Chapter 5

# Scenarios for Ecosystem Services: Rationale and Overview

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## Main Messages

**The Millennium Ecosystem Assessment scenarios address plausible future changes in ecosystems, in the supply of and demand for ecosystem services, and in the consequent changes in human well-being.**

**A survey of user needs and a set of interviews with decision-makers and other leaders identified a set of key concerns to be addressed by the MA scenarios. These concerns included globalization, leadership, poverty and inequality, technology, local flexibility, and surprises. Uncertainties about these factors have large implications for future ecosystem services.** The uncertainties are related to ecosystem management dilemmas—situations in which significant risks are associated with each possible decision. Two dilemmas identified by respondents were: What degree of ecological complexity is needed to provide reliable ecological services? And to what degree can people use technology to substitute for the role of relatively undisturbed ecosystems in the provision of services? Exploring the consequences of different outcomes for the key concerns and different decisions made about the dilemmas form the underlying basis for the differences in the four scenarios.

**The MA scenarios were designed to explore a wide range of contexts under which sustainable development will be pursued, as well as a wide range of approaches to sustainable development. With respect to context, we explore two basic futures—one that becomes increasingly globalized and one that becomes increasingly regionalized. In terms of approaches, we focus on futures that emphasize economic growth and promotion of public goods and futures that emphasize proactive management of ecosystems and their services.** Framed in terms of contexts and approaches, the scenarios are:

- Global Orchestration (globalized, with emphasis on economic growth and public goods),
- Order from Strength (regionalized, with emphasis on national security and economic growth),
- Adapting Mosaic (regionalized, with emphasis on local adaptation and flexible governance), and
- TechnoGarden (globalized, with emphasis on green technology).

The focus on alternative approaches to sustaining ecosystem services distinguishes the MA scenarios from previous global scenario exercises. For each of the four scenarios, we analyzed a set of plausible socioeconomic changes consistent with the contrasting approaches to ecosystem management.

**The purpose of the scenarios is to explore the consequences of the four futures for ecosystem services and human well-being.** The four futures that we examine were developed based on interviews with leaders in nongovernmental organizations, governments, and business from five continents, on the literature, and on policy documents addressing linkages between ecosystem change and human well-being. No scenario will match the future as it actually occurs. No scenario represents business as usual, though all are based on current conditions and trends. None of the scenarios represents a "best" path or a "worst" path. There could be combinations of policies and practices that produce significantly better, or worse, outcomes than any of the scenarios. The future will represent a mix of approaches and consequences described in the scenarios, as well as events and innovations that were not imagined at the time of writing. The scenarios explore a wide variety of choices and their consequences.

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

**The Order from Strength scenario examines the outcomes of a world in which protection through boundaries becomes paramount.** The policies enacted in this scenario lead to a world in which the rich protect their borders, attempting to confine poverty, conflict, environmental degradation, and deterioration of ecosystem services to areas outside those borders. Poverty, conflict, and environmental problems often cross the borders, however, impinging on the well-being of those within. Protected natural areas are not sufficient for nature preservation or the maintenance of ecosystem services.

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

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

**Different modes of governance and management of ecosystem services have complementary advantages and disadvantages:**

- Economic growth and expansion of public goods (such as education and accessible technologies) enables society to respond effectively when environmental problems emerge. However, if the focus on public goods overwhelms attention to the environment and proactive environmental policies are not pursued, there is increased risk of regional interruptions in provision of ecosystem services.

- A focus on strong national security creates some opportunities for ecosystem preserves, but if this is not coupled with active ecosystem management outside the reserves, then pressure on the environment increases and there is greater risk of large disturbances of ecosystem services and vulnerability to interruptions in provision of ecosystem service.

- 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 these services. However, a regional focus diminishes attention to the global commons and exacerbates global environmental problems such as climate change and declining oceanic fisheries.

- Technological innovations and ecosystem engineering, coupled with economic incentive measures to facilitate their uptake, lead to highly efficient provision of ecosystem services. However, novel technologies can create novel environmental problems, and in some cases the resulting disruptions of ecosystem services affect large numbers of people.

**The scenarios differ in the frequency and magnitude of surprising changes in ecosystem services.** In Order from Strength, extreme disturbances of ecosystem services have a moderately wide range with a relatively high mode. Most of the human population is in relatively impoverished regions with deteriorating ecosystem services, and this situation is reflected in breakdowns that affect a relatively large number of people. Global Orchestration has a comparable range but a lower mode. Some severe breakdowns of ecosystem services still occur, but these tend to affect fewer people than in Order from Strength. In Adapting Mosaic, the distribution of extreme events is bimodal. The bimodality results from local vulnerability in some regions, underlying events that affect smaller numbers of people, and from diminished attention to the global commons, which underlies some events that affect large numbers of people. TechnoGarden leads to the widest distribution of large-scale breakdown event magnitudes. The mode is moderate, but the range is wide and some breakdowns affect large numbers of people.

