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Ecosystems and Human Well-being:
Scenarios, Volume 2

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Ecosystems and Human Well-being: Scenarios, Volume 2

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Findings of the Scenarios Working Group
of the Millennium Ecosystem Assessment

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The Scenarios Working Group dedicates this volume to the memory of our valued colleague, Dr. Tsuneyuki Morita. We deeply regret his loss.

Millennium Ecosystem Assessment: Objectives, Focus, and Approach

The Millennium Ecosystem Assessment was carried out between 2001 and 2005 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. The MA responds to government requests for information received through four international conventions—the Convention on Biological Diversity, the United Nations Convention to Combat Desertification, the Ramsar Convention on Wetlands, and the Convention on Migratory Species—and is designed to also meet needs of other stakeholders, including the business community, the health sector, nongovernmental organizations, and indigenous peoples. The sub-global assessments also aimed to meet the needs of users in the regions where they were undertaken.

The assessment focuses on the linkages between ecosystems and human well-being and, in particular, on "ecosystem services." An ecosystem is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit. The MA deals with the full range of ecosystems—from those relatively undisturbed, such as natural forests, to landscapes with mixed patterns of human use and to ecosystems intensively managed and modified by humans, such as agricultural land and urban areas. Ecosystem services are the benefits people obtain from ecosystems. These include *provisioning services* such as food, water, timber, and fiber; *regulating services* that affect climate, floods, disease, wastes, and water quality; *cultural services* that provide recreational, aesthetic, and spiritual benefits; and *supporting services* such as soil formation, photosynthesis, and nutrient cycling. The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ecosystem services.

The MA examines how changes in ecosystem services influence human well-being. Human well-being is assumed to have multiple constituents, including the *basic material for a good life*, such as secure and adequate livelihoods, enough food at all times, shelter, clothing, and access to goods; *health,* including feeling well and having a healthy physical environment, such as clean air and access to clean water; *good social relations,* including social cohesion, mutual respect, and the ability to help others and provide for children; *security,* including secure access to natural and other resources, personal safety, and security from natural and human-made disasters; and *freedom of choice and action,* including the opportunity to achieve what an individual values doing and being. Freedom of choice and action is influenced by other constituents of well-being (as well as by other factors, notably education) and is also a precondition for achieving other components of well-being, particularly with respect to equity and fairness.

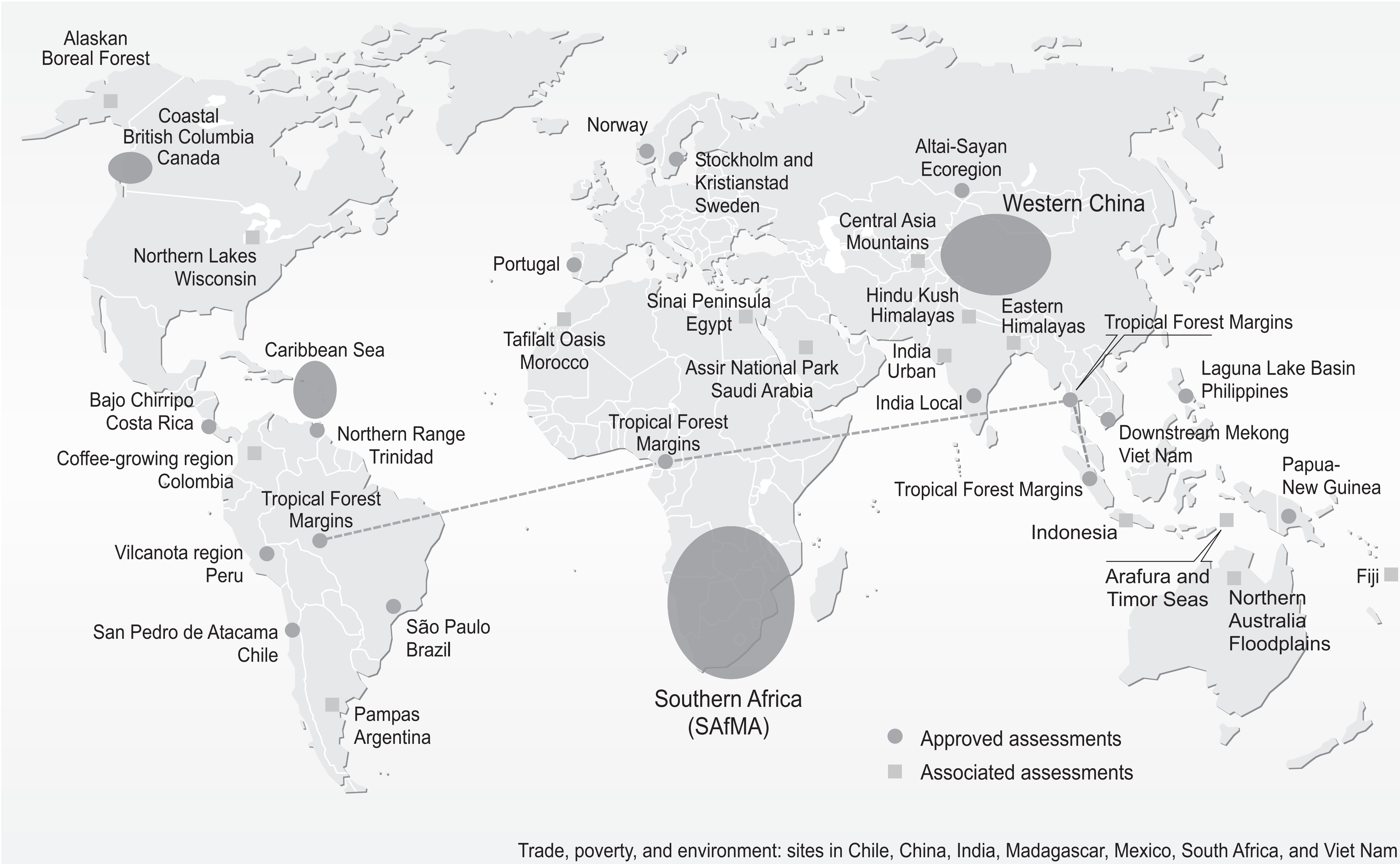
The conceptual framework for the MA posits that people are integral parts of ecosystems and that a dynamic interaction exists between them and other parts of ecosystems, with the changing human condition driving, both directly and indirectly, changes in ecosystems and thereby causing changes in human well-being. At the same time, social, economic, and cultural factors unrelated to ecosystems alter the human condition, and many natural forces influence ecosystems. Although the MA emphasizes the linkages between ecosystems and human well-being, it recognizes that the actions people take that influence ecosystems result not just from concern about human well-being but also from considerations of the intrinsic value of species and ecosystems. Intrinsic value is the value of something in and for itself, irrespective of its utility for someone else.

The Millennium Ecosystem Assessment synthesizes information from the scientific literature and relevant peer-reviewed datasets and models. It incorporates knowledge held by the private sector, practitioners, local communities, and indigenous peoples. The MA did not aim to generate new primary knowledge but instead sought to add value to existing information by collating, evaluating, summarizing, interpreting, and communicating it in a useful form. Assessments like this one apply the judgment of experts to existing knowledge to provide scientifically credible answers to policy-relevant questions. The focus on policy-relevant questions and the explicit use of expert judgment distinguish this type of assessment from a scientific review.

Five overarching questions, along with more detailed lists of user needs developed through discussions with stakeholders or provided by governments through international conventions, guided the issues that were assessed:

- What are the current condition and trends of ecosystems, ecosystem services, and human well-being?
- What are plausible future changes in ecosystems and their ecosystem services and the consequent changes in human well-being?
- What can be done to enhance well-being and conserve ecosystems? What are the strengths and weaknesses of response options that can be considered to realize or avoid specific futures?
- What are the key uncertainties that hinder effective decision-making concerning ecosystems?
- What tools and methodologies developed and used in the MA can strengthen capacity to assess ecosystems, the services they provide, their impacts on human well-being, and the strengths and weaknesses of response options?

The MA was conducted as a multiscale assessment, with interlinked assessments undertaken at local, watershed, national, regional, and global scales. A global ecosystem assessment cannot easily meet all the needs of decision-makers at national and sub-national scales because the management of any



Eighteen assessments were approved as components of the MA. Any institution or country was able to undertake an assessment as part of the MA if it agreed to use the MA conceptual framework, to centrally involve the intended users as stakeholders and partners, and to meet a set of procedural requirements related to peer review, metadata, transparency, and intellectual property rights. The MA assessments were largely self-funded, although planning grants and some core grants were provided to support some assessments. The MA also drew on information from 16 other sub-global assessments affiliated with the MA that met a subset of these criteria or were at earlier stages in development.

	ECOSYSTEM TYPES										ECOSYSTEM SERVICES								
SUB-GLOBAL ASSESSMENT	COASTAL	CULTIVATED	DRYLAND	FOREST	INLAND WATER	ISLAND	MARINE	MOUNTAIN	POLAR	URBAN	FOOD	WATER	FUEL and ENERGY	BIODIVERSITY-RELATED	CARBON SEQUESTRATION	FIBER and TIMBER	RUNOFF REGULATION	CULTURAL, SPIRITUAL, AMENITY	OTHERS
Altai-Sayan Ecoregion			●	●	●			●			●		●	●		●		●	
San Pedro de Atacama, Chile			●		●						●	●		●			●	●	●
Caribbean Sea	●					●	●				●	●		●				●	
Coastal British Columbia, Canada	●			●	●			●			●			●		●	●	●	
Bajo Chirripo, Costa Rica		●		●	●						●	●		●		●		●	●
Tropical Forest Margins		●		●							●	●		●	●	●	●		●
India Local Villages		●		●	●						●	●	●	●		●	●	●	●
Glomma Basin, Norway		●		●	●			●			●		●			●		●	●
Papua New Guinea	●	●				●	●				●	●	●	●		●	●	●	●
Vilcanota, Peru		●	●					●			●	●		●			●	●	●
Laguna Lake Basin, Philippines		●		●	●						●	●		●	●			●	●
Portugal	●	●	●	●	●	●	●	●		●	●	●		●	●	●	●	●	●
São Paulo Green Belt, Brazil	●	●		●	●					●	●	●		●	●	●	●	●	●
Southern Africa	●	●	●	●	●					●	●	●	●	●		●		●	●
Stockholm and Kristianstad, Sweden		●			●					●	●	●		●	●	●	●	●	●
Northern Range, Trinidad	●			●	●			●			●	●		●		●	●	●	●
Downstream Mekong Wetlands, Viet Nam	●	●			●						●	●	●	●	●	●	●	●	●
Western China		●	●	●	●			●			●	●		●	●		●		●
Alaskan Boreal Forest				●	●						●					●		●	●
Arafura and Timor Seas	●					●	●				●			●	●				●
Argentine Pampas		●									●	●						●	●
Central Asia Mountains								●			●	●		●					●
Colombia coffee-growing regions		●						●			●	●		●				●	
Eastern Himalayas				●				●			●	●	●	●				●	
Sinai Peninsula, Egypt			●					●						●			●	●	●
Fiji	●					●					●	●	●						●
Hindu Kush-Himalayas					●			●				●		●			●	●	●
Indonesia	●					●	●				●			●					●
India Urban Resource										●	●	●	●	●	●			●	●
Tafilalt Oasis, Morocco		●	●								●	●						●	●
Northern Australia Floodplains					●						●	●		●			●	●	●
Assir National Park, Saudi Arabia		●		●				●			●						●	●	●
Northern Highlands Lake District, Wisconsin				●	●							●				●	●	●	●

particular ecosystem must be tailored to the particular characteristics of that ecosystem and to the demands placed on it. However, an assessment focused only on a particular ecosystem or particular nation is insufficient because some processes are global and because local goods, services, matter, and energy are often transferred across regions. Each of the component assessments was guided by the MA conceptual framework and benefited from the presence of assessments undertaken at larger and smaller scales. The sub-global assessments were not intended to serve as representative samples of all ecosystems; rather, they were to meet the needs of decision-makers at the scales at which they were undertaken. The sub-global assessments involved in the MA process are shown in the Figure and the ecosystems and ecosystem services examined in these assessments are shown in the Table.

