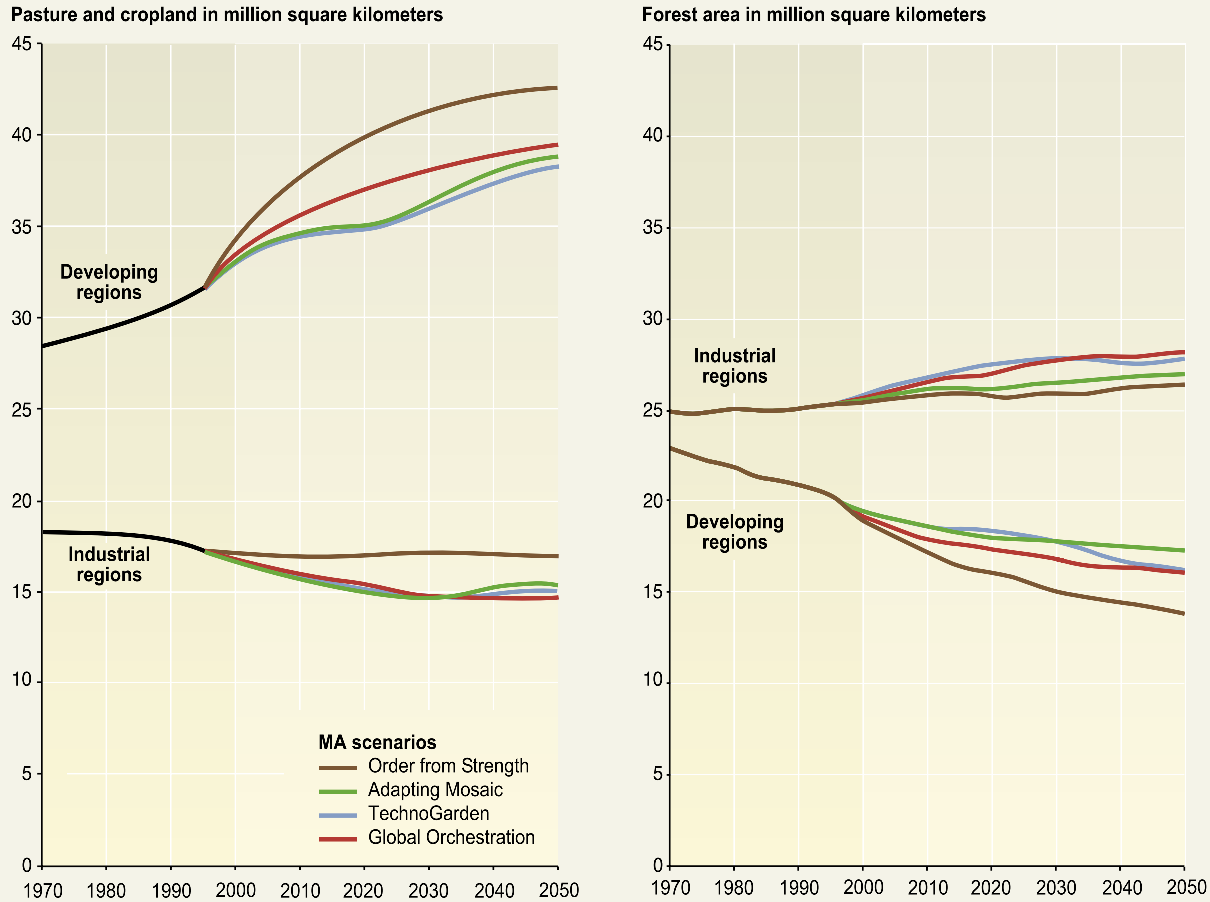
However, the diversity of marine biomass is sensitive to changes in regional policy. Scenarios with policies that focus on maintaining or increasing the value of fisheries result in declining biomass diversity (that is, a few functional groups become much more abundant than others), while scenarios with policies that focus on maintaining the ecosystem responded with increasing biomass diversity (the biomass becomes more evenly distributed among the different functional groups). Rebuilding selected stocks does not necessarily increase biomass diversity as effectively as an ecosystem-focused policy (S10.4).

Ecological Degradation and Human Well-being

Biodiversity loss will lead to a deterioration of ecosystem services, increasing the likelihood of ecological surprises—with negative impacts on human well-being. Examples of ecological surprises include runaway climate change, desertification, fisheries collapse, floods, landslides, wildfires, eutrophication, and disease (S11.1.2, S11.7). Security and social relations are vulnerable to reductions in ecosystem services. Shortages of provisioning services, such as food and water, are obvious and potent causes for conflict, thus harming social relations. But social relations can also be harmed by reduced ecosystem cultural services, such as the loss of iconic species or changes to highly valued landscapes. Likelihood of surprises, society preparedness, and ecosystem resilience interact to determine the vulnerability of human well-being to ecological and other forms of surprise in any given scenario. The vulnerability of human well-being to adverse ecological, social, and other forms of surprise varies among the scenarios (S11.7), but it is greatest in *Order from Strength*, with a focus on security through boundaries and where the society is not proactive to the environment.

Scenarios that limit deforestation show relatively better preservation of regulating services. Tropical deforestation could be reduced by a combination of reduced tropical hardwood consumption in the North, technological developments leading to substitution, and slower population growth in the South (*TechnoGarden*) or through greater protection of local

Figure 4.5. Forest and Cropland/Pasture in Industrial and Developing Regions under the MA Scenarios (S9 Fig 9.15)



Source: Millennium Ecosystem Assessment

ecosystems (*Adapting Mosaic*). In contrast, in the scenarios that are not proactive on the environment, a combination of market forces, undervaluation, and feedbacks lead to substantial deforestation not only in the tropics but also in large swaths of Siberia (*Order from Strength* and *Global Orchestration*). Deforestation increasingly interacts with climate change in all scenarios, causing not only more flooding during storms but also more fires during droughts, greatly increasing the risk of runaway climate change (S11).

Terrestrial ecosystems currently absorb CO_2 at a rate of about 1–2 gigatons of carbon per year (with *medium certainty*) and thereby contribute to the regulation of climate, but the future of this service is uncertain (S9.5). Deforestation is expected to reduce the carbon sink most strongly in a globalized world with a focus on security through boundaries (*Order from Strength*) (*medium certainty*). Carbon release or uptake by ecosystems affects the CO_2 and CH_4 content of the atmosphere at the global scale and thereby global climate. Currently, the biosphere is a net sink of carbon, absorbing approximately 20% of fossil fuel emissions. It is very likely that the future of this service will be greatly affected by expected land use change. In addition, a higher atmospheric CO_2 concentration is expected to enhance net productivity, but this does not necessarily lead to an increase in the carbon sink. The limited understanding of soil respiration processes, and their response to changed agricultural practices, generates uncertainty about the future of this sink.

The MA scenarios project an increase in global temperature between 2000 and 2050 of 1.0–1.5° Celsius, and between 2000 and 2100 of 2.0–3.5° Celsius, depending on the scenario (*low to medium certainty*) (S9.3). There is an increase in global average precipitation (*medium certainty*). Furthermore, according to the climate scenarios of the MA, there is an increase in precipitation

Figure 4.6. Changes in Annual Water Availability in Global Orchestration Scenario by 2100 (S9)

Shades from gray through red indicate regions that are drying.

Source: Millennium Ecosystem Assessment

over most of the land area on Earth (*low to medium certainty*). However, some arid regions (such as North Africa and the Middle East) could become even more arid (*low certainty*). Climate change will directly alter ecosystem services, for example, by causing changes in the productivity and growing zones of cultivated and noncultivated vegetation. It will also indirectly affect ecosystem services in many ways, such as by causing sea level to rise, which threatens mangroves and other vegetation that now protect shorelines.

Acknowledging the uncertainty in climate sensitivity in accordance with the IPCC would lead to a wider range of temperature increase than 2.0–3.5° Celsius. Nevertheless, both the upper and lower end of this wider range would be shifted downward somewhat compared with the range for the scenarios in the IPCC *Special Report on Emission Scenarios* (1.5–5.5° Celsius). This is caused by the fact that the *TechnoGarden* scenario includes climate policies (while the IPCC scenarios did not cover climate policies) and the highest scenarios (*Global Orchestration* and *Order from Strength*) show lower emissions than the highest IPCC scenario (S9.3.4).

The scenarios indicate (*medium certainty*) certain "hot spot regions" of particularly rapid changes in ecosystem services, including sub-Saharan Africa, the Middle East and Northern Africa, and South Asia (S9.8). To meet its needs for development, sub-Saharan Africa is likely to rapidly expand its withdrawal of water, and this will require an unprecedented investment in new water infrastructure. Under some scenarios (*medium certainty*), this rapid increase in withdrawals will cause a similarly rapid increase in untreated return flows to the freshwater systems, which could endanger public health and aquatic ecosystems. This region could experience not only accelerating intensification of agriculture but also further expansion of agricultural land onto natural land. Further intensification could lead to a higher level of contamination of surface and groundwaters.

Expansion of agriculture will come at the expense of the disappearance of a large fraction of sub-Saharan Africa's natural forest and grasslands (*medium certainty*) as well as the ecosystem services they provide. Rising incomes in the Middle East and Northern African countries lead to greater demand for meat, which could lead to a still higher level of dependency on food imports (*low to medium certainty*). In South Asia, deforestation continues, despite increasingly intensive industrial-type agriculture. Here, rapidly increasing water withdrawals and return flows further intensify water stress.

While the GDP per person improves on average in all scenarios, this can mask increased inequity and declines in some ecosystem services (S9.2). Food security improves in the South in all scenarios except in *Order from Strength*, a world with a focus on security through boundaries and reactive to the environment. (See Figure 4.7.) Food security remains out of reach for many people, however, and child malnutrition cannot be eradicated even by 2050, with the number of malnourished children still at 151 million in *Order from Strength*. In a regionalized and environmentally proactive world, there is an improvement of provisioning services in the South through investment in social, natural, and, to a lesser extent, human capital at local and regional levels (*Adapting Mosaic*). Global health improves in a globalized world that places an emphasis on economic development (*Global Orchestration*) but worsens in a regionalized world with a focus on security, with new diseases affecting poor populations and with anxiety, depression, obesity and diabetes affecting richer populations (*Order from Strength*).