**The future of ecosystem services will likely have elements of each of the four scenarios.** Changes in global trends could cause any of the scenarios to branch into one of the other ones.

## 5.1. Introduction

An infinite number of imaginable futures might be explored with the Millennium Ecosystem Assessment scenarios. However, scenarios are most powerful when presented as a small set with clear and striking differences (Van der Heijden 1996). Thus, the Scenarios Working Group had to decide how to compress an infinity of dimensions into a few comprehensible ones. In this chapter, we explain why we chose the four storylines that we develop, describe the key differences among them, and provide a brief sketch of each scenario. We summarize the potential benefits and inadvertent negative consequences of each scenario and describe how each scenario could potentially branch into one of the others. This chapter sets the stage for more detailed presentation of the scenarios in Chapter 8. While the scenarios are both qualitative and quantitative, in this chapter we focus on the qualitative. The quantitative material can be found primarily in Chapter 9.

## 5.2. Why Think about the Future of Ecosystem Services?

In order to make sound choices, people need to understand what the consequences of their actions, or inaction, will be. We have means of estimating how ecosystems and their services may change in coming decades given specific changes in driving forces such as population, economic growth, trade policies, resource management policies, and so forth, but the potential outcomes are both complex and variable. How can a decision-maker weigh different policy options in the face of such complexity and uncertainty?

The MA scenarios are designed to highlight key comparisons among approaches to development and to inform decision-makers about the consequences for ecosystem services of contrasting development paths. The central idea behind scenarios is to examine multiple possible futures and to let differences between them illuminate cause and effect and probable outcomes of certain approaches or decisions. While predictions and forecasts, more common approaches in ecology, focus on the single best or optimal approach, scenarios explicitly consider uncertainties and unknowns.

## 5.3. What Issues Should the Scenarios Address?

The goal of the MA scenarios is to inform diverse decision-makers about the potential futures of ecosystems and ecosystem services and how decisions can affect them. For this purpose, the scenarios needed to address the concerns of decision-makers and represent key aspects of the ecosystem dynamics behind those concerns. To identify focal issues for the MA scenarios, we used interviews with individual decision-makers and leading environmental thinkers, a survey of the needs of the MA's designated user community, and expert understanding of global ecosystem services and their connections to human well-being. Here, we present findings of each of these efforts and explain how they are represented in our four scenarios.

### 5.3.1 User Needs

Scientific assessments are most helpful to decision-makers when the intended users are active stakeholders in the assessment process and, in particular, when the users directly help shape the questions that the assessment will answer. An extensive effort was made to identify the needs of various MA audiences for information from the assessment and to engage those audiences in the governance and design of the MA process. This effort included directly asking various users what questions they wanted the MA to address. Users who responded included representatives from the Convention on Biological Diversity, the Convention to Combat Desertification, Ramsar, and other national government representatives; individuals from the private sector; and members of international nongovernmental organizations, civil society, and indigenous groups. This effort led to a greater understanding of what the active stakeholders hoped to gain from the MA scenarios.

Core questions for scenarios were derived from the user needs identified through these questions:

- What are the **plausible future changes in ecosystems** and in the supply of and demand for ecosystem services and the consequent changes in the constituents of well-being?
- What are the **costs, benefits, and risks** of plausible future changes in ecosystems and how will these costs, benefits, and risks affect different sectors of society and different regions of the world?
- What are the **inadvertent negative consequences** associated with various futures?
- What response options can lessen the **vulnerability** of people/communities?
- Under what circumstances are **thresholds, regime shifts, or irreversible changes** likely to occur?

There were also questions about specific drivers and responses:

- What policies and actions concerning ecosystems can best contribute to **reducing poverty**?
- What will be the positive and negative consequences of a further increase in flows of **nitrogen and phosphorus** in the next several decades?
- What will be the consequence of **biodiversity** loss for ecosystem services and human well-being?
- What will be the impact of changes in **desertification** on provision of ecosystem services and how will this vary across regions? How will demand for ecosystem services increase or decrease the rate of desertification?
- What are the impacts of changes in **wetlands** on provision of ecosystem services? How will demand for ecosystem services increase or decrease the rate of loss of wetlands?

The scenarios address these core questions. They explore the potential futures of ecosystems and the services they provide, including the possible benefits and inadvertent consequences that could emerge in each future. Each scenario also considers vulnerability, resilience, and possibilities for thresholds and regime shifts in socioecological systems given the specific details of how the scenario unfolds.

### 5.3.2 Interviews

Insights from leaders helped focus the MA scenarios directly on the most pressing interests of decision-makers and other scenario users. In addition to the user needs survey described above, we interviewed 59 leaders in NGOs, governments, and business from five continents. (See Figure 5.1.) The leaders were chosen based on recommendations from the MA Board (who were themselves selected from MA users to guide the MA process). The selection process was not random, but it aimed for diversification. We intentionally chose leaders from many sectors and nations in order to gain access to a wide range of concerns and responses. While it would have been interesting to get a broader view by interviewing many additional people, including people who are not leaders, this was not possible due to time constraints.