The work of the MA was conducted through four working groups, each of which prepared a report of its findings. At the global scale, the Condition and Trends Working Group assessed the state of knowledge on ecosystems, drivers of ecosystem change, ecosystem services, and associated human well-being around the year 2000. The assessment aimed to be comprehensive with regard to ecosystem services, but its coverage is not exhaustive. The Scenarios Working Group considered the possible evolution of ecosystem services during the twenty-first century by developing four global scenarios exploring plausible future changes in drivers, ecosystems, ecosystem services, and human well-being. The Responses Working Group examined the strengths and weaknesses of various response options that have been used to manage ecosystem services and identified promising opportunities for improving human well-being while conserving ecosystems. The report of the Sub-global Assessments Working Group contains lessons learned from the MA sub-global assessments. The first product of the MA—*Ecosystems and Human Well-being: A Framework for Assessment,* published in 2003—outlined the focus, conceptual basis, and methods used in the MA. The executive summary of this publication appears as Chapter 1 of this volume.

Approximately 1,360 experts from 95 countries were involved as authors of the assessment reports, as participants in the sub-global assessments, or as members of the Board of Review Editors. The latter group, which involved 80 experts, oversaw the scientific review of the MA reports by governments and experts and ensured that all review comments were appropriately addressed by the authors. All MA findings underwent two rounds of expert and governmental review. Review comments were received from approximately 850 individuals (of which roughly 250 were submitted by authors of other chapters in the MA), although in a number of cases (particularly in the case of governments and MA-affiliated scientific organizations), people submitted collated comments that had been prepared by a number of reviewers in their governments or institutions.

The MA was guided by a Board that included representatives of five international conventions, five U.N. agencies, international scientific organizations, governments, and leaders from the private sector, nongovernmental organizations, and indigenous groups. A 15-member Assessment Panel of leading social and natural scientists oversaw the technical work of the assessment, supported by a secretariat with offices in Europe, North America, South America, Asia, and Africa and coordinated by the United Nations Environment Programme.

The MA is intended to be used:

- to identify priorities for action;
- as a benchmark for future assessments;
- as a framework and source of tools for assessment, planning, and management;
- to gain foresight concerning the consequences of decisions affecting ecosystems;
- to identify response options to achieve human development and sustainability goals;
- to help build individual and institutional capacity to undertake integrated ecosystem assessments and act on the findings; and
- to guide future research.

Because of the broad scope of the MA and the complexity of the interactions between social and natural systems, it proved to be difficult to provide definitive information for some of the issues addressed in the MA. Relatively few ecosystem services have been the focus of research and monitoring and, as a consequence, research findings and data are often inadequate for a detailed global assessment. Moreover, the data and information that are available are generally related to either the characteristics of the ecological system or the characteristics of the social system, not to the all-important interactions between these systems. Finally, the scientific and assessment tools and models available to undertake a cross-scale integrated assessment and to project future changes in ecosystem services are only now being developed. Despite these challenges, the MA was able to provide considerable information relevant to most of the focal questions. And by identifying gaps in data and information that prevent policy-relevant questions from being answered, the assessment can help to guide research and monitoring that may allow those questions to be answered in future assessments.

Contents

Foreword

The Millennium Ecosystem Assessment was called for by United Nations Secretary-General Kofi Annan in 2000 in his report to the UN General Assembly, *We the Peoples: The Role of the United Nations in the 21st Century.* Governments subsequently supported the establishment of the assessment through decisions taken by three international conventions, and the MA was initiated in 2001. The MA was conducted under the auspices of the United Nations, with the secretariat coordinated by the United Nations Environment Programme, and it was governed by a multistakeholder board that included representatives of international institutions, governments, business, NGOs, and indigenous peoples. The objective of the MA was 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.

This volume has been produced by the MA Scenarios Working Group and examines possible changes in ecosystem services during the twenty-first century by developing four global scenarios exploring plausible future changes in drivers, ecosystems, ecosystem services, and human well-being. The material in this report has undergone two extensive rounds of peer review by experts and governments, overseen by an independent Board of Review Editors.

This is one of four volumes (*Current State and Trends, Scenarios, Policy Responses,* and *Multiscale Assessments*) that present the technical findings of the Assessment. Six synthesis reports have also been published: one for a general audience and others focused on issues of biodiversity, wetlands and water, desertification, health, and business and ecosystems. These synthesis reports were prepared for decision-makers in these different sectors, and they synthesize and integrate findings from across all of the working groups for ease of use by those audiences.

This report and the other three technical volumes provide a unique foundation of knowledge concerning human dependence on ecosystems as we enter the twenty-first century. Never before has such a holistic assessment been conducted that addresses multiple environmental changes, multiple drivers, and multiple linkages to human well-being. Collectively, these reports reveal both the extraordinary success that humanity has achieved in shaping ecosystems to meet the need of growing populations and economies and the growing costs associated with many of these changes. They show us that these costs could grow substantially in the future, but also that there are actions within reach that could dramatically enhance both human well-being and the conservation of ecosystems.

A more exhaustive set of acknowledgements appears later in this volume but we want to express our gratitude to the members of the MA Board, Board Alternates, Exploratory Steering Committee, Assessment Panel, Coordinating Lead Authors, Lead Authors, Contributing Authors, Board of Review Editors, and Expert Reviewers for their extraordinary contributions to this process. (The list of reviewers is available at www.MAweb.org.) We also would like to thank the MA Secretariat and in particular the staff of the Scenarios Working Group Technical Support Unit for their dedication in coordinating the production of this volume, as well as the University of Wisconsin-Madison, the Food and Agriculture Organization of the United Nations, and the International Maize and Wheat Improvement Center, which housed this TSU.

We would particularly like to thank the Co-chairs of the Scenarios Working Group, Dr. Stephen Carpenter and Dr. Prabhu Pingali, and the TSU Coordinators, Dr. Elena Bennett and Dr. Monika Zurek, for their skillful leadership of this working group and their contributions to the overall assessment.

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Preface

Scenarios is one of four central volumes of the Millennium Ecosystem Assessment, a four-year international program designed to meet the needs of decision-makers for scientific information on the links between ecosystem change and human well-being. Leading scientists from around the world have been involved with the development of the scenarios and the writing of this book.

Scenarios are plausible, challenging, and relevant sets of stories about how the future might unfold. They are generally developed to help decision-makers understand the wide range of potential futures, confront critical uncertainties, and understand how decisions made now may play out in the future. They are intended to widen perspectives and illuminate key issues that might otherwise be missed or dismissed. The goal of developing scenarios is often to support more informed and rational decision-making that takes both the known and the unknown into account.

We developed four scenarios that focus on ecosystem change and the impacts on human well-being. Each scenario demonstrates development pathways commonly discussed today by decision-makers around the world. They address assumptions that people hold about how the world works and the best paths to a sustainable future. By comparing different scenarios, readers can understand the potential impact of today's decisions on tomorrow's ecosystems and human well-being. The probability of any one of our scenarios being the real future is low: the real future is likely to be some mix of the scenarios that we present. The future could be far worse or far better than any of the individual scenarios, depending on the choices made by decision-makers as well as on unforeseeable events.

The scenarios could be presented in many different ways. We have chosen to present them in three sections. Part I presents the background material for the scenarios. **Chapter 1** summarizes the MA conceptual framework. It describes the assumptions that underlie the MA and explains the basic framework for analysis and decision-making. It was developed through interactions of the experts involved in the MA as well as stakeholders who will use the findings of the MA. **Chapter 2** explores the history of global environmental scenario building for sustainable development. While scenarios first emerged as a war planning technique in the 1950s, the first ones that explicitly included environmental issues were not developed until the 1970s.

Although scenarios have been developed to improve understanding of the environment, **Chapter 3** explains that even these focus primarily on socioeconomic changes and have rarely taken ecological dynamics into account. The authors show that incorporating ecosystem dynamics could radically alter the outcome of some scenarios, and they make the case that including ecosystem knowledge into scenarios about ecosystem change and human well-being is critical.

Quantitative projections using models are an important element of the MA scenarios. Models are used to add quantitative dimensions to scenarios, compare outcomes, evaluate the consistency of scenarios with known conditions and trends, and assess plausibility in relation to generally accepted mechanisms of ecosystem change. Models exist to quantify many, but not all, aspects of the MA scenarios. Even in cases where models exist, however, there may be critical uncertainties or other weaknesses. **Chapter 4** explores the strengths and weaknesses of the models that are available to quantify the MA scenarios in nine areas: forecasting land cover change, impacts of land cover changes on local climates, changes in food demand and supply, changes in biodiversity and extinction rates, impacts of changes in nitrogen and phosphorus cycles, fisheries and harvest, alterations of coastal ecosystems, and impacts on human health. The ninth area considered is integrated assessment models that seek to piece together many different trends by predicting the consequences of changes in critical drivers.

The next four chapters form Part II, the presentation of the scenarios themselves. There are an infinite number of interesting scenarios about ecosystem change and human well-being, but we chose to present four specific ones. **Chapter 5** explains the rationale for choosing these four particular areas and how decision-maker concerns and ecosystem management dilemmas led us to that focus. We also present brief versions of each of the scenarios and some ideas about the potential benefits and risks of each scenario. In **Chapter 6** we present the methods by which the scenarios were developed, including both qualitative and quantitative aspects of scenario development. The qualitative part of the chapter describes how we considered user needs and questions when outlining four storylines, and how the scenarios grew and were modified from this beginning. The quantitative part of the chapter describes the various models that were used to quantify the scenarios as well as the process by which these models were soft-linked. Finally, we describe how we addressed uncertainty in both the qualitative and quantitative parts of the scenarios and the sensitivity analysis for the quantitative aspect of the scenarios.

Chapter 7 presents some of the key input information needed to determine the outcome of the scenarios—the material about the key drivers of ecosystem change. The chapter examines two of the main elements of the MA conceptual framework, indirect and direct drivers. The goal of the chapter is to provide an overview at the global level of key drivers of ecosystem change and the ability to deliver services that improve human well-being. The scenario outlines presented in Chapter 5 can be used to infer changes in the drivers presented in Chapter 7. In turn, the changes in these drivers will go on to determine the outcomes for ecosystem change, which are presented later. The final chapter in this section, **Chapter 8,** is the full presentation of the scenario storylines. Chapter 8 also details the differences and similarities among the four scenarios, as well as providing an in-depth examination of the potential risks and benefits of each of our four scenarios.

The last six chapters, Part III, delve into the implications of the scenarios for ecosystem change and changes in human well-being as well as for managing socioecological systems. In **Chapter 9,** we present estimates of changing ecosystem services in the form of both qualitative and quantitative information. The qualitative information is based on our interpretation of the storylines in Chapters 5 and 8, while the quantitative information is based on the related modeling analysis. Quantification provides insight into demand for food, water, and other ecosystem services and the potential effects on future capacity of ecosystems to provide these services.

Chapter 10 looks specifically at changes in biodiversity across the scenarios. Despite management efforts to stem losses, biodiversity has continued to decline in many parts of the world. This chapter examines what the scenarios tell us about how biodiversity is likely to change in the future and what actions we can take to help maintain biodiversity. Because biodiversity is necessary for the provision of many other ecosystem services, changes in biodiversity in the future may have important implications for the provision of key ecosystem services. Because ecosystems underpin human well-being through supporting, provisioning, regulating, and cultural services, changes in ecosystem services also affect human well-being. Well-being also depends on the supply and quality of human services, technology, and institutions. We examine changes in human well-being across the scenarios in **Chapter 11,** which also looks at the resilience and vulnerability of human well-being to adverse surprises across the scenarios.

Once we understand the similarities and differences in the provision of ecosystem services and human well-being across the scenarios, we can begin to think about ecosystem management. The final three chapters address ecosystem management options and their consequences. We examine the implications of the scenarios for trade-offs between ecosystem services in **Chapter 12.** Trade-offs are reductions in one ecosystem service that accompany increased use of another service or increased intensity of some non-ecosystem-based human activity. The scenarios indicate that major policy decisions in the next 50–100 years will have to address trade-offs among ecosystem services. Many trade-offs, such as the one between agricultural production and water quality, are consistent across all scenarios. We provide a synthesis of the lessons of the MA scenario development in **Chapter 13.** This chapter is directed primarily at the global assessment community. Finally, **Chapter 14** synthesizes the results of the MA scenarios for policy-makers, focusing on the Convention on Biological Diversity, the RAMSAR convention on wetlands, the Convention to Combat Desertification, national governments, communities and nongovernmental organizations, and the private sector.

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Reader's Guide

The four technical reports present the findings of each of the MA Working Groups: Condition and Trends, Scenarios, Responses, and Sub-global Assessments. A separate volume, *Our Human Planet*, presents the summaries of all four reports in order to offer a concise account of the technical reports for decision-makers. In addition, six synthesis reports were prepared for ease of use by specific audiences: Synthesis (general audience), CBD (biodiversity), UNCCD (desertification), Ramsar Convention (wetlands), business and industry, and the health sector. Each MA sub-global assessment will also produce additional reports to meet the needs of its own audiences.