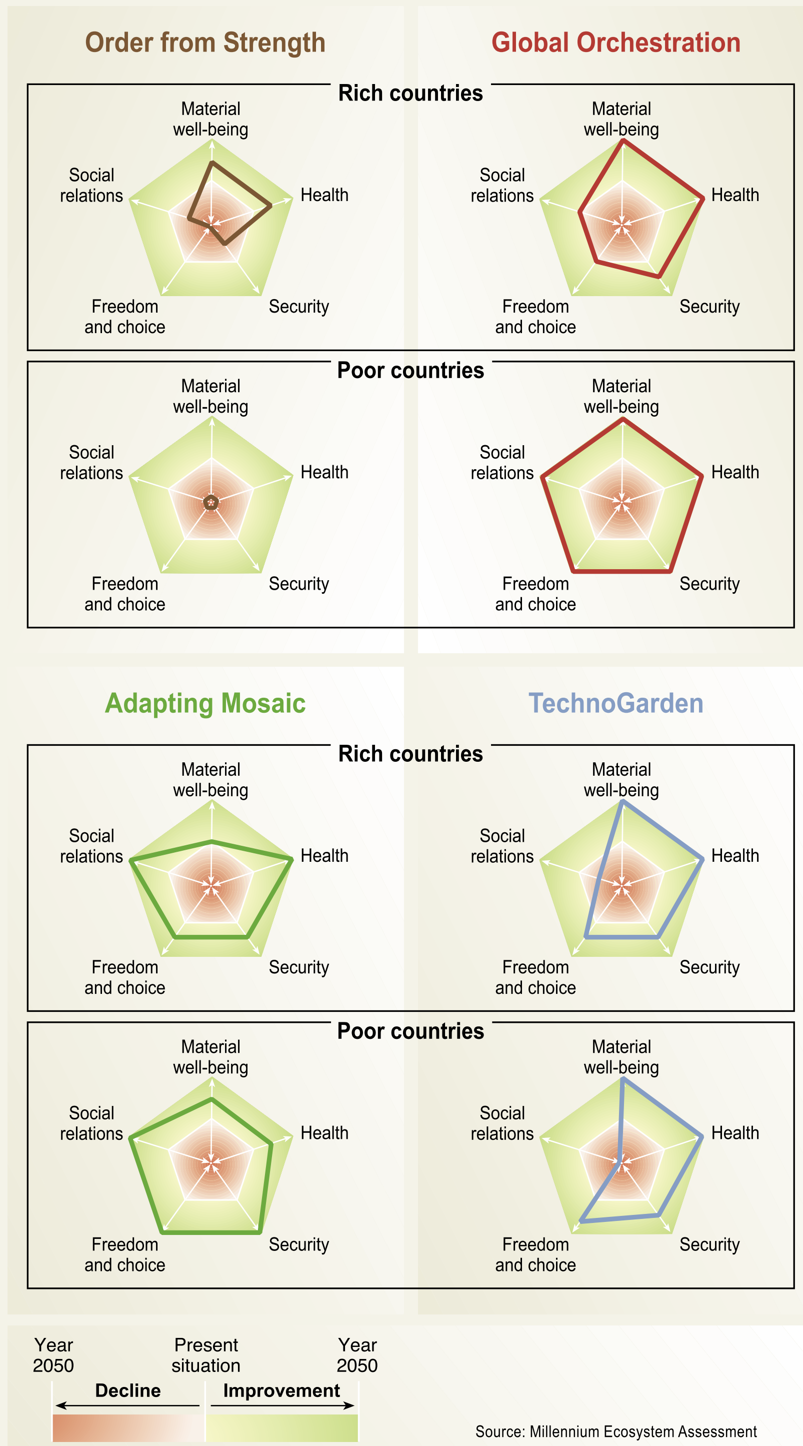
New health technologies and better nutrition could help unleash major social and economic improvements, especially among poor tropical populations, where it is increasingly well recognized that development is being undermined by numerous infectious diseases, widespread undernutrition, and high birth rates. Good health depends crucially on institutions. The greatest improvements in social relations occur in a regionalized world with a focus on the environment, as civil society movements strengthen (*Adapting Mosaic*). Curiously, security is poorest in a world with focus on security through boundaries (*Order from Strength*). This scenario also sees freedom of choice and action reduced both in the North and the South, while other scenarios see an improvement, particularly in the South (S11).

Implications and Opportunities for Trend Reversion

The MA scenarios demonstrate the fundamental interdependence between energy, climate change, biodiversity, wetlands, desertification, food, health, trade, and economy, since ecological change affects the scenario outcomes. This interdependence between environmental and development goals stresses the importance of partnerships and the potential for synergies

Figure 4.7. Changes in Human Well-being and Socioecological Indicators by 2050 under the MA Scenarios (S11)

Each arrow in the star diagrams represents one component of human well-being. The area marked by the lines between the arrows represents well-being as a whole. The 0 line represents the status of each of these components today. If the thick line moves more toward the center of the pentagon, this component deteriorates in relative terms between today and 2050; if it moves more toward the outer edges of the pentagon, it improves.



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among multilateral environmental agreements (S14). As the basis for international cooperation, all global environmental agreements operate under profoundly different circumstances in the four scenarios, and their current instruments—exchange of scientific information and knowledge, technology transfer, benefit sharing, financial support—might need to be revised and complemented by new ones according to changing sociopolitical conditions. The interdependence between socioeconomic development and ecosystems also requires national governments and intergovernmental organizations to influence and moderate the actions of the private sector, communities, and NGOs. The responsibility of national governments to establish good governance at the national and sub-national levels is complemented by their obligation to shape the international context by negotiating, endorsing, and implementing international environmental agreements.

Trade-offs between ecosystem services continue and may intensify. The gains in provisioning services such as food supply and water use will come partly at the expense of other ecosystem services (S12). Major decisions in the next 50–100 years will have to address trade-offs between agricultural production and water quality, land use and biodiversity, water use and aquatic biodiversity, current water use for irrigation and future agricultural production, and in fact all current and future use of nonrenewable resources (S12). Providing food to an increasing population will lead (*with low to medium certainty*) to the expansion of agricultural land, and this will lead to the loss of natural forest and grassland (S9.3) as well as of other services (such as genetic resources, climate regulation, and runoff regulation). While water use will increase in developing countries (*with high certainty*), this is likely to be accompanied by a rapid and perhaps extreme deterioration of water quality, with losses of the services provided by clean fresh waters (genetic resources, recreation, and fish production).

For a given level of socioeconomic development, policies that conserve more biodiversity will also promote higher aggregated human well-being through the preservation of regulating, cultural, and supporting services. Regulating and supporting services are essential for the steady delivery of provisioning services to humans and to sustain life on Earth, while cultural services are important for many people. Although trade-offs are common, various synergistic interactions can allow for the simultaneous enhancement of more than one ecosystem service (S12.4.4). Increasing the supply of some ecosystem services can enhance the supply of others (forest restoration, for instance, may lead to improvements in carbon sequestration, runoff regulation, pollination, and wildlife), although there are also trade-offs (in this case with reduced capacity to provide food, for example). Successful management of synergisms is a key component of any strategy aimed at increasing the supply of ecosystem services for human well-being.

The prospect of large unexpected shifts in ecosystem services can be addressed by adopting policies that hedge (by diversifying the services used in a particular region, for example), choosing reversible actions, monitoring to detect impending changes in ecosystems, and adjusting flexibly as new knowledge becomes available (S.SDM, S5, S14). More attention to indicators and monitoring for large changes in ecosystem services would increase society's capacity to avert large disturbances of ecosystem services or to adapt to them more rapidly if they occur. Without monitoring and policies that anticipate the possibility of large ecosystem changes, society will face increased risk of large impacts from unexpected disruptions of ecosystem services. In the scenarios, the greatest risks of large, unfavorable ecological changes arise in dryland agriculture, marine fisheries, degradation in the quality of fresh waters and coastal marine waters, emergence of disease, and regional climate change. These are also some of the ecosystem attributes most poorly monitored at present.

5. *What response options can conserve biodiversity and promote human well-being?*

■ Biodiversity loss is driven by local, regional, and global factors, so responses are also needed at all scales.

■ Responses need to acknowledge multiple stakeholders with different needs.

■ Given certain conditions, many effective responses are available to address the issues identified.

■ Responses designed to address biodiversity loss will not be sustainable or sufficient unless relevant direct and indirect drivers of change are addressed.

■ Further progress in reducing biodiversity loss will come through greater coherence and synergies among sectoral responses and through more systematic consideration of trade-offs among ecosystem services or between biodiversity conservation and other needs of society.

Some drivers of biodiversity loss are localized, such as overexploitation. Others are global, such as climate change, while many operate at a variety of scales, such as the local impacts of invasive species through global trade. Most of the responses assessed here were designed to address the direct drivers of biodiversity loss. However, these drivers are better seen as symptoms of the indirect drivers, such as unsustainable patterns of consumption, demographic change, and globalization.

At the local and regional scale, responses to the drivers may promote both local biodiversity and human well-being by acting on the synergies between maintenance of local biodiversity and provision of key ecosystem services. Responses promoting local management for global biodiversity values depend on local "capture" of the global values in a way that provides both ongoing incentives for management and support for local well-being (R5).

At the global scale, effective responses set priorities for conservation and development efforts in different regions and create shared goals or programs, such as the biodiversity-related conventions and the Millennium Development Goals. Effective trade-offs and synergies will be promoted when different strategies or instruments are used in an integrated, coordinated way (R5).

The MA assessment of biodiversity responses places human well-being as the central focus for assessment, recognizing that people make decisions concerning ecosystems based on a range of values related to well-being, including the use and non-use values of biodiversity and ecosystems. The assessment therefore has viewed biodiversity responses as addressing values at different scales, with strong links to ecosystem service values and well-being arising at each of these scales. The well-being of local people dominates the assessment of many responses, including those relating to protected areas, governance, wild species management, and various responses related to local capture of benefits.