Based on previous scenario work (Van der Heijden 1996), we designed open-ended, general questions that would elicit a wide range of conversations about issues that interviewees thought were critical determinants of the current and future states of the world. (See Box 5.1.) Interviewees received the questions by e-mail in advance of the interview. Most interviews were conducted by telephone and typically lasted about one hour. In some cases, respondents followed up the interview with further comments by e-mail. A few interviews were conducted entirely by e-mail. Further information about the interview process can be found in Chapter 6.

Most of the interviewees were concerned that ecosystems are changing for the worse, reducing the quality and quantity of many important ecosystem services. That is, the respondents were concerned about the sustainability of ecosystem services. The interviewees disagreed, however, about the main causes of ecosystem degradation. Poverty, inequality, overconsumption, and mismanagement were a few of the factors that interviewees listed as factors in ecosystem degradation. The MA scenarios should therefore elucidate the links between interviewee concerns about ecosystem services and the types of problems that may be caused by each of the key sources they mentioned.

There were also important differences in views about how to address the challenges of sustainable provision of ecosystem services. Generally, these unfold from a basic disagreement about whether the world is generally vulnerable and fragile or generally resilient and recoverable. While one respondent said, "What gives me the most hope for the future is the tremendous resilience that nature has demonstrated in responding to opportunities," another said, "The environment . . . is resilient at the moment, but we cannot treat it with impunity forever." Stances on the resilience or vulnerability of ecosystems were associated with beliefs about the effort that should be placed on environmental problems. Some felt it is imperative to make the environment the key focus of society immediately, while others felt that society should focus first on improving human well-being, with a hope that this would lead to environmental improvements. Useful scenarios will attempt to embrace such divergent views and provide a framework in which these viewpoints can be debated.

Interviewees also talked about the variables that will determine how the future unfolds. Many respondents cited the same variables, but there were diverse views about how those affect the future—even to the point of disagreeing over whether the outcomes would be positive or negative. The factors identified by many respondents were globalization or global connectedness, human values, inequality, leadership, urbanization, technology, and energy sources.

While some respondents said that increased global connectivity would increase communication, trade, and the range of opportunities available to people, other decision-makers expressed concerns about homogenization of Earth's biological and social systems due to globalization. While some respondents were excited about using technology to solve problems and enhance the provision of ecosystem services, others feared that technology might cause more problems than it would solve. Nearly all the decision-makers we interviewed mentioned concern about energy sources. There was consensus that the ways in which society obtains

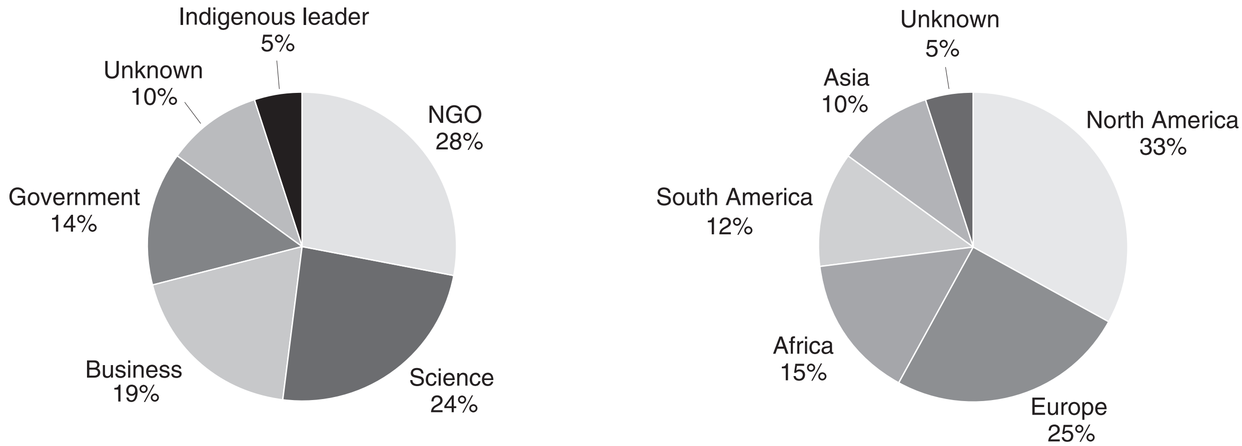


**Figure 5.1. Interviewees by Sector and by Region**

> BOX 5.1
> **Interview Questions**
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> What words would you use to describe the current state of the Earth's natural and human systems?
>
> What words would you use to describe the ideal state of the Earth's natural and human systems in 2050?
>
> What obstacles do you envision to achieving this ideal world?
>
> If you could talk to someone who visited the world in 2050, what would you need to know to understand what the world really looks like in 2050?
>
> Who or what will be most influential in determining the pathway of change into the future?
>
> What is the biggest change you expect between 2003 and 2050?
>
> What surprises might you envision between now and 2050?
>
> What gives you the most hope for the future?

and uses energy will affect the future. Of course, there was disagreement about the best sources of energy. Finally, human values, leadership, and inequality were all considered to be important drivers of the way the future would unfold. However, whether strong leaders and closed borders were better than free trade and cooperation was debated. Inequality was seen as an important driver of many of today's problems, but interviewees did not agree on whether inequality could or even should truly be reduced or on the best way to reduce inequality, nationally, or globally.