All printed materials of the assessment, along with core data and a list of reviewers, are available at www.MAweb.org. In this volume, Appendix A contains color maps and figures. Appendix B lists all the authors who contributed to this volume. Appendix C lists the acronyms and abbreviations used in this report and Appendix D is a glossary of terminology used in the technical reports. Throughout this report, dollar signs indicate U.S. dollars and ton means tonne (metric ton). Bracketed references within the Summary are to chapters within this volume.

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%–58% 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.

Ecosystems and Human Well-being: Scenarios, Volume 2

Summary:
Comparing Alternate Futures of Ecosystem Services and Human Well-being

Core Writing Team: Elena Bennett, Steve Carpenter, Prabhu Pingali, Monika Zurek
Extended Writing Team: Scenarios Working Group

Envisioning the Future for Ecosystems and People

The capacity of Earth's ecosystems to provide life-support services is changing rapidly, at a time when human pressures on ecosystems are also increasing.

These changes in ecosystems have enormous implications for life on Earth. Yet they can seem bewildering because of their complexity, speed, surprises, and demands on human ingenuity.

Scenarios organize information about plausible causes of and responses to long-term change. The central idea is to categorize outcomes into a few plausible futures, making the complex more comprehensible. Contrasts among scenarios illuminate key linkages and probable outcomes of various approaches or decisions.

Ecosystems are always changing, but the rate and magnitude of change are not constant over time. Most of the time, change is gradual, incremental, and perhaps reversible. However, some changes in ecosystems and their services are large in magnitude and can be difficult, expensive, or impossible to reverse (*high certainty*). Examples of ecosystems subject to large, important changes are pelagic fisheries (economic collapse), freshwater lakes and reservoirs (toxic blooms, fish kills), pastoral lands (conversion to woodland with overgrazing and fire suppression), and dryland agriculture (desertification). The thresholds and triggering events for these large changes are often difficult to predict. [3, 5]

Slow losses of resilience set the stage for large changes that occur after the ecosystem crosses a threshold or is subjected to a random event such as a climate fluctuation (*established but incomplete*). For example, incremental buildup of phosphorus in soils gradually increases the vulnerability of lakes and reservoirs to runoff events that trigger oxygen depletion, toxic algae blooms, and fish kills. Cumulative effects of overfishing and nutrient runoff make coral reefs susceptible to severe deterioration triggered by storms, invasive species, or disease. Slow decrease in grass cover crosses a threshold so that grasslands can no longer carry a fire, allowing woody vegetation to dominate and severely decreasing forage for livestock. [3, 5] These long-lasting and costly changes from seemingly random events pose a daunting challenge for decision-makers concerned with ecosystems as well as for people whose livelihoods depend on ecosystems.

Recent trends in human use of ecosystem services reveal rapid changes and great uncertainty about future changes. (See MA *Current State and Trends* volume.) While many ecosystem services are renewable, current rates of use are often greater than the renewal rates, leading to degradation and declines in the future capacity of ecosystems to provide services. Dryland agricultural areas around the world are threatened by desertification. Freshwater supplies have been stressed by increasing withdrawals of groundwater and surface water, as well as by pollution. Marine fish harvest has declined since the late 1980s, and one quarter of marine fish stocks are overexploited or depleted. Despite growing global timber production, the condition of forests is diminishing. The observed rates of species extinction in modern times are as much as 1,000 times higher than the average observed for comparable taxonomic groups from the fossil record. These and many other losses have occurred in the course of using ecosystem services. The capacity of Earth's ecosystems to provide life-support services is changing rapidly, at a time when human pressures on ecosystems are also increasing. **The *Scenarios* volume explores the implications of different approaches for sustaining ecosystem services in the face of growing demand.** [8, 9, 11, 14]

In order to plan for a changing and uncertain future, we must have tools for organizing extensive information about socioecological systems. Scenarios are such a tool. **Scenarios are plausible, provocative, and relevant stories about how the future might unfold. They can be told in both words and numbers. Scenarios are not forecasts, projections, predictions, or recommendations, though model projections may be used to quantify some aspects of the scenarios.** The process of building scenarios is intended to widen perspectives and illuminate key issues that might otherwise be either missed or dismissed. By offering insight into uncertainties and the consequences of current and possible future actions, scenarios support more informed and rational decision-making in situations of uncertainty. Scenarios are a powerful way of exploring possible consequences of different policies. They force us to state our assumptions clearly, enabling the consequences of those assumptions to be analyzed. Scenarios, and the products of scenarios, are not predictions. Rather, they explore consequences of different policy choices based on current knowledge of underlying socioecological processes. [2, 3, 5]

This summary explores the scenarios, how we developed them, and what we have learned in the process. The first section describes the methods and the assumptions behind the scenarios. This is followed by four sections that explore the results for ecosystem services, trade-offs among ecosystem services, biodiversity, and human well-being. We conclude with a section describing research needs for improving future development of scenarios for ecosystem services and human well-being.

Developing the Millennium Ecosystem Assessment Scenarios

The MA scenarios assess the consequences of contrasting development paths for ecosystem services.

Because stresses on ecosystems are increasing, it is likely that large, costly, and even irreversible changes will become more common in the future. This will lead to reduced services provided by ecosystems or increased costs of maintaining services. Management that deliberately maintains resilience of ecosystems can reduce the risk of large, costly, or irreversible change.

Proactive or anticipatory management of ecosystems is particularly important under rapidly changing or novel conditions.

The MA developed a set of global scenarios to address the effects of different development paths on ecosystem services and human well-being. The scenarios extend into the future from the situation described in the MA *Current State and Trends* volume. Three of the four pathways involve major positive actions taken to move toward sustainable development. The alternate pathways of the four contrasting scenarios illustrate many of the tools described in the MA *Policy Responses* volume. Although the scenarios focus on the global scale, many implications for regional and local ecosystems were examined. These provide a bridge to the MA *Multiscale Assessments* volume. **The contrasts among the global scenarios are designed to illuminate key risks and benefits of each pathway and to examine the interaction among drivers of ecosystem change, ecosystem services, and human well-being.**

The MA scenarios explore the potential consequences of alternate pathways to development, and they inform decision-makers about the consequences for ecosystem services. **The scenarios were designed to explore contrasting transitions of society as well as contrasting approaches to policies about ecosystem services.** (See Figure S1). We explore two kinds of transitions—one in which the world becomes increasingly globalized and another in which it becomes increasingly regionalized. Furthermore, we address two different approaches for governance and policies related to ecosystems and their services. In one case, management of ecosystems is reactive, and most problems are addressed only after they become obvious. In the other case, management of ecosystems is proactive, and policies deliberately seek to maintain ecosystem services for the long term.

Framed in terms of these contrasts, the four scenarios developed by the MA were named Global Orchestration (socially conscious globalization, with an emphasis on equity, economic growth, and public goods and with a reactive approach to ecosystems), Order from Strength (regionalized, with an emphasis on security and economic growth and with a reactive approach to ecosystems), Adapting Mosaic (regionalized, with an emphasis on proactive management of ecosystems, local adaptation, and flexible governance), and TechnoGarden (globalized, with an emphasis on using technology to achieve environmental outcomes and with a proactive approach to ecosystems). **The focus on ecosystem services and effects of ecosystems on human well-being distinguish the MA scenarios from previous global scenario exercises.** [2, 3, 5, 8]

The future will represent a mix of approaches and consequences described in the scenarios, as well as events and innovations that have not yet been imagined. No scenario will match the future as it actually occurs. No scenario represents business as usual, although all begin from current conditions and trends. None of the MA scenarios represents a "best" or a "worst" path. Instead, they illustrate choices and trade-offs. There could be combinations of policies that produce significantly better, or worse, outcomes than any of the scenarios. Each of the scenarios begins in 2000 and ends in 2050. Each emphasizes different pathways of development. [2] (See Box S1.)

Interviews with stakeholders and a literature review of major ecological dilemmas were used to identify focal questions, key uncertainties, and cross-cutting assumptions behind the scenarios. (See Figure S2). These focal questions, uncertainties, and assumptions, which are explored in more detail in the next paragraphs, were used to develop the four plausible, alternative futures. Scenarios were then constructed by working through the MA conceptual framework (indirect drivers, direct drivers,

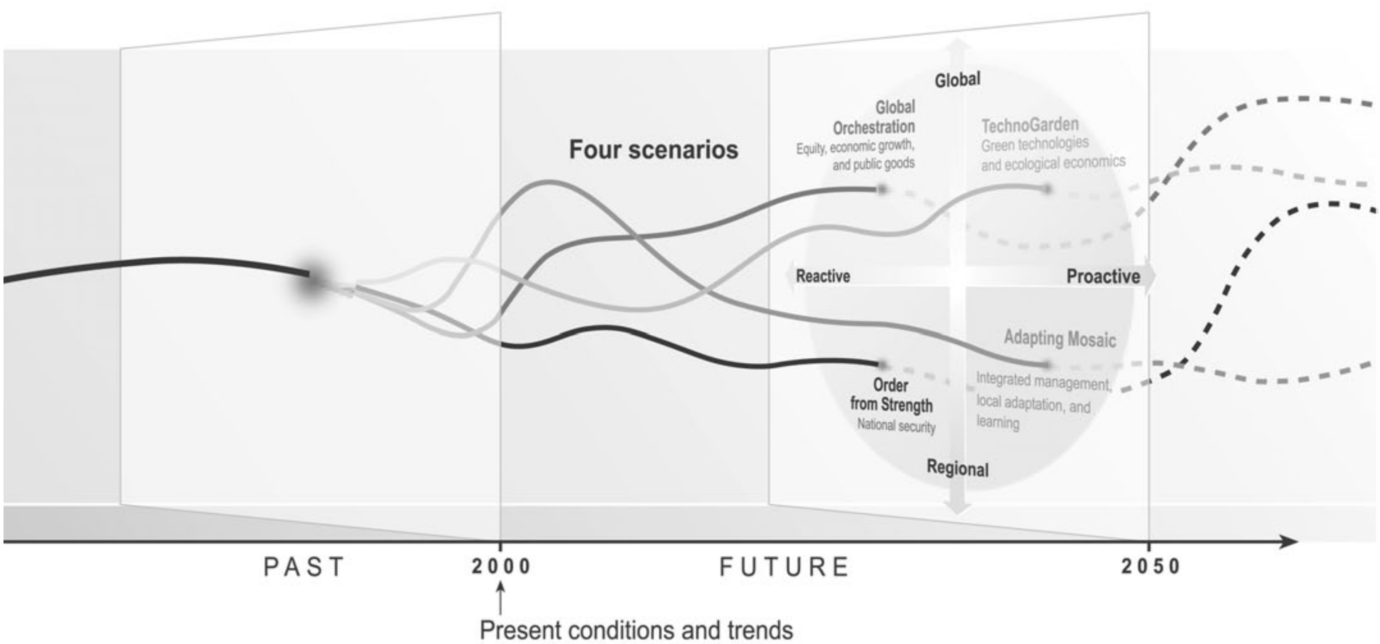


Figure S1. Millennium Ecosystem Assessment Scenarios: Plausible Future Development Pathways until 2050. The scenario differences are based on the approaches pursued toward governance and economic development (regionalized versus globalized) and ecosystem service management (reactive versus proactive).

BOX S1

Global Scenarios of the Millennium Ecosystem Assessment

The Global Orchestration scenario depicts a globally connected society in which policy reforms that focus on global trade and economic liberalization are used to reshape economies and governance, emphasizing the creation of markets that allow equitable participation and provide equitable access to goods and services. These policies, in combination with large investments in global public health and the improvement of education worldwide, generally succeed in promoting economic expansion and lift many people out of poverty into an expanding global middle class. Supranational institutions in this globalized scenario are well placed to deal with global environmental problems such as climate change and fisheries. However, the reactive approach to ecosystem management favored in this scenario makes people vulnerable to surprises arising from delayed action. While the focus is on improving human well-being of all people, environmental problems that threaten human well-being are only considered after they become apparent.

Growing economies, expansion of education, and growth of the middle class leads to demand for cleaner cities, less pollution, and a more beautiful environment. Rising income levels bring about changes in global consumption patterns, boosting demand for ecosystem services, including agricultural products such as meat, fish, and vegetables. Growing demand for these services leads to declines in other services, as forests are converted into cropped areas and pasture, and the services formerly provided by forests decline. The problems related to increasing food production, such as loss of wildlands, are remote to most people because they live in urban areas. These problems therefore receive only limited attention.