Focusing exclusively on values at only one level often hinders responses that could promote values at all levels or reconcile conflicts between the levels. Effective responses function across scales, addressing global values of biodiversity while identifying opportunity costs or synergies with local values. Local consideration of global biodiversity recognizes the value of what is unique at a place (or what is not yet protected elsewhere). The values of ecosystem services, on the other hand, do not always depend on these unique elements. Effective biodiversity responses recognize both kinds of values.

These considerations guide the assessment summarized in this section of a range of response strategies that to varying degrees integrate global and local values and that seek effective trade-offs and synergies for biodiversity, ecosystem services, and human well-being.

Difficulties in measuring biodiversity have complicated assessments of the impact of response strategies. Developing better indicators of biodiversity would enhance integration among strategies and instruments. For example, existing measures often focus on local biodiversity and do not estimate the marginal gains in regional or global biodiversity values. Similarly, biodiversity gains from organic farming are typically expressed only as localized species richness, with no consideration of the degree of contribution to regional or global biodiversity or the trade-offs with high-productivity industrial agriculture.

How Effective Are Protected Areas for Biodiversity Conservation and Improved Human Well-being?

Protected areas are an extremely important part of programs to conserve biodiversity and ecosystems, especially for sensitive habitats (R5). Recent assessments have shown that at the global and regional scales, the existence of current PAs, while essential, is not sufficient for conservation of the full range of biodiversity. Protected areas need to be better located, designed, and managed to deal with problems like lack of representativeness, impacts of human settlement within protected areas, illegal harvesting of plants and animals, unsustainable tourism, impacts of invasive alien species, and vulnerability to global change. Marine and freshwater ecosystems are even less well protected than terrestrial systems, leading to increasing efforts to expand PAs in these biomes. Efforts to expand marine protected areas are also spurred by strong evidence of positive synergies between conservation within PAs and sustainable use immediately outside their boundaries (C18). However, marine protected area management poses special challenges, as enforcement is difficult and much of the world's oceans lie outside national jurisdictions.

Based on a survey of management effectiveness of a sample of nearly 200 protected areas in 34 countries, only 12% were found to have implemented an approved management plan. The assessment concluded that PA design, legal establishment, boundary demarcation, resource inventory, and objective setting were relatively well addressed. But management planning, monitoring and evaluation, and budgets for security and law enforcement were generally weak among the surveyed areas. Moreover, the "paper park" problem remains, whereby geographic areas may be labeled as some category of protected area but not achieve the promised form of management (R5).

Protected areas may contribute to poverty where rural people are excluded from resources that have traditionally supported their well-being. However, PAs can contribute to improved livelihoods when they are managed to benefit local people (R5). Relations with local people should be addressed more effectively through participatory consultation and planning. One possible strategy is to promote the broader use of IUCN protected areas management categories. Success depends on a collaborative management approach between government and stakeholders, an adaptive approach that tests options in the field, comprehensive monitoring that provides information on management success or failure, and empowerment of local communities through an open and transparent system that clarifies access and ownership of resources.

Success of protected areas as a response to biodiversity loss requires better site selection and incorporation of regional trade-offs to avoid some ecosystems from being poorly represented while others are overrepresented. Success of PAs depends on adequate legislation and management, sufficient resources, better integration with the wider region surrounding protected areas, and expanded stakeholder engagement (R5). Moreover, representation and management targets and performance indicators work best when they go beyond measuring the total area apparently protected. Indicators of percent-area coverage of PAs, as associated with the Millennium Development Goals and other targets, for example, only provide a broad indication of the actual extent of protection afforded by PA systems, but regional and national-level planning requires targets that take into account trade-offs and synergies with other ecosystem services.

Protected area design and management will need to take into account the impacts of climate change. The impacts of climate change will increase the risk of extinctions of certain species and change the nature of ecosystems. Shifts in species distribution as a result of climate change are well documented (C4, C19, C25). Today's species conservation plans may incorporate adaptation and mitigation aspects for this threat, drawing on existing tools to help assess species' vulnerability to climate change. Corridors and other habitat design aspects to give flexibility to protected areas are effective precautionary strategies. Improved management of habitat corridors and production ecosystems between protected areas will help biodiversity adapt to changing conditions (R5).

How Effective is Local Capture of Biodiversity Benefits?

The impact of market instruments in encouraging and achieving conservation of biodiversity is unclear (R5). Although tradable development rights offer the potential to achieve a conservation objective at a low cost by offering flexibility in achieving the objectives, they have been the subject of some criticisms—notably for being complex and involving high transaction costs and the establishment of new supporting institutions. For example, a situation could arise in which the most ecologically sensitive land but also the least costly to develop would not be protected. To date, the TDR has not been designed to target specific habitat types and properties.

Transferring rights to own and manage ecosystem services to private individuals gives them a stake in conserving those services, but these measures can backfire without adequate levels of institutional support. For example, in South Africa, changes in wildlife protection legislation allowed a shift in landownership and a conversion from cattle and sheep farming to profitable game farming, enabling conservation of indigenous wildlife. On the other hand, the CAMPFIRE program in Zimbabwe, based on sustainable community-managed use of wildlife, has now become an example of how success can turn into failure, with the state repossessing the areas given to individuals and breaking the levels of trust and transparency—a form of instrumental freedom—that are critically needed for these economic responses to work efficiently and equitably (R17).

Payments to local landowners for ecosystem services show promise of improving the allocation of ecosystem services and are applicable to biodiversity conservation. However, compensating mechanisms addressing the distributive and equitable aspects of these economic instruments may need to be designed in support of such efforts. By 2001, more than 280,000 hectares of forests had been incorporated in Costa Rica within reserves, at a cost of about $30 million per year, with typical annual payments ranging from $35 to $45 per hectare for forest conservation (R5 Box 5.3). However, the existence of direct payment initiatives does not guarantee success in achieving conservation and development objectives or benefits for human well-being. Empirical analyses about the distributive impacts across different social groups are rare.

Direct payments are often more effective than indirect incentives. For example, integrated conservation-development projects—an indirect incentive—designed to allow local populations to improve their well-being by capturing international willingness to pay for biodiversity conservation have in practice rarely been integrated into ongoing incentives for conservation. Overall, long-term success for these response strategies depends on meeting the economic and social needs of communities whose well-being already depends to varying degrees on biodiversity products and the ecosystem services biodiversity supports (R5).

However, direct payments have been criticized for requiring ongoing financial commitments to maintain the link between investment and conservation objectives. Furthermore they have led in some instances to inter- and intra-community conflict.

Yet many success stories show the effectiveness of direct payments and the transfer of property rights in providing incentives for local communities to conserve biodiversity. Effectiveness of payments in conserving regional biodiversity may be enhanced by new approaches that target payments based on estimated marginal gains ("complementarity" values) (R5 Box 5.3).

Significant improvements can be made to mitigate biodiversity loss and ecosystem changes by removing or redirecting economic subsidies that cause more harm than good. Agricultural subsidies in industrial countries reduce world prices for many commodities that developing countries produce. Lower prices provide the wrong incentives, encouraging these countries to adopt unsustainable agricultural activities that destroy ecosystems as well as push many poor farmers into poverty. Therefore the removal or redirection of agricultural subsidies is highly likely by itself to produce major improvements in ecosystem services and to check the rate of biodiversity loss (R5).

The promotion of "win-win" outcomes has been politically correct at best and naive at worst. Economic incentives that encourage the conservation and sustainable use of biodiversity show considerable promise. However, trade-offs between biodiversity, economic gains, and social needs have to be more realistically acknowledged. The benefits of biodiversity conservation are often widespread, even global in the case of existence values or carbon sequestration, while the costs of restricting access to biodiversity often are concentrated on groups living near biodiversity-rich areas (R5).

Why is the Management of Individual Species a Common Response Strategy for Harvestable and Invasive Species?

Direct management of invasive species will become an even more important biodiversity conservation response, typically calling for an ecosystem-level response if the invasive species has become established. Control or eradication of an invasive species once it is established is often extremely difficult and costly, while prevention and early intervention have been shown to be more successful and cost-effective. Common factors in successful eradication cases include particular biological features of the target species (for example, poor dispersal ability), early detection/response, sufficient economic resources devoted for a sufficient duration, and widespread support from the relevant agencies and the public. Successful prevention requires increased efforts in the control and regulation of the transportation of invasive species due to international trade (R5).

Chemical control of invasive plant species, sometimes combined with mechanical removal like cutting or pruning, has been useful for controlling at least some invasive plants, but has not proved particularly successful in eradication. In addition to its low efficiency, chemical control can be expensive. Biological control of invasive species has also been attempted, but results are mixed (R5). For example, the introduction of a non-native predatory snail to control the giant African snail in Hawaii led to extinction of many native snails. Some 160 species of biological agents, mainly insects and fungi, are registered for controlling invasive species in North America, and many of them appear highly effective. However, at least some of the biological agents used are themselves potential invaders. Environmental screening and risk assessment can minimize the likelihood of negative impacts on non-target native species.

Social and economic aspects of the control of invasive species have received less attention, perhaps because of difficulties in estimating these trade-offs. The Global Invasive Species Program is an international response to address the problem. The CBD has adopted Guiding Principles on Invasive Alien Species (Decision VI/23) as a basic policy response, but it is too early to assess the effectiveness of implementation (R5).

Sustainable use of natural resources is an integral part of any sustainable development program, yet its contribution to conservation remains a highly controversial subject within the conservation community. Conserving species when the management objective is ensuring resource availability to support human livelihoods is frequently unsuccessful. This is because optimal management for natural resource extraction frequently has negative impacts on species targeted for conservation. Therefore, care in establishing positive incentives for conservation and sustainable use is critical to successful biodiversity conservation (R5).

Where the goal is species conservation, and where a specific population has a distinct identity and can be managed directly, species management approaches can be effective. However, managing for a single species is rarely effective when the goal is ecosystem functioning, which is tied to the entire suite of species present in the area. Where human livelihoods depend on single species resources, species management can be effective (for example, some fisheries and game species), but where people depend on a range of different wild resources, as is frequently the case, multiple species management is the appropriate approach (R5).