In general, interviewees agreed that the current situation could be improved, but there was little agreement on how to do it. There were diverse beliefs about how to put the world on a sustainable path. One interviewee said, ''We sorely need inspirational leaders. We don't know how to breed or train them. They appear to be almost accidental. But we sorely need them now.'' Another argued that mechanisms for rewarding people for ''good environmental living'' were the most critical need. There was great disagreement about the role of governments. One respondent said that ''governments and heads of state have proven themselves irrelevant,'' while the next said that ''governments must work together.'' (See Box 5.2.)

The scenarios should address the factors that the interviewees found to be important. The scenarios should also attempt to embrace the diversity of viewpoints held by the interviewees. By organizing diverse viewpoints in scenarios, we hope to facilitate debate and discussion. Clarification of terms is one way in which scenarios could facilitate discussion. In the interviews, it was often difficult to determine whether apparent disagreements were actual disagreements about the facts or simply misunderstandings derived from different interpretations of the same words. For example, interviewees disagreed about whether globalization was a positive or a negative factor. This disagreement could reflect different beliefs about the future, or it could reflect different definitions of globalization (for instance, globalization as trade dominated by policies that favor wealthy nations versus globalization with policies that open international markets for all nations versus globalization as something larger than just trade).

Interviewees agree that sustainable development is needed, but disagree about how best to achieve it. There are diverse views about which actions to take and about the sequences in which actions should be taken. The message for scenario building is clear. Useful scenarios will help decision-makers understand the possible and likely effects of key actions or paths that we might choose to take: fair global economic policies, use of technology to provide or improve provision of ecosystem services, the role of top-down control and leadership, the effects of multiscale decision-making and local flexibility, and the role of ecosystem dynamics in determining the end result of decisions. Useful scenarios will also embrace the diversity of views about the importance of these factors.

### 5.3.3 Ecological Management Dilemmas

Ecological dynamics underlie the concerns of decision-makers and MA users. These ecological dynamics influence the results of management actions, but important aspects of

**BOX 5.2**

**Selected Quotes from the Interviews**

**Sustainable development is needed, and managing ecosystem services and human well-being is a key aspect of that:**

"There is tangible evidence that natural systems are stressed to the limits of tolerance."

"Natural systems are fragile, threatened, degraded, and overburdened by human demand. At the same time, human systems are unequal in access to resources."

**Globalization is an important player, but there is disagreement about whether it is a major problem or a significant solution:**

"Governments and heads of state have proven themselves irrelevant when it comes to solving real problems. They are more successful when acting in their homes but not when coming together to face global issues."

"Governments must work together – we can't save half a planet."

**Considering poverty is important:**

"There is unequal distribution of resources, population, and trade, leading to a vicious circle of environmental degradation in the most vulnerable parts of the world, which will ultimately negatively impact the whole globe's security."

**Considering technology is important:**

"We might also see some astonishing technological breakthroughs involving biotechnology, not just in genetically modified organisms but also in fields such as organic computers that may be self-reproducing."

**On the importance of local and regional flexibility:**

"The ideal state of the world is when there is respect for the ecosystem and living within its limitations avoiding experimentation with changing it, where everyone has enough to cover the basic needs of water, food, and shelter and conserve the natural resources, where everyone tries to live with the seasonal changes without the need to modify the surroundings (e.g., temperature and humidity) artificially within the limits of our body adaptability (which we should use to its maximum capacity)."

"Business leaders understand that surprise is the rule and flexibility is key to surviving the surprises."

**On the importance of surprises:**

"The next 50 years will tell us whether that self-proclaimed marvel of evolution, the human mind, can surprise us even as we are surprised by chaotic events."

the dynamics are unknown and uncontrollable. Thus, far-reaching ecosystem management decisions are often made in situations where the ecological responses are unknown. (See Box 5.3.) In these cases, all options appear to have potentially severe negative outcomes, and the outcomes are highly ambiguous (Ludwig 2001). These situations are termed ecological management dilemmas (Bennett et al. in press). Managers generally transform or manage an ecosystem with the aim of obtaining a set of desired ecosystem services. A number of perverse consequences are possible, however, such as reductions in future ecosystem services, increases in vulnerability of ecosystems to disturbance, or unforeseen trade-offs in other ecosystem services. (See Chapter 3.) The prospect of perverse consequences creates dilemmas for ecological management.