Global economic expansion expropriates or degrades many of the ecosystem services poor people once depended on for their survival. While economic growth more than compensates for these losses in some regions by increasing our ability to find substitutes for particular ecosystem services, in many other places it does not. An increasing number of people are affected by the loss of basic ecosystem services essential for human life. While risks seem manageable in some places, in other places there are sudden, unexpected losses as ecosystems cross thresholds and degrade irreversibly. Loss of potable water supplies, crop failures, floods, species invasions, and outbreaks of environmental pathogens increase in frequency. The expansion of abrupt, unpredictable changes in ecosystems, many with harmful effects on increasingly large numbers of people, is the key challenge facing managers of ecosystem services.

The Order from Strength scenario represents a regionalized and fragmented world concerned with security and protection, emphasizing primarily regional markets, and paying little attention to common goods. Nations see looking after their own interests as the best defense against economic insecurity, and the movement of goods, people, and information is strongly regulated and policed. The role of government expands as oil companies, water systems, and other strategic businesses are either nationalized or subjected to more state oversight. Trade is restricted, large amounts of money are invested in security systems, and technological change slows due to restrictions on the flow of goods and information. Regionalization exacerbates global inequality.

Agreements on global climate change, international fisheries, and the trade in endangered species are only weakly and haphazardly implemented, resulting in degradation of the global commons. Local problems often go unresolved, but major problems are sometimes handled by rapid disaster relief to at least temporarily resolve the immediate crisis. Many powerful countries cope with local problems by shifting burdens to other, less powerful countries, increasing the gap between rich and poor. In particular, natural resource–intensive industries are moved from wealthier nations to poorer and less powerful ones. Inequality increases considerably within countries as well.

Ecosystem services become more vulnerable, fragile, and variable in Order from Strength. For example, parks and reserves exist within fixed boundaries, but climate change crosses them, leading to the unintended extirpation of many species. Conditions for crops are often suboptimal, and the ability of societies to import alternative foods is diminished by trade barriers. As a result, there are frequent shortages of food and water, particularly in poor regions. Low levels of trade tend to restrict the number of invasions by exotic species; however, ecosystems are less resilient and invaders are therefore more often successful when they arrive.

In the Adapting Mosaic scenario, hundreds of regional ecosystems are the focus of political and economic activity. This scenario sees the rise of local ecosystem management strategies and the strengthening of local institutions. Investments in human and social capital are geared toward improving knowledge about ecosystem functioning and management, which results in a better

ecosystem services, and human well-being), using both qualitative and quantitative analyses. Qualitative and quantitative results were cross-checked at every stage. Quantitative results of one stage often affected qualitative results of the next stage, but qualitative results of one stage could not always be fed back into the existing numerical models. Finally, feedbacks from ecosystem services and human well-being played an important role in development of indirect and direct driver trajectories for the qualitative assessment. Such feedbacks are difficult to incorporate in the quantitative models, however. [6]

Interviews identified many benefits, risks, opportunities, and threats from contrasting paths of globalization and governance for ecosystem management. While some advantages and disadvantages are clear, many have not been thoroughly explored, so we designed the scenarios to do that. The following bullets describe the theme of the scenarios, which were chosen to explore various tensions (the storyline most closely associated with each theme appears in parentheses at the end of the bullet). [8, 11, 12, 13, 14]

- Economic growth and expansion of education and access to technology increases the capacity to respond effectively when environmental problems emerge. However, if the focus on reducing poverty and increasing human and social capital overwhelms attention to the environment, and if proactive environmental policies are not pursued, there is increased risk of regional or even global interruptions in the provision of ecosystem services. Severe and irreversible declines in ecosystem services and human well-being may occur if we do not understanding of resilience, fragility, and local flexibility of ecosystems. There is optimism that we can learn, but humility about preparing for surprises and about our ability to know everything about managing ecosystems.

There is also great variation among nations and regions in styles of governance, including management of ecosystem services. Many regions explore actively adaptive management, investigating alternatives through experimentation. Others use bureaucratically rigid methods to optimize ecosystem performance. Great diversity exists in the outcome of these approaches: some areas thrive, while others develop severe inequality or experience ecological degradation. Initially, trade barriers for goods and products are increased, but barriers for information nearly disappear (for those who are motivated to use them) due to improving communication technologies and rapidly decreasing costs of access to information.

Eventually, the focus on local governance leads to some failures in managing the global commons. Problems like climate change, marine fisheries, and pollution grow worse, and global environmental problems intensify. Communities slowly realize that they cannot manage their local areas because global and regional problems are infringing, and they begin to develop networks among communities, regions, and even nations to better manage the global commons. Solutions that were effective locally are adopted among networks. These networks of regional successes are especially common in situations where there are mutually beneficial opportunities for coordination, such as along river valleys. Sharing good solutions and discarding poor ones eventually improves approaches to a variety of social and environmental problems, ranging from urban poverty to agricultural water pollution. As more knowledge is collected from successes and failures, provision of many services improves.

The TechnoGarden scenario depicts a globally connected world relying strongly on technology and highly managed, often engineered ecosystems to deliver ecosystem services. Overall efficiency of ecosystem service provision improves but is shadowed by the risks inherent in large-scale human-made solutions and rigid control of ecosystems.

Technology and market-oriented institutional reform are used to achieve solutions to environmental problems. These solutions are designed to benefit both the economy and the environment. These changes co-develop with the expansion of property rights to ecosystem services, requiring people to pay for pollution they create and paying people for providing key ecosystem services through actions such as preservation of key watersheds. Interest in maintaining, and even increasing, the economic value of these property rights, combined with an interest in learning and information, leads to an increase in the use of ecological engineering approaches for managing ecosystem services.

Investment in green technology is accompanied by a significant focus on economic development and education, improving people's lives and helping them understand how ecosystems make their livelihoods possible. A variety of problems in global agriculture are addressed by focusing on the multifunctional aspects of agriculture and a global reduction of agricultural subsidies and trade barriers. Recognition of the role of agricultural diversification encourages farms to produce a variety of ecological services rather than simply maximizing food production. The combination of these movements stimulates the growth of new markets for ecosystem services, such as trade in carbon storage, and the development of technology for increasingly sophisticated ecosystem management. Gradually, environmental entrepreneurship expands as new property rights and technologies co-evolve to stimulate the growth of companies and cooperatives providing reliable ecosystem services to cities, towns, and individual property owners.

Innovative capacity expands quickly in lower-income nations. The reliable provision of ecosystem services as a component of economic growth, together with enhanced uptake of technology due to rising income levels, lifts many of the world's poor into a global middle class. While the provision of basic ecosystem services improves the well-being of the world's poor, the reliability of the services, especially in urban areas, is increasingly critical and increasingly difficult to ensure. Not every problem has succumbed to technological innovation. Reliance on technological solutions sometimes creates new problems and vulnerabilities. In some cases, we seem to be barely ahead of the next threat to ecosystem services. In such cases, new problems often seem to emerge from the last solution, and the costs of managing the environment are continually rising. Environmental breakdowns that affect large numbers of people become more common. Sometimes new problems seem to emerge faster than solutions. The challenge for the future will be to learn how to organize socioecological systems so that ecosystem services are maintained without taxing society's ability to implement solutions to novel, emergent problems.

address natural capital at the same time that we address social capital. (Global Orchestration)

- A focus on strong national security, which restricts the flow of goods, information, and people, coupled with a reactive approach to ecosystem management, can create great stress on ecosystems, particularly in poorer countries. While there may be some opportunities for conservation of biodiversity in wealthy or highly prized areas, in general a focus on security in wealthy nations leads to a loss of biodiversity in developing ones, as they often lack the resources to create measures for biodiversity protection. Without active, proactive management of ecosystems in a world like this, pressure on the environment increases; there is greater risk of large disturbances of ecosystem services and vulnerability to interruptions in provision of ecosystem services. Severe and irreversible declines in ecosystem services and human well-being may occur if we do not address ecosystem management where we live, in addition to focusing on reserves. (Order from Strength)
- When regional ecosystem management is proactive and oriented around adapting to change, ecosystem services become more resilient and society becomes less vulnerable to disturbances of ecosystem services. However, a regional focus can diminish attention to the global commons and exacerbates global environmental problems, such as climate change and declining oceanic fisheries. An adaptive approach may also have high initial costs and an initially slower rate of environmental improvement. If the focus on natural capital overwhelms attention to

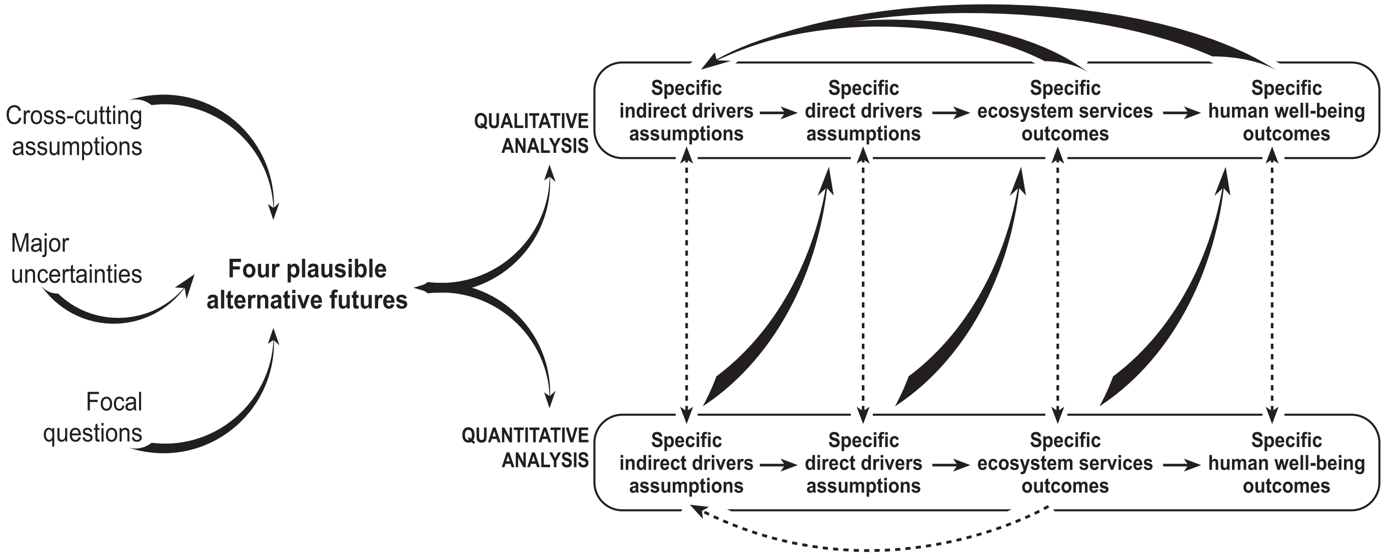


Figure S2. Flow Chart of MA Scenario Development. The focal questions, major uncertainties, and cross-cutting assumptions were used to develop basic ideas about four plausible alternative futures. These futures were elaborated using qualitative and quantitative methods. At each step, quantitative and qualitative results were cross-checked (the dotted lines between boxes). Quantitative results of each step were used to help determine qualitative results of the next step (diagonal arrows). Finally, feedbacks from qualitative ecosystem services and human well-being outcomes were used to re-evaluate assumptions about indirect drivers. This feedback procedure was also done in a qualitative way for some quantitative ecosystem services outcomes.

immediate human well-being, poverty alleviation may be somewhat slower. (Adapting Mosaic)

- Technological innovations and ecosystem engineering, coupled with economic incentive measures to facilitate their uptake, can lead to highly efficient delivery of provisioning ecosystem services. However, technologies can create new environmental problems, and in some cases the resulting disruptions of ecosystem services affect large numbers of people. In addition, efficient provision of ecosystem services may lead to greater demand for ecosystem services rather than less pressure on ecosystems to provide the same amount of service. (TechnoGarden)

The scenarios were also designed to explore key ecosystem management dilemmas. One such dilemma is that ecosystem management that neglects slow changes in resilience or vulnerability of ecosystems increases the susceptibility of ecosystems to large, rapid changes (*established but incomplete*). For example, government subsidies to agriculture have allowed farmers to continue harmful practices that eventually lead to larger losses of ecosystem services. When fish stocks decline, subsidies that sustain fishing effort prevent recovery of the stocks. Dependency on biocides can increase the vulnerability of agroecosystems to evolution of biocide-resistant pests. Because stresses on ecosystems are increasing, it is likely that large, costly, and even irreversible changes will become more common in the future. On the other hand, management that deliberately maintains resilience of ecosystems can reduce the risk of large, costly, or irreversible change (*established but incomplete*). The scenarios were constructed to explore this dynamic. [5, 8, 9, 10]