How Effective Are Strategies for Integrating Biodiversity Issues in Production Sectors?

At the national level, integrating biodiversity issues into agriculture, fishery, and forestry management encourages sustainable harvesting and minimizes negative impacts on biodiversity. Biodiversity will only be conserved and sustainably used when it becomes a mainstream concern of production sectors. Agriculture is directly dependent on biodiversity, but agricultural practices in recent decades have focused on maximizing yields. Research and development have focused on few relatively productive species, thus ignoring the potential importance of biodiversity. Effective response strategies include sustainable intensification, which minimizes the need for expanding total area for production, so allowing more area for biodiversity conservation. Practices such as integrated pest management, some forms of organic farming, and protection of field margins, riparian zones, and other noncultivated habitats within farms can promote synergistic relationships between agriculture, domestic biodiversity, and wild biodiversity. However, assessments of biodiversity contributions from such management reveal little data about contributions to regional biodiversity conservation (C26, R5).

A review of 36 initiatives to conserve wild biodiversity while enhancing agricultural production demonstrated benefits to landscape and ecosystem diversity, while impacts on species diversity were very situation-specific. Assessing the impact of these approaches suffers from a lack of consistent, comprehensively documented research on the systems, particularly regarding interactions between agricultural production and ecosystem health (R5).

Tropical deforestation at a local level can be controlled most effectively when the livelihood needs of local inhabitants are addressed within the context of sustainable forestry. The early proponents of forest certification hoped it would be an effective response to tropical deforestation, but most certified forests are in the North, managed by large companies and exporting to Northern retailers (C9, C21). The proliferation of certification programs to meet the needs of different stakeholders has meant that no single program has emerged as the only credible or dominant approach internationally (R8.3.9). Forest management policies should center on existing land and water ownership at the community level. Relevant legal tools include redesigning ownership to small-scale private control of forests, public-private partnerships, direct management of forests by indigenous people, and company-community partnerships. New land tenure systems must be context-relevant and accompanied by enforcement if they are to be effective. They need to include elements of education, training, health, and safety to function effectively (R5, R8).

What Can the Private Sector Contribute to Biodiversity Objectives?

The private sector can make significant contributions to biodiversity conservation. Some parts of the private sector are showing greater willingness to contribute to biodiversity conservation and sustainable use due to the influence of shareholders, customers, and government regulation. Showing greater corporate social responsibility, many companies are now preparing their own biodiversity action plans, managing their own landholdings in ways that are more compatible with biodiversity conservation, supporting certification schemes that promote more sustainable use, working with multiple stakeholders, and accepting their responsibility for addressing biodiversity issues in their operations. Influence of shareholders or customers is limited in cases where the company is not publicly listed or is government-owned.

Further developments are likely to focus on two main areas. First, in addition to assessing the impact of companies on biodiversity, important though this is, increasing emphasis will be given to ecosystem services and how companies rely on them. This will require development of mechanisms for companies to understand their risk exposure and to manage those risks. Second, greater collaboration is likely to take place between NGOs and business in order to more fully explore ways to reduce harmful trade-offs and identify positive synergies that could lead to more effective sustainable management practices (R5).

What Institutions, Forms of Governance, and Multilateral Processes Can Promote Effective Conservation of Biodiversity?

Governance approaches to support biodiversity conservation and sustainable use are required at all levels, with supportive laws and policies developed by central governments providing the security of tenure and authority essential for sustainable management at lower levels. The principle that biodiversity should be managed at the lowest appropriate level has led to decentralization in many parts of the world, with variable results. The key to success is strong institutions at all levels, with security of tenure and authority at the lower levels essential to providing incentives for sustainable management (R5).

At the same time that management of some ecosystem services is being devolved to lower levels, management approaches are also evolving to deal with large-scale processes with many stakeholders. Problems such as regional water scarcity and conservation of large ecosystems require large-scale management structures. For example, most of the major rivers in Southern Africa flow across international borders, so international water co-management organizations are being designed to share the management of riparian resources and ensure water security for all members. However, political instability in one state may negatively affect others, and power among stakeholders is likely to be uneven.

Neither centralization nor decentralization of authority always results in better management. For example, the power of Catchment Management Agencies in South Africa is constrained to their catchment, but impacts may be felt from outside or upstream. The best strategy may be one with multi-subsidiarity—that is, functions that subordinate organizations perform effectively belong more properly to them (because they have the best information) than to a dominant central organization, and the central organization functions as a center of support, coordination, and communication (R5).

Legal systems in countries are multilayered and in many countries, local practices or informal institutions may be much stronger than the law on paper. Important customs relate to the local norms and traditions of managing property rights and the ecosystems around them. Since these are embedded in the local societies, changing these customs and customary rights through external incentive and disincentive schemes is very difficult unless the incentives are very carefully designed. Local knowledge, integrated with other scientific knowledge, becomes absolutely critical for addressing ways of managing local ecosystems.

More effort is needed in integrating biodiversity conservation and sustainable use activities within larger macroeconomic decision-making frameworks. New poverty reduction strategies have been developed in recent years covering a wide range of policies and different scales and actors. However, the integration or mainstreaming of ecosystems and ecosystem services is largely ignored. The focus of such strategies is generally on institutional and macroeconomic stability, the generation of sectoral growth, and the reduction of the number of people living on less than $1 a day in poor countries. It is well documented that many of the structural adjustment programs of the mid- to late 1980s caused deterioration in ecosystem services and a deepening of poverty in many developing countries (R17).

International cooperation through multilateral environmental agreements requires increased commitment to implementation of activities that effectively conserve biodiversity and promote sustainable use of biological resources. Numerous multilateral environmental agreements have now been established that contribute to conserving biodiversity. The Convention on Biological Diversity is the most comprehensive, but numerous others are also relevant, including the World Heritage Convention, the Convention on International Trade in Endangered Species of Wild Fauna and Flora, the Ramsar Convention on Wetlands, the Convention on Migratory Species, the U.N. Convention to Combat Desertification, the U.N. Framework Convention on Climate Change, and numerous regional agreements. Their impacts at policy and practical levels depend on the will of the contracting parties (R5).

Effective responses may build on recent attempts (such as through joint work plans) to create synergies between conventions. The lack of compulsory jurisdiction for dispute resolution is a major weakness in international environmental law. However, requirements to report to conventions put pressure on countries to undertake active measures under the framework of those treaties. An effective instrument should include incentives, plus sanctions for violations or noncompliance procedures to help countries come into compliance. Links between biodiversity conventions and other international legal institutions that have significant impacts on biodiversity (such as the World Trade Organization) remain weak (R5).

The international agreements with the greatest impact on biodiversity are not in the environmental field but rather deal with economic and political issues. These typically do not take into account their impact on biodiversity. Successful responses will require that these agreements are closely linked with other agreements and that solutions designed for one regime do not lead to problems in other regimes. For example, efforts to sequester carbon under the Kyoto Protocol should seek to enhance biodiversity, not harm it (for example, by planting multiple species of native trees rather than monospecific plantations of exotic species) (R5).

Although biodiversity loss is a recognized global problem, most direct actions to halt or reduce loss need to be taken locally or nationally. Indirect drivers like globalization and international decisions on trade and economics often have a negative effect on biodiversity and should be addressed at the international level, but the proximate responsibility to detect and act directly on biodiversity loss is at the local and national level. For threatened endemic species or ecosystems limited to an area within a single country or local administrative unit, the relevant agencies should give high priority to these species or ecosystems, with appropriate support from global, regional, or national support systems (R5).

How Can the Identification, Design, and Implementation of Responses Be Improved?

Numerous response options exist to improve the benefits from ecosystem services to human societies without undermining biodiversity. The political and social changes now occurring in many parts of the world will have far-reaching consequences for the way ecosystem services and human well-being are managed in the future; it is thus imperative to develop an increased understanding of the enabling conditions needed for choosing and implementing responses. (See Box 5.1.)

Responses do not work in a vacuum. A variety of enabling conditions—a combination of instrumental freedoms and institutional frameworks—play critical roles in determining the success or failure of a response strategy. The success or failure of many responses is largely influenced by the various institutional frameworks in place in a country (CF3, R17).

Education and communication programs have both informed and changed preferences for biodiversity conservation and have improved implementation of biodiversity responses (R5). Scientific findings and data need to be made available to all of society. A major obstacle for knowing (and therefore valuing), preserving, sustainably using, and sharing benefits equitably from the biodiversity of a region is the human and institutional capacity to research a country's biota. The CONABIO initiative in Mexico and INBio in Cost Rica offer examples of successful national models for converting basic taxonomic information into knowledge for biodiversity conservation policies, as well as for other policies relating to ecosystems and biodiversity.

Ecosystem restoration activities are now common in many countries and include actions to restore almost all types of ecosystems, including wetlands, forests, grasslands, estuaries, coral reefs, and mangroves. Restoration will become an increasingly important response as more ecosystems become degraded and as demands for their services continue to grow. Ecosystem restoration, however, is generally far more expensive an option than protecting the original ecosystem, and it is rare that all the biodiversity and services of a system can be restored (R5).

Rather than the "win-win" outcomes promoted (or assumed) by many practitioners of integrated conservation and development projects, conflict is more often the norm, and trade-offs between conservation and development need to be acknowledged. Identifying and then negotiating trade-offs is complex, involving different policy options, different priorities for conservation and development, and different stakeholders. In the case of biodiversity conservation, the challenge is in negotiating these trade-offs, determining levels of acceptable biodiversity loss, and encouraging stakeholder participation. Where trade-offs must be made, decision-makers must consider and make explicit the consequences of all options. Better trade-offs from policies that remove perverse incentives or create markets for biodiversity protection can achieve a given level of biodiversity protection (regionally) at lower cost (R5).