Ecological management dilemmas challenge decision-makers to seek policies that are robust to uncertainty, surprise, and failure of actions to evoke expected responses. That is, the policy should achieve acceptable outcomes even under unexpected conditions. Flexibility and learning mechanisms become an essential part of the management process to cope with the fact that management actions need to continually adapt to evolving ecological dynamics (Walters 1986; Gunderson et al. 1995; Carpenter 2003). Ecological dilemmas are not susceptible to the routine approaches of ecosystem management because they involve complex ecological dynamics and uncertainties (Holling and Meffe 1996; Ludwig 2001). Instead, they require approaches that are more flexible, more attentive to change, and more innovative (Gunderson and Holling 2002). The construction of institutions that address ongoing change in ecosystems, emerging ecological dilemmas, and sustainable management of ecosystem services is currently an active area of uncertainty, debate, and research (National Research Council 1999, 2002; Berkes et al. 2003). The scenarios should reflect the current diversity of viewpoints about how ecological management dilemmas should best be addressed.

Two ecological dilemmas were frequently raised by the interviewees and MA user community: What degree of ecological complexity is needed to provide reliable ecological services? (See Box 5.4.) And to what degree can people use technology to substitute for the role of relatively undisturbed ecosystems in provision of services? These unknowns are critical because the answers provide a clue about the best approaches to managing for ecosystem services in any particular situation. The answers will affect the resolution of many of the questions asked by the MA user community and the concerns of the interviewees. Since we currently do not know how much ecological complexity is enough, the costs and benefits of future complexity are hard to evaluate. We also do not fully understand when technology can be used to substitute for an ecosystem's role in provision of ecosystem services and when technology might lead to deleterious side effects. We sought scenarios that address these ecological dilemmas in a useful way with respect to the concerns that decision-makers presented in the interviews.

### 5.3.4 Drivers and Current Conditions

The scenarios should also be rooted in the present. Transformations described in the scenarios should emerge from the important drivers and current condition of socioecological systems. These are presented in Chapter 7. Working

**BOX 5.3**

**Catastrophic Change in Ecosystems**

Most of the time, changes in ecosystems and their services are gradual and incremental. Most of these gradual changes are detectable, and many are predictable. However, some changes in ecosystems and their services are large in magnitude as well as difficult, expensive or impossible to reverse (*high certainty*) (Scheffer et al. 2001). These changes are important, massive, and hard to predict, so they may come as surprises. Some systems that are known to exhibit large, hard-to-reverse changes (adverse changes indicated in parentheses here) include pelagic fisheries (economic collapse), freshwater lakes and reservoirs (toxic blooms, fish kills), pastoral lands (conversion to woodland), and dryland agriculture (salinization, desertification) (Carpenter 2003; Folke et al. 2005; Walker and Meyers 2004).

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*) (Folke et al. 2005; Groffman et al. 2005). For example, slow 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 (Carpenter 2003). Gradual overfishing and nutrient runoff make coral reefs susceptible to severe deterioration triggered by storms, invasive species, or disease (Bellwood et al. 2004; Hughes et al. 2003). 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 (Walker 1993). In the Sahel, decades-long droughts are caused by strong feedbacks between vegetation and the atmosphere and may be triggered by slow changes in land degradation (Foley et al. 2003).

Because multiple, interacting stresses on ecosystems are increasing, it is likely that harmful large ecosystem shifts will become more common in the future (*established but incomplete*). On the other hand, proactive ecosystem management and wise use of ecological technology can reduce the impact of harmful shifts in ecosystems and assist people in adapting to unexpected change (*established but incomplete*).

from these initial conditions and drivers, the Scenarios Working Group developed plausible pathways to four very different futures by 2050. The year 2050 was chosen to be far enough in the future to reveal the effects of important ecological feedbacks and to consider long-term futures and yet near enough that the causal chain between current decisions and eventual outcomes could be reasonably traced.

## 5.4. Introduction to and Overview of the Scenarios

The interviewee concerns and user needs, and the ecological uncertainties that underlie them, are the factors that the scenarios should address. We identified four clusters of beliefs that embrace most of the fears, hopes, and expectations for the future that were encountered in the interviews and the statements of user needs.

Many leaders felt that the future would bring increased emphasis on national security, leading to greater protection of borders with associated consequences for economic development and changes in direct drivers of ecosystem services. Other respondents felt that the future could, or should, bring greater emphasis on fair, globally accepted economic and environmental policies, as well as greater attention by governments to public goods. Some interviewees pointed to the prospect of technology for managing ecosystem services with greater efficiency. Still others found hope in local adaptive capacity for flexible, innovative management of socioecological systems. The future may well involve a mix of these perspectives.

Our approach to the four clusters of beliefs was informed by previous explorations of sustainability concepts. Among these are ideas about investment in manufactured, human, and natural capital (Dasgupta and Mäler 2000, 2001); objectives of business development, community empowerment, and environmental conservation (Munasinghe and Shearer 1995); trade-offs among individualist, hierarchist, and egalitarian social perspectives (Janssen and DeVries 1998); and integrated theories for ecosystems, social systems, and management systems (Gunderson and Holling 2002).