Managing for surprise is another dilemma explored by the scenarios. **The MA scenarios differ in the frequency and magnitude of surprising changes in ecosystem services due to the management undertaken in each scenario, not due to any underlying ecological differences across the scenarios.** Each scenario implies different distributions of extreme events. (See Figure S3.) Examples of extreme events that affect ecosystem services are famines, technological failure of systems for quality control of food or water, massive floods, or serious and long-lasting heat waves or storms. The impact of an extreme event is driven by both the chance of an event happening and the vulnerability of people to the event. Extreme events

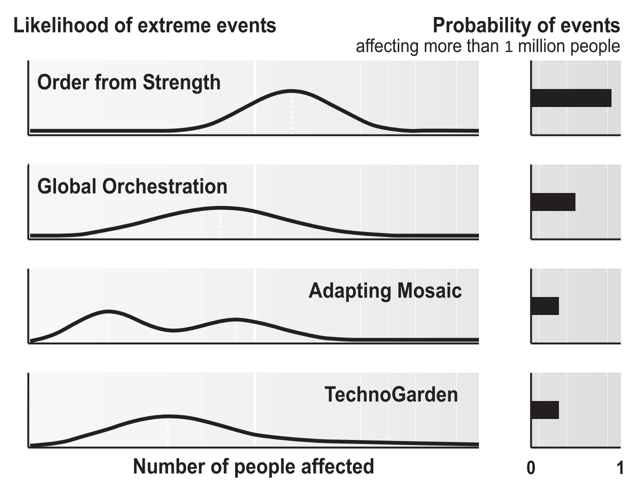


Figure S3. Probabilities of Extreme Events That Involve Ecosystem Services in MA Scenarios. Left column: Magnitude of extreme event (measured as the number of people affected) on the x-axis versus likelihood of events of a given magnitude, on the y-axis. Right column: Length of the bar indicates the annual probability of events that affect more than 1 million people.

affecting at least 1 million people are most common in Order from Strength and least common in Adapting Mosaic and TechnoGarden. [5, 8]

Proactive or anticipatory management of ecosystems is particularly important under rapidly changing or novel conditions. (See Table S1.) Ecological surprises are inevitable. Currently well understood phenomena that were surprises of the past century include the ability of pests to evolve resistance to biocides, the contribution to desertification of certain types of land use, biomagnification of toxins, and the increase in vulnerability of ecosystems to eutrophication and invasion due to removal of keystone predators. While we do not know which surprises will arise in the next 50 years, we can be certain that some will occur. Restoration of ecosystems or ecosystem services following degradation is usually time-consuming and expensive, if possible at all, so anticipatory management to build resilient, self-maintaining ecosystems is likely to be extremely cost-effective. This is particularly true when conditions are changing rapidly, when conditions are variable, when control of ecosystems is limited, or when uncertainty is high. [3]

The MA scenarios examine the need to develop and expand mechanisms of ecosystem management that avoid large ecosystem changes (by reducing stress on ecosystems), allow for the possibility of large ecosystem changes (by choosing reversible actions, experimenting cautiously, and monitoring appropriate ecological indicators), and increase the capacity of societies to adapt to large ecosystem changes (diversifying the portfolio of ecosystem services and developing flexible governance systems that adapt effectively to ecosystem change). [3, 5]

Table S1. Costs and Benefits of Proactive Management as Contrasted with Reactive Ecosystem Management

	Proactive Ecosystem Management	Reactive Ecosystem Management
Payoffs	benefit from lower risk of unexpected losses of ecosystem services, achieved through investment in more-efficient use of resources (water, energy, fertilizer, and so on), more innovation of green technology, the capacity to absorb unexpected fluctuations in ecosystem services, adaptable management systems, and ecosystems that are resilient and self-maintaining do well under changing or novel conditions build natural, social, and human capital	avoid paying for monitoring efforts do well under smoothly or incrementally changing conditions build manufactured, social, and human capital
Costs	technological solutions can create new problems costs of unsuccessful experiments costs of monitoring some short-term benefits are traded for long-term benefits	expensive unexpected events persistent ignorance (repeating the same mistakes) lost option values inertia of less flexible and adaptable management of infrastructure and ecosystems loss of natural capital

Quantitative and qualitative results for drivers, ecosystem services, and human well-being are presented in Tables S2 and S3. Indirect drivers are generally the result of group consensus and represent our assumptions about the factors that underlie each of the scenarios. Direct drivers are most often model outcomes based on the indirect drivers. For example, model outcomes show carbon emissions to be quite high in the scenarios with high economic growth, especially if proactive climate policies are not adopted. (See Figure S4.) Ecosystem service outcomes are a mixture of model outcomes and qualitative estimates, both based on the direct drivers. Most human well-being outcomes, determined largely by the ecosystem services outcomes while taking into account other social conditions, such as wealth and education, are qualitative estimates.

For some drivers, ecosystem services, and human well-being indicators, quantitative projections were calculated using established, peer-reviewed global models. Quantifiable items include drivers such as economic growth and land use change and ecosystem services such as water withdrawals, food production, and carbon emissions. Other drivers (such as rates of technologic change), 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) for which there are no appropriate global models were estimated qualitatively. Qualitative estimates were the consensus professional judgment of experts in relevant fields.

We explored the status of quantitative modeling in at least nine areas relevant to the MA: land cover change, impacts of land cover changes on local climates, changes in food demand and supply, changes in biodiversity and extinction rates, impacts of changes in nitrogen/phosphorus cycles, fisheries and harvest, alterations of coastal ecosystems, and impacts on human health as well as the use of integrated assessment models that seek to piece together many different trends by predicting the consequences of changes in critical drivers. **All these models have weaknesses, but the alternative is no quantification whatsoever. Therefore, we used appropriate models with caution and explicitly stated our uncertainties.** Key uncertainties include limitations on the spatial or temporal resolution of input data, bias or random error in input data, poor or unknown correspondence between modeled mechanisms and natural processes (model uncertainty), lack of information about model parameters, limited experience with linking the different models, and the impossibility of predicting human events and individual choices (which may be altered by the forecasts themselves). [4]

In general, models address incremental changes but fail to address thresholds, risk of extreme events,

Table S2. Main Assumptions about Indirect and Direct Driving Forces across the Scenarios [8, 9]

	Global Orchestration	Order from Strength: Industrial Nations[a]	Order from Strength: Developing Nations[a]	Adapting Mosaic	TechnoGarden
Indirect Driving Forces					
Demographics	high migration; low fertility and mortality levels; 2050 population: 8.1 billion	relatively high fertility and mortality levels (especially in developing countries); low migration, 2050 population: 9.6 billion		high fertility level; high mortality levels until 2010 then to medium by 2050; low migration, 2050 population: 9.5 billion	medium fertility levels, medium mortality; medium migration, 2050 population: 8.8 billion
Average income growth	high	medium	low	similar to Order from Strength but with increasing growth rates toward 2050	lower than Global Orchestration, but catching up toward 2050
GDP growth rates/capita per year until 2050 (global)	1995–2020: 2.4% per year 2020–50: 3.0% per year	1995–2020: 1.4% per year 2020–50: 1.0% per year		1995–2020: 1.5% per year 2020–50: 1.9% per year	1995–2020: 1.9% per year 2020–50: 2.5% per year
Income distribution	becomes more equal	similar to today		similar to today, then becomes more equal	becomes more equal
Investments into new produced assets	high	medium	low	begins like Order from Strength, then increases	high
Investments into human capital	high	medium	low	begins like Order from Strength, then increases in tempo	medium
Overall trend in technology advances	high	low		medium-low	medium in general; high for environmental technology
International cooperation	strong	weak—international competition		weak—focus on local environment	strong
Attitude toward environmental policies	reactive	reactive		proactive—learning	proactive
Energy demand and lifestyle	energy-intensive	regionalized assumptions		regionalized assumptions	high level of energy-efficiency
Energy supply	market liberalization; selects least-cost options; intensified use of technology	focus on domestic energy resources		some preference for clean energy resources	preference for renewable energy resources and rapid technology change
Climate policy	no	no		no	yes, aims at stabilization of CO_2-equivalent concentration at 550 ppmv
Approach to achieving sustainability	economic growth leads to sustainable development	national-level policies; conservation; reserves, parks		local-regional co-management; common-property institutions	green-technology; eco-efficiency; tradable ecological property rights
Direct Driving Forces					
Land use change	global forest loss until 2025 slightly below historic rate, stabilizes after 2025; ~10% increase in arable land	global forest loss faster than historic rate until 2025, near current rate after 2025; ~20% increase in arable land compared with 2000		global forest loss until 2025 slightly below historic rate, stabilizes after 2025; ~10% increase in arable land	net increase in forest cover globally until 2025, slow loss after 2025; ~9% increase in arable land
Greenhouse gas emissions by 2050	CO_2: 20.1 GtC-eq CH_4: 3.7 GtC-eq N_2O: 1.1 GtC-eq other GHGs: 0.7 GtC-eq	CO_2: 15.4 GtC-eq CH_4: 3.3 GtC-eq N_2O: 1.1 GtC-eq other GHGs: 0.5 GtC-eq		CO_2: 13.3 GtC-eq CH_4: 3.2 GtC-eq N_2O: 0.9 GtC-eq other GHGs: 0.6 GtC-eq	CO_2: 4.7 GtC-eq CH_4: 1.6 GtC-eq N_2O: 0.6 GtC-eq other GHGs: 0.2 GtC-eq

Air pollution emissions	SO_2 emissions stabilize, NO_x emissions increase from 2000 to 2050	both SO_2 and NO_x emissions increase globally	SO_2 emissions decline; NO_x emissions increase slowly	strong reductions in SO_2 and NO_x emissions
Climate change	2.0°C in 2050 and 3.5°C in 2100 above pre-industrial	1.7°C in 2050 and 3.3°C in 2100 above pre-industrial	1.9°C in 2050 and 2.8°C in 2100 above pre-industrial	1.5°C in 2050 and 1.9°C in 2100 above pre-industrial
Nutrient loading	increase in N transport in rivers	increase in N transport in rivers	increase in N transport in rivers	decrease in N transport in rivers

[a] "Industrial " and "developing " refer to the countries at the beginning of the scenario; some countries may change categories by 2050.

Table S3. Outcomes for Ecosystem Services and Human Well-being in 2050 Compared with 2000 across the Scenarios [8, 9]

	Global Orchestration		**Order from Strength**		**Adapting Mosaic**		**TechnoGarden**	
	Industrial[a]	**Developing[a]**	**Industrial[a]**	**Developing[a]**	**Industrial[a]**	**Developing[a]**	**Industrial[a]**	**Developing[a]**
ECOSYSTEM SERVICES								
Provisioning Services								
Sufficient access to food	↑	↑	↔	↓	↔	↓	↑	↑
Fuel	↑	↑	↑	↑	↑	↑	↑	↑
Genetic resources	↔	↔	↓	↓	↑	↑	↔	↑
Biochemicals/Pharmaceuticals discoveries	↓	↑	↓	↓	↔	↔	↑	↑
Ornamental resources	↔	↔	↔	↓	↑	↑	↔	↔
Freshwater	↑	↑	↔	↓	↑	↓	↑	↔
Regulating Services								
Air quality regulation	↔	↔	↔	↓	↔	↔	↑	↑
Climate regulation	↔	↔	↓	↓	↔	↔	↑	↑
Water regulation	↔	↓	↓	↓	↑	↑	↔	↑
Erosion control	↔	↓	↓	↓	↑	↑	↔	↑
Water purification	↔	↓	↓	↓	↑	↑	↔	↑
Disease control: Human	↔	↑	↔	↓	↔	↑	↑	↑
Disease control: Pests	↔	↓	↓	↓	↑	↑	↔	↔
Pollination	↓	↓	↓	↓	↔	↔	↓	↓
Storm protection	↔	↓	↔	↓	↑	↑	↑	↔
Cultural Services								
Spiritual/religious values	↔	↔	↔	↓	↑	↑	↓	↓
Aesthetic values	↔	↔	↔	↓	↑	↑	↔	↔
Recreation and ecotourism	↓	↑	↓	↑	↓	↓	↑	↑
Cultural diversity	↓	↓	↓	↓	↑	↑	↓	↓
Knowledge systems (diversity and memory)	↔	↓	↓	↓	↑	↑	↔	↔
HUMAN WELL-BEING								
Material well-being	↑	↑	↑	↓	↔	↑	↑	↑
Health	↑	↑	↑	↓	↑	↑	↑	↑
Security	↑	↑	↓	↓	↑	↑	↑	↑
Social Relations	↔	↑	↓	↑	↑	↑	↓	↓
Freedom and Choice	↔	↑	↓	↓	↑	↑	↑	↑

[a] "Industrial " and "developing " refer to the countries at the beginning of the scenario; some countries may change categories by 2050.