Box 5.1. Key Factors of Successful Responses to Biodiversity Loss

- *Mobilize knowledge*. Ensure that the available knowledge is presented in ways that can be used by decision-makers.
- *Recognize complexity*. Responses must serve multiple objectives and sectors; they must be integrated.
- *Acknowledge uncertainty*. In choosing responses, understand the limits to current knowledge, and expect the unexpected.
- *Enable natural feedbacks*. Avoid creating artificial feedbacks that are detrimental to system resilience.
- *Use an inclusive process*. Make information available and understandable to a wide range of affected stakeholders.
- *Enhance adaptive capacity*. Resilience is increased if institutional frameworks are put in place that allow and promote the capacity to learn from past responses and adapt accordingly.
- *Establish supporting instrumental freedoms*. Responses do not work in a vacuum, and it is therefore critical to build necessary supporting instrumental freedoms—enabling conditions like transparency, markets, education—needed in order for the responses to work efficiently and equitably.
- *Establish legal frameworks*. A legally binding agreement is generally likely to have a much stronger effect than a soft law agreement.
- *Have clear definitions*. Agreements with clear definitions and unambiguous language will be easier to implement.
- *Establish principles*. Clear principles can help guide the parties to reach future agreement and guide the implementation of an agreement.
- *Elaborate obligations and appropriate rights*. An agreement with a clear elaboration of obligations and rights is more likely to be implemented.
- *Provide financial resources*. Availability of financial resources increases the opportunities for implementation.
- *Provide mechanisms for implementation*. Where financial resources are not sufficient, market mechanisms may increase the potential for implementation.
- *Establish implementing and monitoring agencies*. The establishment of subsidiary bodies with authority and resources to undertake specific activities to enhance the implementation of the agreements is vital to ensure continuity, preparation, and follow-up to complex issues.
- *Establish good links with scientific bodies*. As ecological issues become more complex, it becomes increasingly important to establish good institutional links between the legal process and the scientific community.
- *Integrate traditional and scientific knowledge*. Identify opportunities for incorporating traditional and local knowledge in designing responses.

The "ecosystem approaches" as developed by the CBD and others provide principles for integration across scales and across different responses. Central to the rationale is that the full range of measures is applied in a continuum from strictly protected to human-made ecosystems and that integration can be achieved through both spatial and temporal separation across the landscape, as well as through integration within a site. The MA sub-global assessments highlight useful synergies and trade-offs where different responses are integrated into a coherent regional framework (SG9). While some effective approaches will not require quantification of biodiversity gains, quantifying marginal gains and losses from different sources can strengthen such integration and enable one strategy to complement another in a targeted, strategic way (R17).

Society may receive greater net benefits when opportunity costs of conservation in a particular location are adjusted to reflect positive gains from ecosystem services provided and when the setting of biodiversity targets takes all land and water use contributions into account (C5 Box 5.2, R5, R17). Debates about the relative value of formal protected areas versus lands that are more intensely used by people but that conserve at least some components of biodiversity are more constructive when conservation is seen as a continuum of possibilities. Weaknesses of both ends of the spectrum can be overcome by linking them in integrated regional strategies (R5).

For example, an area converted to agriculture can lead to loss of biodiversity but can still contribute to regional biodiversity if it contributes certain complementary elements of biodiversity to overall regional biodiversity conservation. Formal protected areas are criticized for foreclosing other opportunities for society, but an integrated regional approach can build on the biodiversity protection gains from the surrounding lands, thereby reducing some of the pressure for biodiversity protection in the face of other anticipated uses over the region. Many contributions to overall biodiversity protection are made from production landscapes or other lands outside of protected areas, and integration allows these contributions to be credited at the regional planning scale and to increase regional net benefits. However, the ideal of measurable gains from production lands should not reduce the more general efforts to mainstream biodiversity into other sectors; even without formal estimates of complementarity values, mainstreaming policies can be seen as important aspects of integration. (R5)

What Response Options Exist to Address Other Drivers of Biodiversity Loss?

Many of the responses designed with the conservation of biodiversity or ecosystem service as the primary goal will not be sustainable or sufficient unless indirect and direct drivers of change are addressed. Numerous responses that address direct and indirect drivers would be particularly important for biodiversity and ecosystem services:

- *Elimination of subsidies that promote excessive use of specific ecosystem services*. Subsidies paid to the agricultural sectors of OECD countries between 2001 and 2003 averaged over $324 billion annually, or one third the global value of agricultural products in 2000 (S7). These subsidies lead to overproduction, reduce the profitability of agriculture in developing countries, and promote overuse of fertilizers and pesticides. Similar problems are created by fishery subsidies, which amounted to approximately $6.2 billion in OECD countries in 2002, or about 20% of the gross value of production (S7). Although removal of perverse subsidies will produce net benefits, it will not be without costs. Some of the people benefiting from production subsidies (through either the low prices of products that result from the subsidies or as direct recipients of subsidies) are poor and would be harmed by their removal. Compensatory mechanisms may be needed for these groups. Moreover, removal of agricultural subsidies within the OECD would need to be accompanied by actions designed to minimize adverse impacts on ecosystem services in developing countries. But the basic challenge remains that the current economic system relies fundamentally on economic growth that disregards its impact on natural resources.
- *Promotion of sustainable intensification of agriculture* (C4, C26). The expansion of agriculture will continue to be one of the major drivers of biodiversity loss well into the twenty-first century. In regions where agricultural expansion continues to be a large threat to biodiversity, the development, assessment, and diffusion of technologies that could increase the production of food per unit area sustainably, without harmful trade-offs related to excessive consumption of water or use of nutrients or pesticides, would significantly lessen pressure on biodiversity. In many cases, appropriate technologies already exist that could be applied more widely, but countries lack the financial resources and intuitional capabilities to gain and use these technologies. Where agriculture already dominates landscapes, the maintenance of biodiversity within these landscapes is an important component of total biodiversity conservation efforts, and, if managed appropriately, can also contribute to agricultural productivity and sustainability through the ecosystem services that biodiversity provides (such as through pest control, pollination, soil fertility, protection of water courses against soil erosion, and the removal of excessive nutrients).
- *Slowing and adapting to climate change* (R13). By the end of the century, climate change and its impacts may be the dominant direct driver of biodiversity loss and change of ecosystem services globally. Harm to biodiversity will grow with both increasing rates in change in climate and increasing absolute amounts of change. For ecosystem services, some services in some regions may initially benefit from increases in temperature or precipitation expected under climate scenarios, but the balance of evidence indicates that there will be a significant net harmful impact on ecosystem services worldwide if global mean surface temperature increase more than 2º Celsius above preindustrial levels or faster than 0.2º Celsius per decade (*medium certainty*). Given the

inertia in the climate system, actions to facilitate the adaptation of biodiversity and ecosystems to climate change will be necessary to mitigate negative impacts. These may include the development of ecological corridors or networks.

- *Slowing the global growth in nutrient loading (even while increasing fertilizer application in regions where crop yields are constrained by the lack of fertilizers, such as parts of sub-Saharan Africa).* Technologies already exist for reduction of nutrient pollution at reasonable costs, but new policies are needed for these tools to be applied on a sufficient scale to slow and ultimately reverse the increase in nutrient loading (R9).
- *Correction of market failures and internalization of environmental externalities that lead to the degradation of ecosystem services* (R17, R10, R13). Because many ecosystem services are not traded in markets, markets fail to provide appropriate signals that might otherwise contribute to the efficient allocation and sustainable use of the services. In addition, many of the harmful trade-offs and costs associated with the management of one ecosystem service are borne by others and so also do not weigh into decisions regarding the management of that service. In countries with supportive institutions in place, market-based tools can be used to correct some market failures and internalize externalities, particularly with respect to provisioning ecosystem services.
- *Increased transparency and accountability of government and private-sector performance in decisions that affect ecosystems, including through greater involvement of concerned stakeholders in decision-making* (RWG, SG9). Laws, policies, institutions, and markets that have been shaped through public participation in decision-making are more likely to be effective and perceived as just. Stakeholder participation also contributes to the decision-making process because it allows for a better understanding of impacts and vulnerability, the distribution of costs and benefits associated with trade-offs, and the identification of a broader range of response options that are available in a specific context. And stakeholder involvement and transparency of decision-making can increase accountability and reduce corruption.
- *Integration of biodiversity conservation strategies and responses within broader development planning frameworks.* For example, protected areas, restoration ecology, and markets for ecosystem services will have higher chances of success if these responses are reflected in the national development strategies or in poverty reduction strategies, in the case of many developing countries. In this manner, the costs and benefits of these conservation strategies and their contribution to human development are explicitly recognized in the Public Expenditure Review and resources for the implementation of the responses can be set aside in national Mid-Term Budgetary Frameworks (R17).
- *Increased coordination among multilateral environmental agreements and between environmental agreements and other international economic and social institutions* (R17). International agreements are indispensable for addressing ecosystem-related concerns that span national boundaries, but numerous obstacles weaken their current effectiveness. The limited, focused nature of the goals and mechanisms included in most bilateral and multilateral environmental treaties does not address the broader issue of ecosystem services and human well-being. Steps are now being taken to increase coordination among these treaties, and this could help broaden the focus of the array of instruments. However, coordination is also needed between the multilateral environmental agreements and the more politically powerful international legal institutions, such as economic and trade agreements, to ensure that they are not acting at cross-purposes.
- *Enhancement of human and institutional capacity for assessing the consequences of ecosystem change for human well-being and acting on such assessments* (RWG). Technical capacity for agriculture, forestry, and fisheries management is still limited in many countries, but it is vastly greater than the capacity for effective management for ecosystem services not derived from these sectors.
- *Addressing unsustainable consumption patterns* (RWG). Consumption of ecosystem services and nonrenewable resources affects biodiversity and ecosystems directly and indirectly. Total consumption is a factor of per capita consumption, population, and efficiency of resource use. Slowing biodiversity loss requires that the combined effect of these factors be reduced.