Economic development is sometimes viewed as the key to sustainable development. The Environmental Kuznets Curve suggests that as economic growth occurs, environmental quality is first degraded and later improved (Stern 1998). The conclusion that many have drawn from this theory and the evidence supporting it is that economic growth should lead to improvements in the environment. Other evidence also indicates that poverty alleviation may lead to improvements in ecosystems. For example, the poorest people are often directly dependent on ecosystems for services such as food, fuel, and water. In times of scarcity or high population, these groups may overharvest from local ecosystems. By diversifying economic opportunity, both human well-being and direct impacts on ecosystems may be reduced. On the other hand, greater consumption is often associated with greater impact on the environment (Wackernagel and Rees 1995). The disparity in income among nations leads to enormous disparity in political and economic power as well as a much greater impact on global life-support systems by rich countries than poor (Ehrlich and Ehrlich 2004). The connections between economic policies and the status of ecosystem services are multiple and complex. All the scenarios explore these connections to some degree.

In the Global Orchestration scenario, we explore the possibilities of a world in which global economic policies are the primary approach to sustainability. The recognition that many of the most pressing problems of the time seem to have roots in poverty and inequality leads many leaders toward a strategy of globally orchestrating fair policies to improve well-being of those in poorer countries by removing trade barriers and subsidies. Nations also make progress on global environmental problems, such as greenhouse gas emissions and depletion of pelagic marine fisheries. The results for ecosystem services are mixed. While human well-being is improved in many of the poorest countries, it is still not clear in 2050 whether the net impact on ecosystems will be positive or negative.

Some respondents believe that national security will become an overarching concern in the future. Should this

**BOX 5.4**

### Biodiversity, Disturbance, and Resilience of Ecosystem Services

Ecosystem resilience is maintained by genetic and species diversity as well as by spatial patterns of landscapes, environmental fluctuations, and temporal cycles with which species evolved. Management for resilience recognizes the importance of heterogeneity and change, including the natural processes of species turnover, extinction, and evolution. Ecosystem resilience is the amount of disturbance that an ecosystem can withstand and still maintain essentially the same structure, processes, and flow of ecosystem services (Holling 1973). As described here, the renewal and reorganization of ecosystems after disturbance depends on the functional groups of species within ecosystems and the diversity of responses to environmental fluctuations within those functional groups.

Disturbance is routine in ecosystem dynamics (White and Pickett 1985). All species evolved in the presence of certain types, magnitudes, frequencies, and spatial patterns of disturbance and are thus adapted to these disturbances (Paine et al. 1998). Disturbances within the typical range usually result in little long-term change in ecosystem characteristics, processes, or services, even though species turnover may be extensive (Turner et al. 1997). Moreover, the typical disturbance regime is often necessary for maintaining ecosystem resilience. Without disturbance, critical groups of species or processes disappear over time (White and Pickett 1985).

Events outside the range of typical disturbances can transform ecosystems, creating new and surprising ecosystem structures and processes. Disturbances that cause surprising transformations often involve compounded perturbations, with multiple events within the normal recovery interval of the ecosystem or unusual combinations of drivers (Paine et al. 1998). Ecosystem transformations can also result from anthropogenic disturbances, which are often chronic (instead of pulsed) and may be unlike anything experienced before in the evolutionary history of the species (Bengtsson et al. 2003).

The biotic structure of an ecosystem also affects the outcome of disturbance. Population attributes such as dispersal ability or generation time affect the response of particular species to disturbance. Aspects of community structure, including biodiversity, play a critical role in the responses of ecosystems to disturbance (Chapin et al. 2000; Kinzig et al. 2002; Loreau et al. 2002).

Functional groups are sets of species that perform similar ecosystem processes. Ecologists have identified functional groups by clustering microbes, plants, or animals according to biological similarities (Holling 1992; Frost et al. 1995; Walker et al. 1999; Havlicek and Carpenter 2001). At least two different effects of functional groups on ecosystem processes have been recognized (Yachi and Loreau 1999; Ives et al. 1999, 2000). First, if several functional groups are complementary in their use of resources, the diversity among functional groups tends to increase the total flow of ecosystem services (Yachi and Loreau 1999; Hulot et al. 2000; Reich et al. 2004; Petchey et al. 2004). For example, functional groups of plants 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.

Second, diversity within functional groups maintains the rate of ecosystem processes despite environmental fluctuations if the individual species respond differently to such fluctuations (Yachi and Loreau 1999; Ives et al. 1999, 2000; Walker et al. 1999; Norberg 2004; Bai et al. 2004). This phenomenon is called response diversity. When the environment changes, a formerly rare species with different characteristics can become dominant (Frost et al. 1995). Response diversity is the key to the insurance effect of biodiversity on ecosystem services (Elmqvist et al. 2003). In the face of uncertain and often novel anthropogenic changes in the environment, preserving the diversity of species and functional groups increase the chance that species are retained that later play a crucial role in the ecosystem. In this sense, species and functional diversity provide "insurance" against future environmental change. In contrast to monetary insurance against unexpected accidents, however, the insurance provided by diversity is not guaranteed, and the environmental change for which diversity may provide insurance is not unexpected. Preserving biodiversity is not a substitute for reducing other kinds of anthropogenic stresses on ecosystems.