Key: ↑ = increase in ecosystems' ability to provide the service, ↔ = ability of ecosystem to provide the service remains the same as in 2000, ↓ = decrease in ecosystems' ability to provide the service

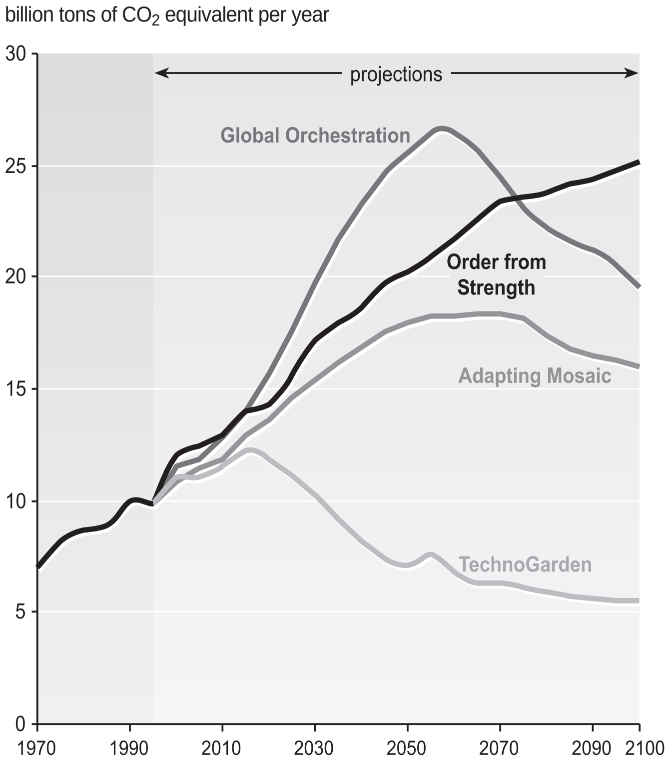


Figure S4. Total Greenhouse Gas Emissions in CO_2 Equivalents per Year versus Time in the MA Scenarios (equivalent emissions based on 100-year GWPs) [9]

or impacts of large, extremely costly, or irreversible changes in ecosystem services. We addressed these phenomena qualitatively by considering the risks and impacts of large but unpredictable ecosystem changes in each scenario. Some ecosystem services and aspects of human well-being could not be quantified and could be assessed only qualitatively. [4]

The Future of Ecosystem Services

The capacity of ecosystems to provide services in the future is jeopardized by rates of use that exceed rates of renewal and by degradation of regulating ecosystem services.

Although the current flow of many ecosystem services to people has increased, the status of many ecosystems, including stocks of provisioning ecosystem services, has shifted to degraded conditions (*well established).* These include losses in marine fish stocks and dryland agriculture; emergence of diseases that threaten plants, animals, and humans; deterioration of water quality in fresh waters and coastal oceans; and regional climate changes and increased climate variability. Such shifts are likely to increase in the future (*established but incomplete*). The impact of unexpected ecosystem changes depends on the intensity of stress on ecosystems as well as societal expectations about reliability of ecosystem services and the capacity of societies to cope with changes in the provision of ecosystem services. [8, 9, 13]

For some components of the future state of human-ecosystem interactions, all four scenarios make similar projections:

- Demand for provisioning services, such as food, fiber, and water, increases due to growth in population and economies (*high certainty*).
- Food security remains out of reach for many people, and child malnutrition will be difficult to eradicate even by 2050 (*low to medium certainty*), despite increasing food supply under all four scenarios (*medium to high certainty*) and more diversified diets in poor countries (*low to medium certainty*). (See Figure S5.)
- Vast changes with great geographic variability occur in freshwater resources and their provisioning of ecosystem services in all scenarios. (See Figure S6.) Climate change will lead to increased precipitation over more than half of Earth's surface and this will make more water available to society and ecosystems (*medium certainty*). However, increased precipitation is also likely to increase the frequency of flooding in many areas (*high certainty*). Increases in precipitation will not be universal, and climate change will also cause a substantial decrease in precipitation in some areas, with an accompanying decrease in water availability (*medium certainty*). These areas could include highly populated arid regions such as the Middle East and Southern Europe (*low to medium certainty*). While water withdrawals decrease in most industrial countries, water withdrawals and wastewater discharges are expected to increase enormously in Africa and some other developing regions, and this will intensify their water stress and overshadow the possible benefits of increased water availability (*medium certainty*).
- The services provided by freshwater resources (such as aquatic habitat, fish production, and water supply for households, industry, and agriculture) deteriorate severely in developing countries under the scenarios that are reactive to environmental problems. Less severe but still important declines are expected in the scenarios that are more proactive about environmental problems (*medium certainty*).
- Growing demand for fish and fish products leads to an increasing risk of a major and long-lasting decline of

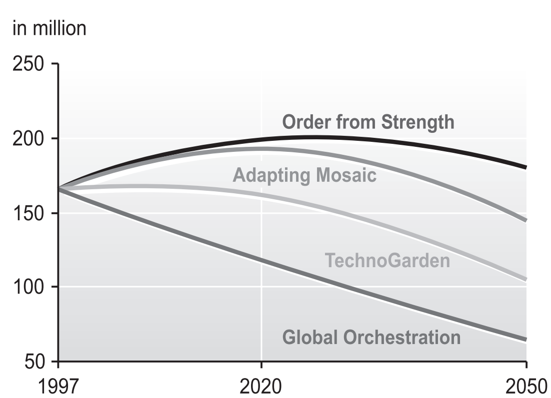


Figure S5. Number of Malnourished Children in Developing Countries over Time in MA Scenarios [9]

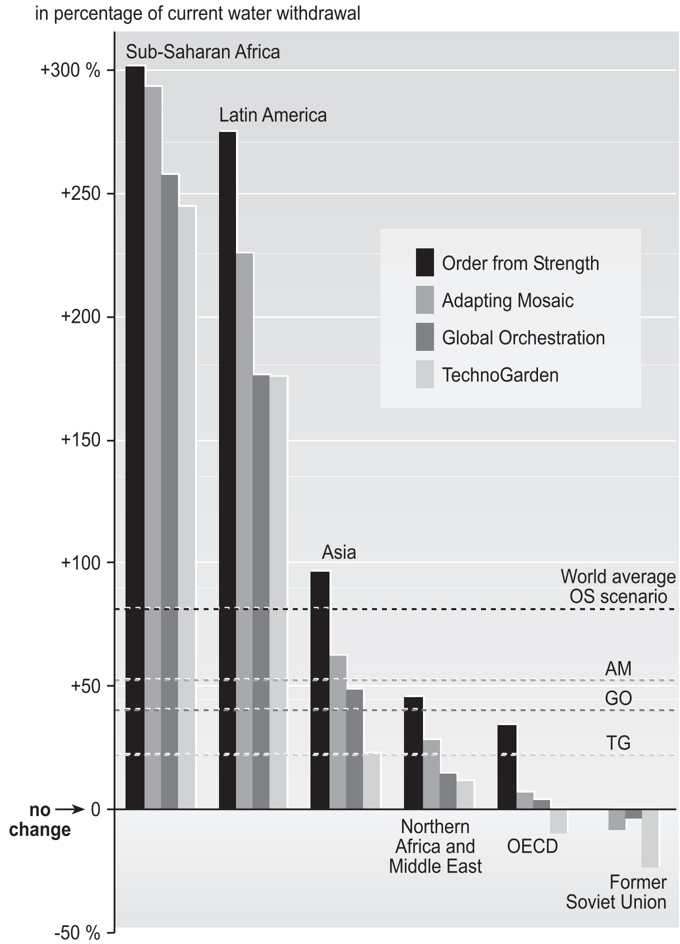


Figure S6. Change in Water Withdrawals from 2000 to 2050 in MA Scenarios, Globally and for Six Groups of Nations [9]

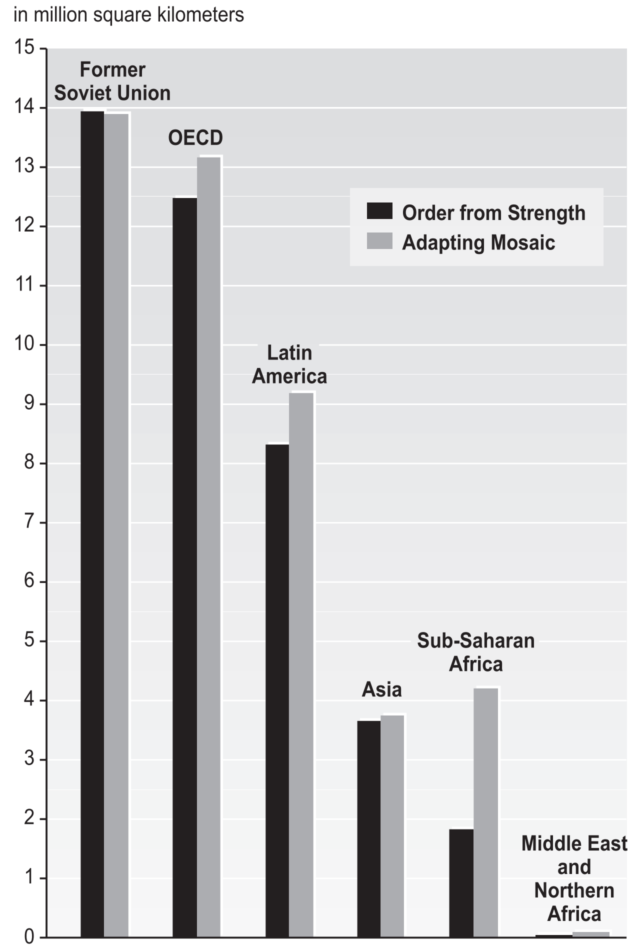


Figure S7. Forest Area in 2050 in Adapting Mosaic and Order from Strength Scenarios in Six Groups of Nations. Forest area is the net result of losses of pre-existing forest and establishment of new forest on land that was formerly used for something else [9]

regional marine fisheries (*medium to high certainty*). Aquaculture cannot relieve this pressure so long as it continues to rely heavily on marine fish as a food source.

Land use change is expected to continue to be a major driver of changes in the provision of ecosystem services up to 2050 (*medium to high certainty*) [9]. The scenarios indicate (*low to medium certainty*) that 10–20% of current grassland and forestland will be lost between now and 2050. This change occurs primarily in low-income and arid regions. (See Figure S7.) The provisioning services associated with affected biomes (such as genetic resources, wood production, and habitat for terrestrial biota) will also be reduced. The degree to which natural land is lost differs among the scenarios. Order from Strength has the greatest land use changes, with large increases in both crop and grazing areas. The two proactive scenarios, 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 faced with increasing risk in some areas due to reduced runoff or intensified land use in all scenarios.

Threats to drylands are multiscale—ranging from global climate change to local pastoral practices. In addition, dryland ecosystem services are particularly vulnerable to substantial and persistent reductions in ecosystem services driven by climate change, water stress, and intensive use. For example, sub-Saharan Africa is projected to expand water withdrawals rapidly to meet needs for development. Under some scenarios, this causes a rapid increase in untreated return flows to freshwater systems, which could endanger public health and aquatic ecosystems (*medium certainty*). Expansion and intensification of agriculture in this area may lead to loss of natural ecosystems and higher levels of surface and groundwater contamination. Loss of ecosystem services related to these changes could undermine the future provision of ecosystem services in this region, eventually leading to increased poverty. **Global institutions to address dryland problems (such as desertification) need to consider responses at multiple scales, such as mitigation of climate change, technological development, and trade and resource transfers that foster local adaptation.** [14]

In our scenarios, continued population growth, improving economic conditions, and climate change over the next decades exert additional pressure on land resources and pose additional risk of desertification in dryland regions. **Subsi-**

dizing food production and water development in vulnerable drylands can have the unintended effect of increasing the risk of even larger breakdowns of ecosystem services in future years. Local adaptation and conservation practices can mitigate some losses of dryland ecosystem services, although it will be difficult to reverse trends toward loss of food production capacity, water supplies, and biodiversity in drylands. [14]

Threats of wetland drainage and conversion, with adverse impacts on capacity of ecosystems to provide adequate supplies of clean water, increased in all scenarios. Reductions in trade that accompany greater regionalization can increase pressure on agricultural land and water withdrawals. To some extent, these adverse effects can be mitigated by economic growth, technology, or regional adaptive management. However, economic growth without proactive ecosystem management can increase the risk of large disturbances of water supplies, water quality, and other aquatic resources such as fish and wildlife. [14]

Terrestrial ecosystems are currently a net sink of CO_2 at a rate of 1.2 (+/− 0.9) gigatons of carbon per year (*high certainty*). They thereby contribute to the regulation of climate. But the scenarios indicate that the future of this service is uncertain. Deforestation is expected to reduce the carbon sink. Proactive environmental policies can maintain a larger terrestrial carbon sink. [9]

The Future of Biodiversity

Present goals for reduced rates of biodiversity loss will be difficult to achieve because of changes in land use that have already occurred and ongoing stresses from climate change and nutrient enrichment.