6. *What are the prospects for reducing the rate of loss of biodiversity by 2010 or beyond and what are the implications for the Convention on Biological Diversity?*

■ **Biodiversity will continue to decline during this century. While biodiversity makes important contributions to human well-being, many of the actions needed to promote economic development and reduce hunger and poverty are likely to reduce biodiversity. This makes the policy changes necessary to reverse these trends difficult to agree on and implement in the short term.**

■ **Since biodiversity is essential to human well-being and survival, however, biodiversity loss has to be controlled in the long term. A reduction in the rate of loss of biodiversity is a necessary first step. Progress in this regard can be achieved by 2010 for some components, but it is unlikely that it can be achieved for biodiversity overall at the global level by 2010.**

■ **Many of the necessary actions to reduce the rate of biodiversity loss are already incorporated in the programs of work of the Convention on Biological Diversity, and if fully implemented they would make a substantial difference. Yet even if existing measures are implemented, this would be insufficient to address all the drivers of biodiversity loss.**

In April 2002, the Conference of the Parties of the Convention on Biological Diversity adopted the target, subsequently endorsed in the Johannesburg Plan of Implementation adopted at the World Summit on Sustainable Development, to "achieve by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional, and national level as a contribution to poverty alleviation and to the benefit of all life on earth" (CBD Decision VI/26). In 2004, the Conference of the Parties adopted a framework for evaluation, including a small number of global 2010 sub-targets, and a set of indicators that will be used in assessing progress (C4.5.2).

To assess progress toward the target, the Conference of the Parties defines biodiversity loss as the "long-term or permanent qualitative or quantitative reduction in components of biodiversity and their potential to provide goods and services, to be measured at global, regional, and national levels" (CBD Decision VII/30). The objectives of the Convention and the 2010 target are translated into policies and concrete action through the agreement of international guidelines and the implementation of work programs of the Convention and through National Biodiversity Strategies and Action Plans.

An unprecedented effort would be necessary to achieve by 2010 a significant reduction of the current rate of biodiversity loss at global, regional, and national levels. The 2010 target implies that the rate of loss of biodiversity—as indicated by measures of a range of components or attributes—would need to be significantly less in 2010 than the current or recent trends described in Key Question 3 of this report. This is unlikely to be achieved globally for various reasons: current trends show few indications of slowing the rate of loss; most of the direct drivers of biodiversity loss are projected to increase; and inertia in natural and human institutional systems implies lags of years, decades, or even centuries between actions taken and their impact on biodiversity and ecosystems (C4, S7, S10, R5).

With appropriate responses at global, regional, and especially national level, it is possible to achieve, by 2010, a reduction in the rate of biodiversity loss for certain components of biodiversity or for certain indicators, and in certain regions, and several of the 2010 sub-targets adopted by the CBD could be met. Overall the rate of habitat loss—the main driver of biodiversity loss in terrestrial ecosystems—is slowing in certain regions and could slow globally if proactive approaches are taken (S10). This may not necessarily translate into lower rates of species loss, however, because of the nature of the relationship between numbers of species and area of habitat, because decades or centuries may pass before species extinctions reach equilibrium with habitat loss, and because other drivers of loss, such as climate change, nutrient loading, and invasive species, are projected to increase. While rates of habitat loss are decreasing in temperate areas, they are projected to continue to increase in tropical areas (C4, S10).

At the same time, if areas of particular importance for biodiversity and functioning ecological networks are maintained within protected areas or by other conservation mechanisms, and if proactive measures are taken to protect endangered species, the rate of biodiversity loss of the targeted habitats and species could be reduced. Further, it would be possible to achieve many of the sub-targets aimed at protecting the components of biodiversity if the response options that are already incorporated into the CBD programs of work are implemented. However, it appears highly unlikely that the sub-targets aimed at addressing threats to biodiversity—land use change, climate change, pollution, and invasive alien species—could be achieved by 2010. It will also be a major challenge to maintain goods and services from biodiversity to support human well-being (C4, S10, R5). (See Table 6.1.)

(*continued on page 80*)

Table 6.1. Prospects for Attaining the 2010 Sub-targets Agreed to under the Convention on Biological Diversity

Goals and Targets	Prospects for Progress by 2010
Protect the components of biodiversity	
Goal 1. Promote the conservation of the biological diversity of ecosystems, habitats, and biomes.	
Target 1.1: At least 10% of each of the world's ecological regions effectively conserved.	Good prospects for most terrestrial regions. Major challenge to achieve for marine regions. Difficult to provide adequate protection of inland water systems.
Target 1.2: Areas of particular importance to biodiversity protected.	
Goal 2. Promote the conservation of species diversity.	
Target 2.1: Restore, maintain, or reduce the decline of populations of species of selected taxonomic groups.	Many species will continue to decline in abundance and distribution, but restoration and maintenance of priority species possible.
Target 2.2: Status of threatened species improved.	More species will become threatened, but species-based actions will improve status of some.
Goal 3. Promote the conservation of genetic diversity.	
Target 3.1: Genetic diversity of crops, livestock, and harvested species of trees, fish, and wildlife and other valuable species conserved, and associated indigenous and local knowledge maintained.	Good prospects for ex situ conservation. Overall, agricultural systems likely to continue to be simplified. Significant losses of fish genetic diversity likely. Genetic resources in situ and traditional knowledge will be protected through some projects, but likely to decline overall.
Promote sustainable use	
Goal 4. Promote sustainable use and consumption.	
Target 4.1: Biodiversity-based products derived from sources that are sustainably managed, and production areas managed consistent with the conservation of biodiversity.	Progress expected for some components of biodiversity. Sustainable use unlikely to be a large share of total products and production areas.
Target 4.2: Unsustainable consumption of biological resources or that has an impact on biodiversity reduced.	Unsustainable consumption likely to increase.
Target 4.3: No species of wild flora or fauna endangered by international trade.	Progress possible, for example through implementation of the Convention on International Trade in Endangered Species of Wild Fauna and Flora.
Address threats to biodiversity	
Goal 5. Pressures from habitat loss, land use change and degradation, and unsustainable water use reduced.	
Target 5.1: Rate of loss and degradation of natural habitats decreased.	Unlikely to reduce overall pressures in the most biodiversity-sensitive regions. However, proactive protection of some of the most important sites is possible.
Goal 6. Control threats from invasive alien species.	
Target 6.1: Pathways for major potential alien invasive species controlled.	Pressure is likely to increase (from greater transport, trade, and tourism, especially in *Global Orchestration* scenario). Measures to address major pathways could be put in place (especially in *Global Orchestration* and *TechnoGarden* scenarios).
Target 6.2: Management plans in place for major alien species that threaten ecosystems, habitats, or species.	Management plans could be developed.

Goals and Targets	Prospects for Progress by 2010
Address threats to biodiversity *(continued)*	
Goal 7. Address challenges to biodiversity from climate change and pollution.	
Target 7.1: Maintain and enhance resilience of the components of biodiversity to adapt to climate change.	Pressures from both climate change and pollution, especially nitrogen deposition, will increase. These increases can be mitigated under UNFCCC for climate change and through agricultural and trade policy, as well as through energy policy for nitrogen pollution. Mitigation measures include carbon sequestration through LULUCF and use of wetlands to sequester or denitrify reactive nitrogen.
Target 7.2: Reduce pollution and its impacts on biodiversity.	Proactive measures to reduce impacts on biodiversity possible, but challenging given other pressures.
Maintain goods and services from biodiversity to support human well-being	
Goal 8. Maintain capacity of ecosystems to deliver goods and services and support livelihoods.	
Target 8.1: Capacity of ecosystems to deliver goods and services maintained.	Given expected increases in drivers, can probably be achieved only on a selective basis by 2010. Attainment of target 8.2 would contribute to the achievement of the MDG 2015 targets, especially targets 1, 2, and 9.
Target 8.2: Biological resources that support sustainable livelihoods, local food security, and health care, especially of poor people, maintained.	
Protect traditional knowledge, innovations, and practices	
Goal 9. Maintain sociocultural diversity of indigenous and local communities.	
Target 9.1: Protect traditional knowledge, innovations, and practices.	It is possible to take measures to protect traditional knowledge and rights, but continued long-term decline in traditional knowledge likely.
Target 9.2: Protect the rights of indigenous and local communities over their traditional knowledge, innovations, and practices, including their rights to benefit sharing.	
Ensure the fair and equitable sharing of benefits arising out of the use of genetic resources	
Goal 10. Ensure the fair and equitable sharing of benefits arising out of the use of genetic resources.	
Target 10.1: All transfers of genetic resources are in line with the CBD, the International Treaty on Plant Genetic Resources for Food and Agriculture, and other applicable agreements.	Progress is possible. In the MA scenarios, more equitable outcomes were obtained under the *Global Orchestration* and *TechnoGarden* scenarios, but were not achieved under *Order from Strength*.
Target 10.2: Benefits arising from the commercial and other utilization of genetic resources shared with the countries providing such resources.	

(*continued on page 80*)

Table 6.1. Prospects for Attaining the 2010 Sub-targets Agreed to under the Convention on Biological Diversity (*continued*)

Goals and Targets	Prospects for Progress by 2010
Ensure provision of adequate resources	
Goal 11. Parties have improved financial, human, scientific, technical, and technological capacity to implement the Convention.	
Target 11.1: New and additional financial resources are transferred to developing-country Parties to allow for the effective implementation of their commitments under the Convention, in accordance with Article 20. Target 11.2: Technology is transferred to developing-country Parties to allow for the effective implementation of their commitments under the Convention, in accordance with Article 20.	Progress is possible. In the MA scenarios, this outcome would be more likely under the *Global Orchestration* and *TechnoGarden* scenarios, but is less likely to be achieved through *Adapting Mosaic* and would not be achieved under *Order from Strength*.

There is substantial scope for greater protection of biodiversity through actions justified on their economic merits for material or other benefits to human well-being. Conservation of biodiversity is essential as a source of particular biological resources, to maintain different ecosystem services, to maintain the resilience of ecosystems, and to provide options for the future. These benefits that biodiversity provides to people have not been well reflected in decision-making and resource management, and thus the current rate of loss of biodiversity is higher than what it would be had these benefits been taken into account (R5). (See Figure 6.1.)