It is an oversimplification to equate species richness with resilience of ecosystem services. Instead, the effect of diversity on resilience depends on organization of species among functional groups, spatial pattern, and scaling of ecosystem processes in time and space (Elmqvist et al. 2003; Folke et al. 2004). A species invasion that adds to species richness can decrease the resilience of ecosystem services if it reduces response diversity.

When chronic, progressively worsening stress to an ecosystem removes species in order of their susceptibility to the stress, the surviving species are more tolerant of this specific stress (Ives and Cardinale 2004). These species, however, may provide little insurance against other types of environmental changes. If the ecosystem is subjected to a different kind of stress or disturbance, these few species may be eliminated, thereby causing a greater loss of ecosystem services. Thus the maintenance of ecosystem services requires the maintenance of diversity during multiple, successive environmental changes.

Diversity of spatial pattern creates a kind of response diversity (Elmqvist et al. 2003). Dispersal of species among patches in heterogeneous landscapes confers resilience to disturbances that affect only part of the landscape or seascape (Peterson et al. 1998; Nyström and Folke 2001; Loreau et al. 2003; Cardinale et al. 2004). If a process is eliminated from part of the landscape or seascape but is present in other patches within dispersal range of the affected patch, then the missing process can be reestablished. Furthermore, the pattern of local elimination and recolonization through dispersal may establish numerous ecosystem configurations, thereby creating local ecosystem diversity throughout a landscape or seascape.

Response diversity acts across scales through interspecific differences in the use of space (such as dispersal ability, patch size, and home range size) and time (such as generation time, dormancy period, and seasonality). Ecological disturbances usually occur in a specific range of time-space scales, allowing persistence of species, structures, or processes that occur at the scales that were not affected (Elmqvist et al. 2003). Therefore, replication of ecological processes across a wide range of scales confers resilience (Peterson et al. 1998). Species that act across a wide range of space scales (such as highly mobile species) or time scales (such as long-lived species or large-bodied generalist predators) are an important element of ecosystem response diversity (Peterson et al. 1998). Regional losses of such species increase the risk of catastrophic ecosystem changes that cause large reductions in ecosystem services (Elmqvist et al. 2003).

Traditional societies may have known about response diversity for a long time. Berkes et al. (2003) describe several societies that appear to manage for response diversity and may thereby build resilience of ecosystem services.

In summary, proactive ecosystem management builds ecosystem resilience through maintenance of genetic and species diversity, as well as spatial patterns of landscapes and temporal cycles of environmental fluctuations and disturbance with which species evolved. In contrast, ecosystem management practices that reduce response diversity, remove whole functional groups or trophic levels, expose ecosystems to chronic novel stress or novel disturbances, or create compounded perturbations (unusual combinations of disturbances at intervals shorter than the normal recovery cycle of the ecosystem) increase the risk of large-scale breakdowns in ecosystems and losses of ecosystem services (Folke et al. 2004).

occur, nations or blocs may concentrate on inward-looking economic development, so that the globalization of the economy may proceed more slowly than in Global Orchestration. While some regions would remain well endowed with ecosystem services, other regions that now have fewer ecosystem services may remain impoverished.

The Order from Strength scenario examines the outcomes of a world in which protection through boundaries becomes paramount. The policies enacted in this scenario lead to a world in which the rich protect their borders, attempting to confine poverty, conflict, environmental degradation, and deterioration of ecosystem services to areas outside the borders. Poverty, conflict, and environmental problems often cross the borders, however, impinging on the well-being of those within. Protected natural areas are not sufficient for nature preservation or the maintenance of ecosystem services. In addition to losses of ecosystem services in poor regions, global ecosystem services are degraded due to lack of attention to the global commons.

The survey and interview results indicated that many of those interviewed think that complexity and local flexibility are a critical component of the path to sustainability. Social and ecological scientists have addressed the conditions in which disaggregated management systems outperform centralized ones (Grossman 1989; Scott 1998; Gunderson et al. 1995; National Research Council 2002). Because ecosystems are subject to large and potentially irreversible changes (Chapter 3), certain types of centralized ecosystem management schemes are subject to catastrophic failure (Holling and Meffe 1996). According to a large number of case studies, enabling conditions for successful ecosystem management include small size, well-defined boundaries, shared norms, social capital, appropriate leadership, fairness in allocation of ecosystem services, and locally devised, easily enforceable access and management rules (National Research Council 2002). It is important to note that central governments do not undermine local authority for ecosystem management (Ostrom 1990; Wade 1988; National Research Council 2002).