Ecosystem management practices that maintain response diversity, functional groups, and trophic levels while mitigating chronic stress are more likely to increase the supply of ecosystem services and decrease the risk of large losses of ecosystem services than practices that ignore these factors.

The scenarios indicate that present goals for reduced rates of biodiversity loss, such as the 2010 targets of the Convention of Biological Diversity, will be difficult to achieve because of changes in land use that have already occurred, ongoing stresses from climate change, and nutrient enrichment. In all scenarios, projections indicate significant negative impacts on biodiversity and its related ecosystem services. However, these scenarios were not designed to optimize the path for preserving biodiversity. Negative impacts on biodiversity can be reduced by proactive steps to, for example, decrease the rate of land conversion, integrate conservation practices with landscape planning, restore ecosystems, and mitigate emissions of nutrients and greenhouse gasses. It is important to note that decreasing rates of land conversion may impair our ability to meet increased demands for food or other ecosystem services. [10, 14]

Significant decline of ecosystem services can occur from species loss even if species do not become globally extinct. Some terrestrial ecosystem services will be lost (*very certain*) as local native populations are extirpated (become locally extinct). Examples include loss of cultural services when a culturally important forest species is extirpated, loss of supporting services when pollinator species are extirpated, and loss of provisioning services when an important medicinal plant becomes locally extinct. [10]

Production and resilience of ecosystems are often enhanced by genetic and species diversity as well as by spatial patterns of landscapes and temporal cycles (such as successional cycles) with which species evolved. Within ecosystems, species and groups of species perform functions that contribute to ecosystem processes and services in different ways. Diversity among functional groups increases the flux of ecosystem processes and services (*established but incomplete*). For example, plant species that root at different depths, that grow or flower at different times of the year, and that differ in seed dispersal and dormancy act together to increase ecosystem productivity.

Within functional groups, species respond differently to environmental fluctuations. This response diversity derives from variation in the response of species to environmental drivers, heterogeneity in species distributions, differences in ways that species use seasonal cycles or disturbance patterns, or other mechanisms. Response diversity increases the chance that ecosystems will contain species or functional groups that become important for maintaining ecosystem processes and services in future changed environments (*medium certainty*). **Ecosystem management practices that maintain response diversity, functional groups, and trophic levels while mitigating chronic stress will increase the supply and resilience of ecosystem services and decrease the risk of large losses of ecosystem services** (*established but incomplete*). [5]

Habitat loss in terrestrial environments is projected to lead to decline in local diversity of native species in all four scenarios by 2050 (*high certainty*). (See Figure S8.) Loss of habitat results in the immediate extirpation of local populations and the loss of the services that these populations provided. [10]

Decreases in river flows from water withdrawals and climate change (decreases occur in 30% of all major river basins) are projected to result in loss of species under all scenarios (*low certainty*). Rivers that are forecast to lose 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. The current average GDP in countries with diminishing river flows is about 20% lower than in countries whose rivers are not drying. [10]

Habitat loss will eventually lead to global extinctions as species approach equilibrium with the remnant habitat. Although there is *high certainty* that this will happen eventually, the time to equilibrium is *very uncertain*, especially given continued habitat loss through time. Between 10% and 15% of vascular plant species present in 1970 were lost across the four scenarios when species numbers reached equilibrium with reduced habitat (*low certainty*). This may be an under-

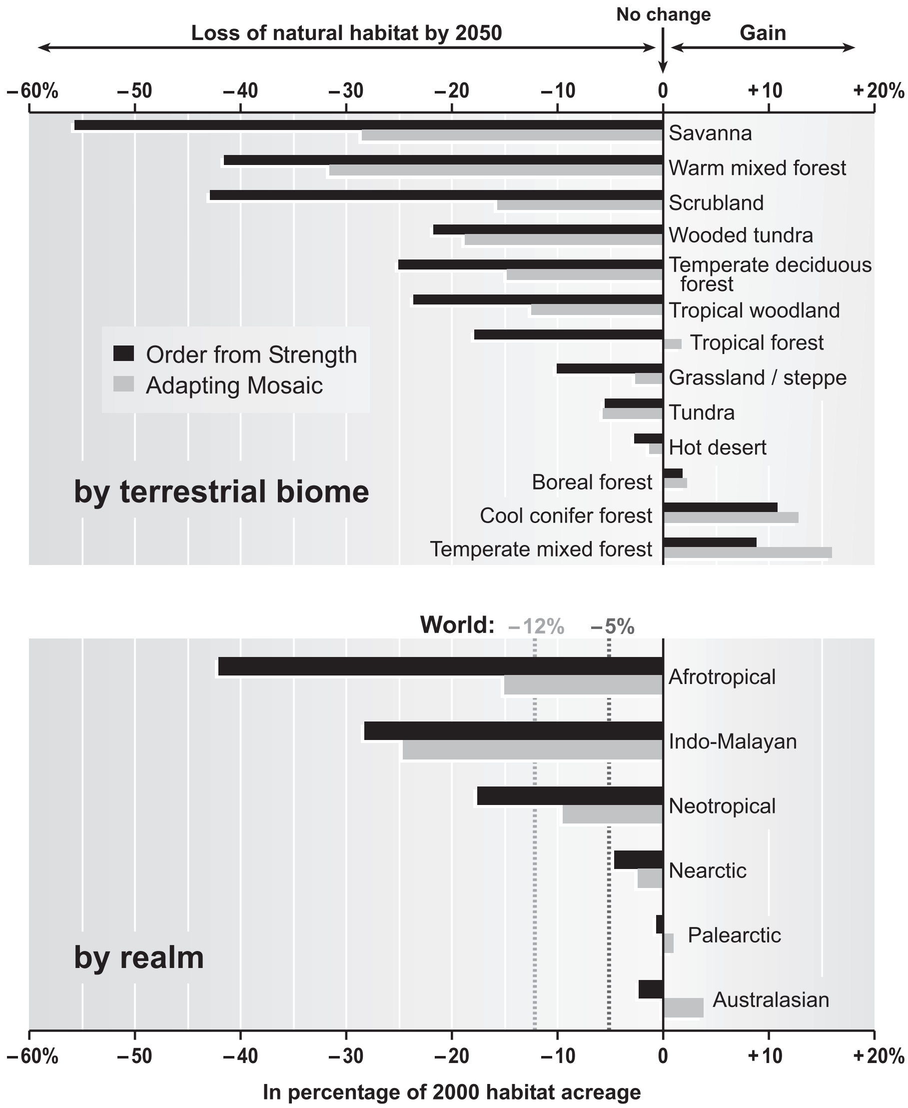


Figure S8. Loss or Gain of Natural Habitat from 1970 to 2050 in Adapting Mosaic and Order from Strength Scenarios. Habitat changes are indicated by biome and by biogeographic realm. [9, 10]

estimate because it addresses only those changes due to habitat loss and does not consider the effects of other stressors such as climate change or nutrient deposition. Time lags between habitat reduction and extinction provide a precious opportunity for humans to rescue those species that otherwise may be on a trajectory toward extinction. [10]

Trade-offs among Ecosystem Services

Increasing the flow of provisioning services often leads to reductions in supporting, regulating, and cultural ecosystem services. This may reduce the future capacity of ecosystems to provide services.

Building understanding about how ecosystems provide services will increase society's capacity to avert large disturbances of those services or to adapt to them rapidly when they do occur.

Trade-offs exist in all of the MA scenarios between food and water and between food and biodiversity. Each scenario takes a slightly different approach to addressing these trade-offs. By comparing these approaches and their outcomes, we can learn about managing trade-offs. [12]

- **In all four MA scenarios, application of fertilizers, including manure, in excess of crop needs caused large nutrient flows into fresh waters and estuaries** (*high certainty*). (See Figure S9.) This overenrichment of water causes serious declines in ecosystem services (food, recreation, fresh water, and biodiversity) provided by aquatic ecosystems. There are possibilities for mitigating these trade-offs through technological enhancements such as agricultural efficiency (in the use of land, water, and fertilizers) and through productivity-enhancing, resource-conserving technologies, which combine natural capital conservation with yield improvement techniques.
- **In all four MA scenarios, conversion of land to agricultural uses for food production reduced biodiversity.** Clearing diverse land cover for crop production reduces biodiversity by eliminating local populations.

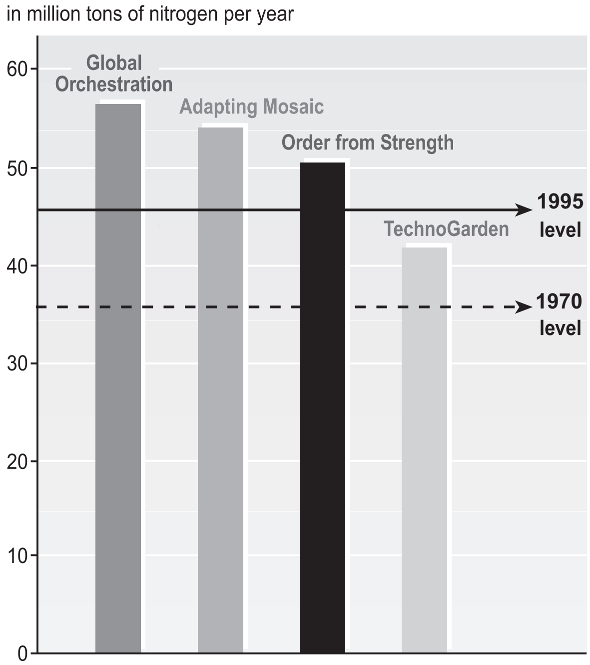


Figure S9. Global River Nitrogen Export in 2030 in MA Scenarios. Reference lines show global river nitrogen export in 1970 and 1995.

Removing water from lakes and rivers for use can reduce aquatic biodiversity because less aquatic habitat is available. There are possibilities for mitigating these trade-offs through agricultural land management that explicitly maintains biodiversity or through more efficient use of water.

- **In all four MA scenarios, use of water for irrigation of crops reduced the availability of water for other uses, such as household or industrial use or the maintenance of other ecosystem services.** Although water is a renewable resource, the amount available in any one place at any one time is finite. Thus, excessive use of water for irrigation can restrict the amount of water for other important uses.

All scenarios show the general tendency of management to focus intensely on increasing the availability of provisioning services, which often leads to reductions in the provision of supporting, regulating, and cultural ecosystem services. (See Figure S10.) Efforts to increase the short-term provision of services typically reduce the capacity of ecosystems to provide the full array of services in the future. This vulnerability can be difficult to detect because ecosystems often exhibit threshold behavior that can mask declines in regulating and supporting services until a collapse occurs. Such trade-offs have far-reaching consequences for maintaining ecosystem functioning in the long term. For example, decisions about fertilizer use in the 1960s are still affecting water quality in the twenty-first century.