However, the total amount of biodiversity that would be conserved based strictly on utilitarian considerations is likely to be less than the amount present today (*medium certainty*). Even if utilitarian benefits were taken fully into account, planet Earth would still be losing biodiversity, as other utilitarian benefits often "compete" with the benefits of maintaining greater diversity. Many of the steps taken to increase the production of specific ecosystem services require the simplification of natural systems (in agriculture, for example). Moreover, managing ecosystems without taking into account the full range of ecosystem services may not necessarily require the conservation of biodiversity. (For example, a forested watershed could provide clean water and timber whether it was covered by a diverse native forest or a single-species plantation, but a single-species plantation may not provide significant levels of many other services, such as pollination, food, and cultural services.) Ultimately, the level of biodiversity that survives on Earth will be determined to a significant extent by ethical concerns in addition to utilitarian ones (C4, C11, S10, R5).

Trade-offs between achieving the MDG targets for 2015 and reducing the rate of biodiversity loss are likely. For example, improving rural road networks—a common feature of hunger reduction strategies—will likely accelerate rates of biodiversity loss (directly through habitat fragmentation and indirectly by facilitating unsustainable harvests of bushmeat and so on). Moreover, one of the MA scenarios (*Global Orchestration*) suggests that future development paths that show relatively good progress toward the MDG of eradicating extreme poverty and improving health also showed relatively high rates of habitat loss and associated loss of species over 50 years. (See Figure 6.2.) This does not imply that biodiversity loss is, in itself, good for poverty and hunger reduction. Instead, it indicates that many economic development activities aimed at poverty reduction are likely to have negative impacts on biodiversity unless the value of biodiversity and related ecosystem services are factored in (S10, R19).

In fact, some short-term improvements in material welfare and livelihoods due to actions that lead to the loss of biodiversity that is particularly important to the poor and vulnerable may actually make these gains temporary—and may in fact exacerbate all constituents of poverty in the long term. To avoid this, efforts for the conservation and sustainable use of biodiversity need to be integrated into countries' strategies for poverty reduction (S10, R5).

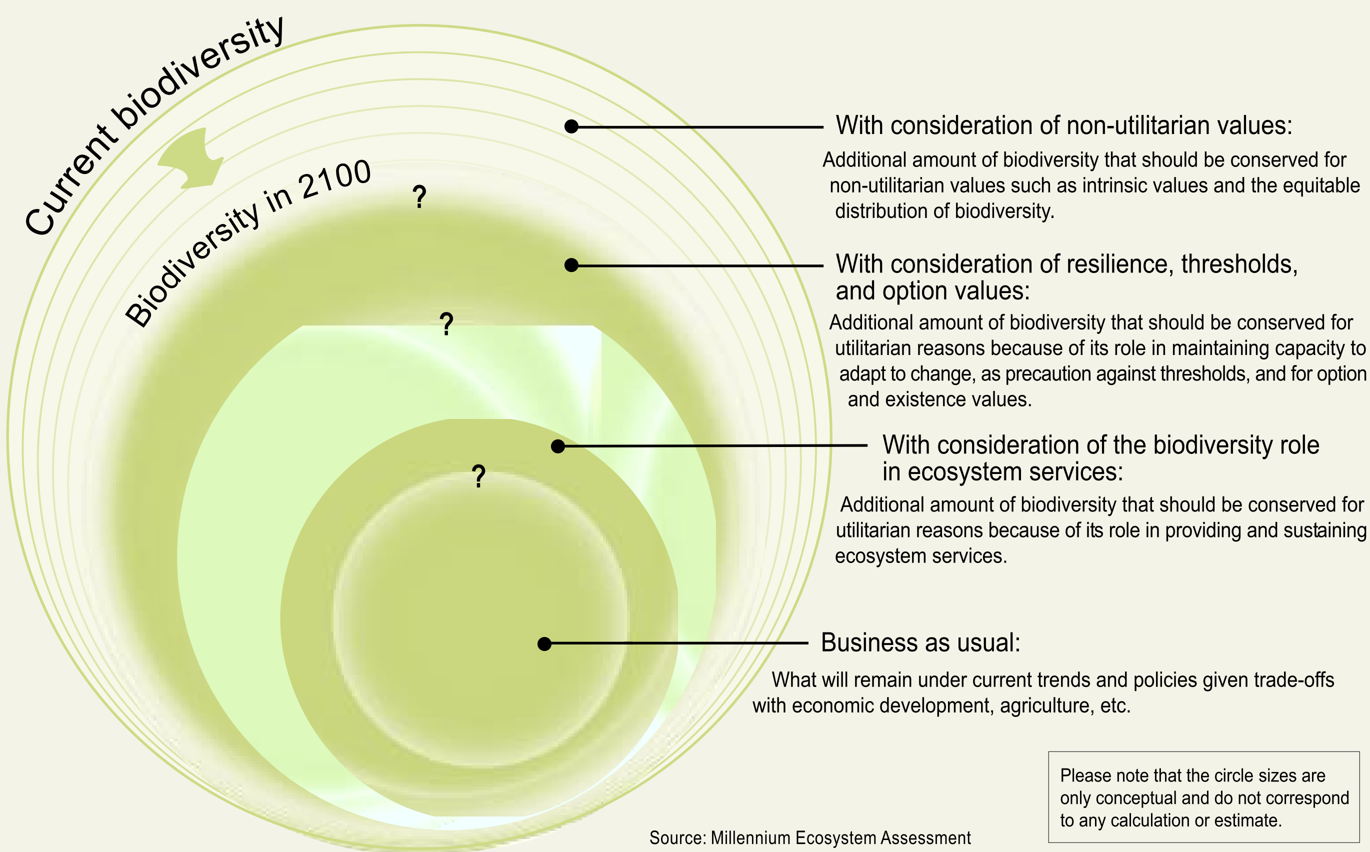
But there are potential synergies as well as trade-offs between the short-term MDG targets for 2015 and reducing the rate of loss of biodiversity by 2010. For a reduction in the rate of biodiversity loss to contribute to poverty alleviation, priority would need to be given to protecting the biodiversity of particular importance to the well-being of poor and vulnerable people. Given that biodiversity underpins the provision of ecosystem services that are vital to human well-being, long-term sustainable achievement of the Millennium Development Goals requires that biodiversity loss is reduced controlled as part of MDG 7 (ensuring environmental sustainability).

Given the characteristic response times for human systems (political, social, and economic) and ecological systems, longer-term goals and targets—say, for 2050—are needed in addition to short-term targets to guide policy and actions. Biodiversity loss is projected to continue for the foreseeable future (S10). The indirect drivers of biodiversity loss are related to economic, demographic, sociopolitical, cultural, and technological factors. Consumption of ecosystem services and of energy and nonrenewable resources has an impact, directly and indirectly, on biodiversity and ecosystems. Total consumption is a factor of per capita consumption, population, and efficiency of natural resource use. Halting biodiversity loss (or reducing it to a minimal level) requires that the combined effect of these factors in driving biodiversity loss be reduced (C4, S7).

Differences in the inertia of different drivers of biodiversity change and different attributes of biodiversity itself make it difficult to set targets or goals over a single time frame. For some drivers, such as the overharvesting of particular species, lag times are rather short; for others, such as nutrient loading and, especially, climate change, lag times are much longer. Addressing the indirect drivers of change may also require somewhat longer time horizons given political, socioeconomic, and demographic inertias. Population is projected to stabilize around the middle of the century and then decrease. Attention also needs to be given to addressing unsustainable consumption patterns. At the same time, while actions can be taken to reduce the drivers and their impacts on biodiversity, some change is inevitable, and adaptation to such change will become an

Figure 6.1. How Much Biodiversity Will Remain a Century from Now under Different Value Frameworks?

The outer circle in the Figure represents the present level of global biodiversity. Each inner circle represents the level of biodiversity under different value frameworks. The white area represents non-utilitarian values like ensuring equitable access to biodiversity and intrinsic values. Question marks indicate uncertainties where the boundaries exist.



Source: Millennium Ecosystem Assessment

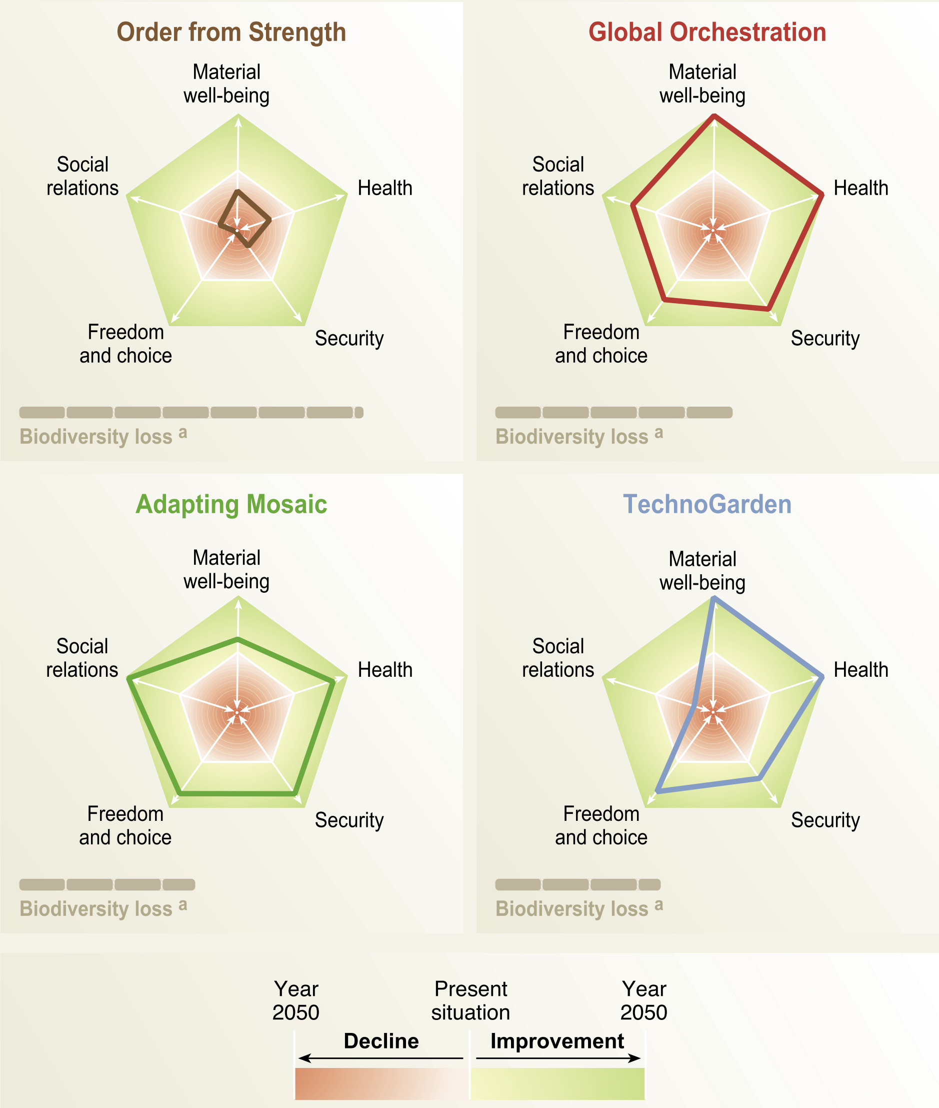
Please note that the circle sizes are only conceptual and do not correspond to any calculation or estimate.

increasingly important component of response measures (C4.5.2, S7, R5).