Scenarios in which long-term consequences of trade-offs are not taken into consideration exhibit the largest risk of declines in supporting and regulating services (such as climate change and biodiversity loss). Scenarios with a proactive approach to ecosystem management via flexible ecosystem governance mechanisms and learning or technological innovations are more likely to sustain ecosystem services in the future. [12]

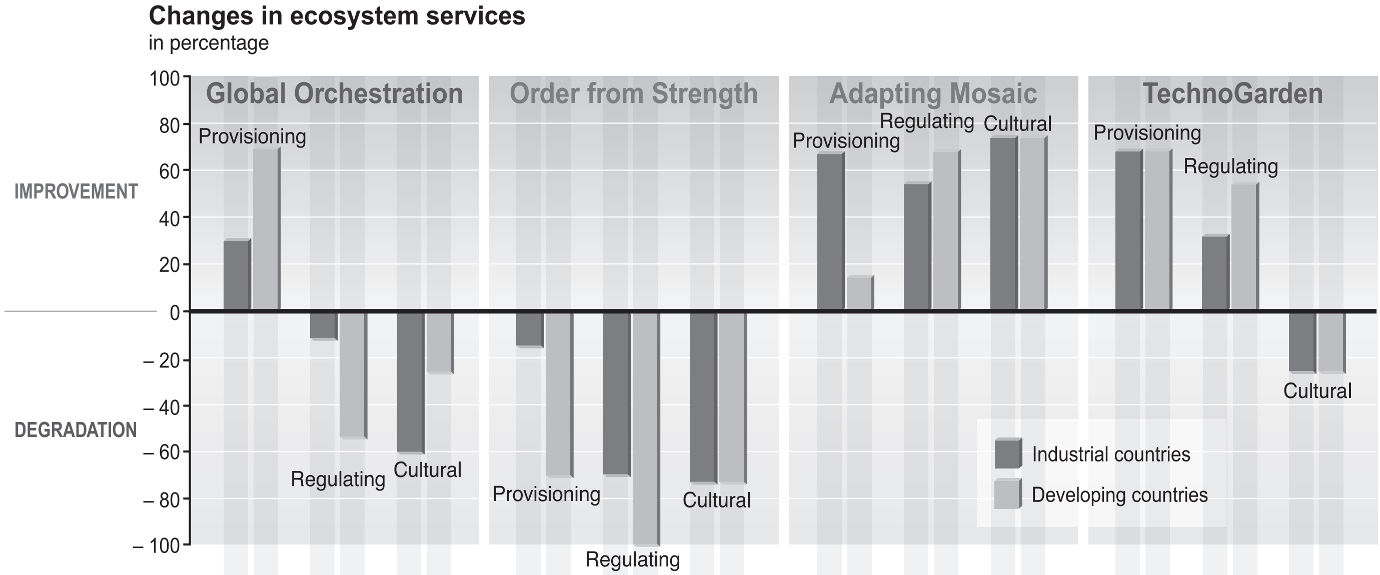
At every scale, there are opportunities for combining advantageous approaches to achieve synergistic benefits. For example, actions to preserve marine fish species have been shown to make coral reefs more resistant to the pressures associated with declines in other species or excess nutrients. Actions to preserve local fisheries have been shown to have positive benefits on human well-being through enhancing social interactions and networking among fishers in the region. Advantages can be found by combining techniques from each of the scenarios. For example, combining the advantages of green technology (TechnoGarden) with fairer markets (Global Orchestration) and flexible ecosystem management that encourages local creativity (Adapting Mosaic) may lead to improvements in ecosystem services and human well-being beyond those found in any individual scenario. [12]

In the scenarios in which monitoring was a focus, societies built an understanding of large changes in ecosystem services that increased their capacity to anticipate and avert large disturbances of ecosystem services or to adapt to them more rapidly if they did occur. In the scenarios in which monitoring was not done and policies that anticipate the possibility of large breakdowns in ecosystem services were not implemented (Global Orchestration and Order from Strength), societies faced increased risk of large impacts from unexpected disruptions of ecosystem services. The greatest risks of large, unfavorable ecological changes arise in dryland agriculture, marine fisheries, quality of fresh and coastal marine waters, disease emergence, and regional climate change. [8, 12, 14]

The Future of Human Well-being

Attempts to improve human well-being that do not actively take ecosystems into account can cause unintended but rapid, severe, and persistent degradation of ecosystem services.

Most of the 2015 targets established for the Millennium Development Goals were not achieved in the MA scenarios. The scenarios also indicate that some strategies for achieving goals such as poverty reduction and hunger reduction quickly could increase pressures on ecosystems, thereby compromising the ability to continue progress toward these goals in the future and undermining progress toward the MDG of environmental sustainability. Although the MA scenarios were not designed to chart an optimal path to meeting the MDGs, they provide useful information about plausible paths. Attempts to meet the MDGs by 2015, which will largely involve increased use of provisioning ecosystem services, may lead to ecosystem degradation and reductions in regulating and supporting services that undermine future ecosystem capacity to supply provisioning services. This



Number of services																								
Enhanced	3	4	0	1	0	1	1	1	0	0	0	1	4	3	5	6	4	4	4	4	4	6	1	1
No change	2	2	8	2	3	2	3	0	3	0	2	0	2	1	4	3	0	0	2	2	4	2	2	2
Degraded	1	0	1	6	2	2	2	5	6	9	3	4	0	2	0	0	1	1	0	0	1	1	2	2

Figure S10. Net Changes in Availability of Provisioning, Regulating, and Cultural Ecosystem Services by 2050 in MA Scenarios for Industrial and Developing Countries. The y-axis is the net percentage of ecosystem services enhanced or degraded. For example, 100% degradation of the six provisioning ecosystem services would mean that all of these were degraded in 2050 relative to 2000, while 50% enhancement could mean that three were enhanced and the other three were unchanged, or that four were enhanced, one was degraded, and the other two were unchanged. The data used to calculate the y-axis are presented beneath the figure.

degradation may increase the risk of regime shifts and other surprises that seriously undermine human well-being. [14]

Ecosystem services are essential for human well-being. However, the relationship between human well-being and ecosystem services is discontinuous. Above some threshold, a marginal increase in ecosystem services contributes only slightly to human well-being, but below that threshold, a small decrease in ecosystem services can substantially reduce it. [11]

Across the dimensions of human well-being, each scenario yields a different package of gains, losses, and vulnerabilities for different regions and populations. (See Figure S11.) In our scenarios, actions that focused on improving the lives of the poor by reducing barriers to international flows of goods, services, and capital tended to lead to the most improvement for those who are currently the most disadvantaged. Health and social relations improve, but human vulnerability to ecological surprises is high.

Globally integrated approaches that focused on technology and property rights for ecosystem services generally improved human well-being in terms of health, security, social relations, and material needs. When those same technologies were used globally, however, local culture was lost or undervalued. High levels of trade lead to more rapid spread of emergent diseases, somewhat reducing the gains in health in all areas. Locally focused, learning-based approaches led to the largest improvements in social relations, but with variability by region. Order from Strength, which focuses on reactive policies in a regionalized world, has the least favorable outcomes for human well-being, as the global distribution of ecosystem services and human resources that underpin human well-being are increasingly skewed. [11]

Toward Future Assessments of Ecosystem Services

The future capacity of ecosystems to provide services is often determined by feedbacks at multiple scales. Future projects on ecosystem service scenarios should explicitly nest or link assessments at several scales from the beginning.

Active adaptive ecosystem management (experimentation with monitoring and analysis to learn more-sustainable management methods) could greatly improve outcomes for ecosystem services and human well-being.

In considering multiple aspects of ecosystem services and feedbacks with human well-being, this assessment is the first of its kind. Lessons learned from the MA suggest many opportunities to improve the development of ecosystem service scenarios in the future.

The future capacity of ecosystems to provide services is often determined by feedbacks at multiple scales. Future projects on ecosystem service scenarios should explicitly nest or link assessments at several scales from the beginning. This innovation would pro-

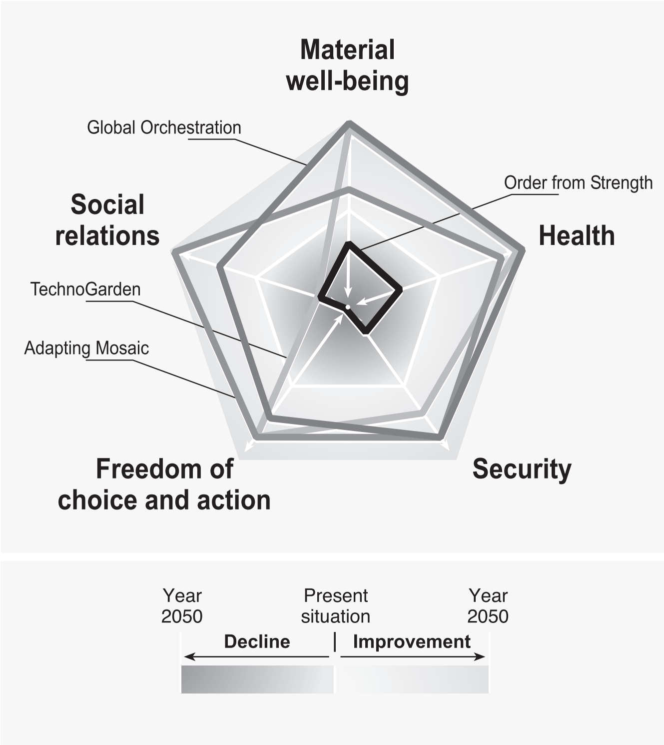


Figure S11. Changes in Components of Human Well-being in 2050 in MA Scenarios. The pentagon in the middle represents the situation in 2000. Moving outward from that indicates an improvement in that component of human well-being in that scenario by the year 2050. Moving inward from the pentagon indicates a decline in that aspect of human well-being since 2000.

vide decision-makers with information that links local, national, regional, and global futures of ecosystem services directly. In addition, future projects should allow more time for iterations between qualitative and quantitative assessments of the storylines. This additional work would improve the harmonization of qualitative and quantitative assessments and allow for a more diverse set of simulations to address risks and regime shifts. [4, 6, 13]

Active adaptive ecosystem management (experimentation with monitoring and analysis to learn more-sustainable management methods) could greatly improve outcomes for ecosystem services and human well-being. Existing assessment models for most ecosystem services do not account for effects of active adaptive management at local to regional scales. Thus most of our projections of ecosystem services represent outcomes in the *absence* of local-to-regional adaptive change. Actively adaptive management could significantly improve the outcomes relative to the projections presented here. (See the MA *Policy Responses* volume.) [4, 5, 13]

There are important gaps between the processes depicted in the MA conceptual framework and the existing capacity of ecosystem modeling. Major elements of the conceptual framework that are not well addressed by models include the effects of changes in ecosystems on flows of ecosystem services and the effects of changes in ecosystem services on changes in human well-being. In addition, existing models focus mainly on a subset of provisioning and regulating ecosystem services, largely neglecting cultural and supporting ecosystem services. Cultural ecosystem services, together with the other ecosystem services, play a critical role in adaptive responses and changes in human attitudes and behaviors toward nature. [4, 13]

The underlying chapters in this volume list many specific needs for improved models. Models are needed to address thresholds and the risk of large, costly, or irreversible changes in ecosystem services. There is emerging understanding that the diversity of species response and the heterogeneity of landscapes affect the resilience of ecosystem services. This important feedback needs to be incorporated in ecosystem service models. [4, 5, 9, 10, 13]

Future projects on ecosystem service scenarios should allow more time for assessing decision-maker needs at the outset of the project and should include decision-makers in the scenarios development team. Differences among disciplines in core beliefs about functioning of the global system are a crucial uncertainty that is addressed in the scenarios. Better interdisciplinary communication would make it easier to understand and assimilate these differences in future scenario exercises. Finally, communication of scenarios requires development of synthetic graphics, nontechnical narratives, and nontechnical illustrations. Future projects on ecosystem service scenarios should allocate more time for creation of these important communication and outreach products. [13]

Synthesis

Future conditions of ecosystem services could be worse or better than in the present, depending on policy choices.

None of the MA scenarios represents an optimal outcome. A selected mix of policies from several scenarios may yield better outcomes than any single scenario.

The Millennium Ecosystem Assessment scenarios show that the condition of ecosystem services in the future could be significantly worse or better than in the present. Scenarios that improve the condition of ecosystem services and human well-being involve substantial changes in policy. Examples include:

- major investments in public goods and poverty reduction, together with elimination of harmful trade barriers and subsidies (Global Orchestration);
- widespread use of actively adaptive ecosystem management and investment in education (Adapting Mosaic); and
- significant investments in technologies to use ecosystem services more efficiently, along with widespread inclusion of ecosystem services in markets (TechnoGarden).

Although examples of all these policies are known from the world of today, such policies are not widespread at the present time.

The MA scenarios were not designed to determine optimal policies for any specific locale, nation, international bloc, or Earth as a whole. Different combinations of policies may produce significantly better results than any of the scenarios presented here. Successful hybrid policies may capitalize on the advantages of several scenarios while avoiding the risks. For example, combining the local-learning approach of Adapting Mosaic with the global coordination and technological advances of TechnoGarden may capitalize on the benefits of both scenarios while avoiding the loss of cultural services found in TechnoGarden and the global commons problems found in Adapting Mosaic.

Part I

State of Knowledge Concerning Ecosystem Forecasts and Scenarios