The world in 2100 could have substantial remaining biodiversity or could be relatively homogenized and contain relatively low levels of diversity. Sites that are globally important for biodiversity could be protected while locally or nationally important biodiversity is lost. Science can help to inform the costs and benefits of these different futures and identify paths to achieve them, along with the risks and the thresholds. Where there is insufficient information to predict the consequences of alternative actions, science can identify the range of possible outcome. Science can thus help ensure that social decisions are made with the best available information. But ultimately the choice of biodiversity futures must be determined by society.

Figure 6.2. Trade-offs between Promoting Human Well-being and Limiting Biodiversity Loss under the Four MA Scenarios to 2050 (S.SDM, S10)

Loss of biodiversity is least in the two scenarios that feature a proactive approach to environmental management (*TechnoGarden* and *Adapting Mosaic*), while the *Global Orchestration* scenario does most to promote human well-being and achieves the fastest progress toward the MDG of eradicating extreme poverty. The *Order from Strength* scenario performs badly on both sets of objectives.



[a] Loss of vascular plant species on land

Source: Millennium Ecosystem Assessment

Appendixes

Appendix A
Abbreviations, Acronyms, and Figure Sources

Abbreviations and Acronyms

AM – *Adapting Mosaic* (scenario)

CBD – Convention on Biological Diversity

CO_2 – carbon dioxide

CONABIO – National Commission for the Knowledge and Use of Biodiversity (Mexico)

GDP – gross domestic product

GO – *Global Orchestration* (scenario)

INBio – National Biodiversity Institute (Costa Rica)

IPCC – Intergovernmental Panel on Climate Change

IUCN – World Conservation Union

LULUCF – land use, land use change, and forestry

MA – Millennium Ecosystem Assessment

MDG – Millennium Development Goal

NGO – nongovernmental organization

NO_x – nitrogen oxides

NWFP – non-wood forest product

OECD – Organisation for Economic Co-operation and Development

OS – *Order from Strength* (scenario)

PA – protected area

TDR – tradable development rights

TEV – total economic value

TG – *TechnoGarden* (scenario)

TSR – total species richness

UNFCCC – United Nations Framework Convention on Climate Change

Figure Sources

Most Figures used in this report were redrawn from Figures included in the technical assessment reports in the chapters referenced in the Figure captions. Preparation of several Figures involved additional information as follows:

Figures 1.2 and 1.3

These figures present the 14 biomes of the WWF terrestrial biome classification, based on WWF terrestrial ecoregions: Olson, D. M., E. Dinerstein, E. D. Wikramanayake, N. D. Burgess, G. V. N. Powell, E. C. Underwood, J. A. D'Amico, I. Itoua, H. E. Strand, J. C. Morrison, C. J. Loucks, T. F. Allnutt, T. H. Ricketts, Y. Kura, J. F. Lamoreux, W. W. Wettengel, P. Hedao, and K. R. Kassem, 2001: Terrestrial ecoregions of the world: a new map of life on earth. *BioScience*, 51, 933–938.

Figure 2.1

This figure was developed from material cited in R17: Polasky, S., E. Nielson, E. Lonsdorf, P. Fackler and A. Starfield. *Conserving Species in a Working Lanscape: Land Use with Biological and Economic Objectives*. Ecological Applications (in press).

Figures 3.4 and 3.5

These figures were developed from BirdLife International material cited in C4 and C20: Butchart, S. H. M., A. J. Stattersfield, L. A. Bennun, S. M. Shutes, H. R. Akçakaya, J. E. M. Baillie, S. N. Stuart, C. Hilton-Taylor, and G. M. Mace, 2004. *Measuring global trends in the status of biodiversity: Red List Indices for birds*. Philosophical Transactions, LoS Biology.

Figure 3.7

The source figure (C20 Fig 20.12) is derived from the Living Planet Index in: Loh, J., and M. Wackernagel, eds., 2004: *The Living Planet Report 2004*. Gland, Switzerland: World Wide Fund for Nature and Cambridge, UK: UNEP-WCMC.

Figure 3.11

This figure was developed from figure 4.3 in: Scholes, R. J., and Biggs, R. (eds) 2004: *Ecosystem Services in Southern Africa: A Regional Assessment. The Regional-Scale Component of the Southern African Millennium Ecosystem Assessment*. CSIR, Pretoria, South Africa.

Figure 3.15

This figure was developed from material cited in C4: Wade, T. G., K. H. Riitters, J. D. Wickham, and K. B. Jones. 2003. Distribution and causes of global forest fragmentation. *Conservation Ecology* 7(2): 7. Online at: www.consecol.org/vol7/iss2/art7.

Figure 3.16

The source figure (C20 Fig 20.12) is based on data and maps provided in: Revenga, C., J. Brunner, N. Henninger, K. Kassem, and R. Payne, 2000: *Pilot Analysis of Global Ecosystems: Freshwater Systems*, World Resources Institute, Washington D.C., 83 pp.

Figure Sources *(continued)*

Figures 3.17 and 3.18

The source figures (S7 Fig 7.16 and 7.18) were developed from IFADATA statistics, downloaded from www.fertilizer.org/ifa/statistics.asp.

Figure 3.19

The source Figure (R9 Fig 9.2) was modified to include two additional deposition maps for 1860 and 2050 that had been included in the original source for R9 Fig 9.2: Galloway, J. P., et al., 2004, *Biogeochemistry* 70: 153–226.

Figure 3.20

The source figure (S7 Fig 7.13) is based on: IPCC 2002: *Climate Change 2001: Synthesis Report*. Cambridge University Press, Cambridge.

Figures 4.2 and 4.3

These figures use the IMAGE land-cover biome classification, which differs from the WWF terrestrial biomes used in figures 1.2 and 1.3, and is a modified version of the BIOME model: Prentice, I. C., W. Cramer, S. P. Harrison, R. Leemans, R. A. Monserud and A. M. Solomon, 1992. *A global biome model based on plant physiology and dominance, soil properties and climate*. Journal of Biogeography, 19, 117–134. Further information on the IMAGE model is available from www.rivm.nl/image

Figure 4.4

This figure incorporates historical changes in the WWF biomes as per figures 1.2 and 1.3, with changes under the MA scenarios using the biome classification of IMAGE, as used in figures 4.2 and 4.3.

Figure 4.6

This figure was developed using data present in S9 and prepared by the Center for Environmental Systems Research, University of Kassel.

Appendix B

Assessment Report Tables of Contents

Note that text references to CF, CWG, SWG, RWG, or SGWG refer to the entire Working Group report. ES refers to the Main Messages in a chapter.

Ecosystems and Human Well-being: A Framework for Assessment

Current State and Trends: Findings of the Condition and Trends Working Group

Scenarios: Findings of the Scenarios Working Group

Policy Responses: Findings of the Responses Working Group

Multiscale Assessments: Findings of the Sub-global Assessments Working Group

Sub-Global Assessments

Millennium Ecosystem Assessment Publications

Technical Volumes (available from Island Press)

Ecosystems and Human Well-being: A Framework for Assessment

Current State and Trends: Findings of the Condition and Trends Working Group, Volume 1

Scenarios: Findings of the Scenarios Working Group, Volume 2

Policy Responses: Findings of the Responses Working Group, Volume 3

Multiscale Assessments: Findings of the Sub-global Assessments Working Group, Volume 4

Our Human Planet: Summary for Decision-makers

Synthesis Reports (available at MAweb.org)

Ecosystems and Human Well-being: Synthesis

Ecosystems and Human Well-being: Biodiversity Synthesis

Ecosystems and Human Well-being: Desertification Synthesis

Ecosystems and Human Well-being: Human Health Synthesis

Ecosystems and Human Well-being: Wetlands Synthesis

Ecosystems and Human Well-being: Opportunities and Challenges for Business and Industry

Secretariat Support Organizations

The United Nations Environment Programme (UNEP) coordinates the Millennium Ecosystem Assessment Secretariat, which is based at the following partner institutions:

Food and Agriculture Organization of the United Nations, Italy

Institute of Economic Growth, India

International Maize and Wheat Improvement Center (CIMMYT), Mexico (*until 2002*)

Meridian Institute, United States

National Institute of Public Health and the Environment (RIVM), Netherlands (*until mid-2004*)

Scientific Committee on Problems of the Environment (SCOPE), France

UNEP-World Conservation Monitoring Centre, United Kingdom

University of Pretoria, South Africa

University of Wisconsin-Madison, United States

World Resources Institute (WRI), United States

WorldFish Center, Malaysia

Maps and graphics: Emmanuelle Bournay and Philippe Rekacewicz, UNEP/GRID-Arendal, Norway

The production of maps and graphics was made possible by the generous support of the Ministry of Foreign Affairs of Norway and UNEP/GRID-Arendal.

Photos:

Front cover:
- Pete Oxford

Back cover:
- Staffan Widstrand

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ISBN 1-56973-588-3

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