While there is clear evidence of success in local ecosystem management, the multiscalar nature of ecosystems poses challenges for this approach. For example, local management of thousands of subwatersheds may not lead to sustainable management of a continental river system if there are significant externalities that are not properly included in local accounting. Some of our respondents feared that a disaggregated world would exacerbate global problems or benefit ecological services only in regions that were relatively wealthy, well educated, and well endowed with natural capital. These trade-offs in the scales of ecosystem management are addressed in the scenarios.

The Adapting Mosaic scenario explores the benefits and risks of disaggregation. In this scenario, lack of faith in global financial and environmental institutions, combined with increasing understanding of the importance of resilience and local flexibility, leads to diminishing power and influence of these institutions compared with local and regional ones. Eventually, this leads to diverse local practices for ecosystem management. The results are mixed, as some regions do a good job managing ecosystems and others do not. High levels of communication enable regions to compare experiences and learn from one another. Gradually, the number of successful experiments begins to grow. While global problems are ignored initially, later in the scenario they are approached with flexible strategies based on successful experiences with locally adaptive management.

Still others are optimistic about the use of technology to sustain ecosystem services. Technology has led to great improvements in agricultural production efficiency, in medicine, and in the provision of other ecosystem services. Advances in technology have the potential to build human well-being through more efficient use of ecosystem services as well as through better understanding of ecosystem conditions and trends. Greater efficiency could reduce the overall impact on ecosystems and thereby increase opportunity for sustainability of ecosystem services.

On the other hand, technological solutions sometimes lead to unexpected problems (Tenner 1997). Acceleration of technology may be a factor in the increased incidence of environmental problems, demanding more and more ingenious responses (Homer-Dixon 2000). For example, increased use of pesticides in agriculture may lead to pests that are resistant, requiring a newer and better technology to remove them. In addition, efficiency gains are often focused on a single service, rather than a bundle of services; in fact, increased efficiency in provision of one service may cause declines in provision of other services. Highly efficient environmental management systems often rely on predictions, but ecosystem changes are often unpredictable and errors in prediction lead to costly mistakes (Oreskes 2003; Pielke 2003). Other problems derive from the complexity of the decision systems in which environmental predictions are used (Dörner 1996; Sarewitz et al. 2000). For these reasons, some experts are cautious about the use of technology to manage ecosystem services more efficiently. Increasing reliance on technology could increase the frequency and severity of unexpected problems, erode the resilience of ecosystems, and over time cause ecosystem services to become more vulnerable.

The TechnoGarden scenario explores the potential role of technology in providing or improving the provision of ecosystem services. In this scenario, people push ecosystems to their limits of producing the optimum amount of ecosystem services through the use of technology. Often, the technologies they use are more flexible than today's environmental engineering and they allow multiple needs to be met from the same ecosystem. In the beginning of the scenario, these technologies are primarily developed in wealthier countries and slowly dispersed to poorer places, but later—promoted by a global focus on education—they are developed everywhere. Provision of ecosystem services in this scenario is high worldwide, but flexibility is low due to high dependence on a consistent provision of services. In some cases, unexpected problems and secondary effects created by technology and erosion of ecological resilience lead to vulnerable ecosystem services that are subject to interruption or breakdown.

In summary, the four MA scenarios represent diverse views of the future of ecosystem services. While advocates for particular viewpoints may state them as assertions, the Scenarios Working Group regards them as questions to be addressed. Each of the four scenarios addresses different sets of beliefs about how the global system might change in directions that could sustain ecosystem services. (See Figure 5.2.) Global Orchestration describes a world in which policy initiatives attempt to establish fair global markets and organize transnational responses to certain global environmental problems. Order from Strength addresses the beliefs of those who hold that the future will, or should, bring security, including protection of natural resources and ecosystem services. In the world of Adapting Mosaic, the focus of economics and politics shifts to local or regional scales. TechnoGarden presents a future in which great emphasis is placed on the development of technology for efficient management of ecosystem services.

Some key characteristics of the global system during each scenario are presented and compared in Table 5.1. As we shall see, the contrasting conditions of these scenarios lead to different bundles of benefits and risks for ecosystem services and human well-being. In the remainder of the chapter, we present short sketches of each scenario, compare their benefits and risks, and describe situations in which the conditions of one scenario could branch toward the conditions of a different scenario.

## 5.5 Sketches of the Scenarios

This section presents short synopses of the four scenarios. Each scenario is told by an observer looking back at 2000 from 2050. These brief descriptions are intended to provide an overview of the dynamics in each scenario. Longer, more detailed narratives are presented in Chapter 8. Some quantitative model results are presented in Chapter 8, and full model results are presented in Chapter 9.

### 5.5.1 Global Orchestration

***Summary:*** *The past 50 years have shown that some ecosystem services can be maintained or improved by appropriate macro-scale policies. Notable successes occurred in reducing or controlling many global pollutants and in slowing, or in some cases reversing, loss of marine fish stocks. In some situations, it turned out that ecosystem services improved as economies developed. On the other hand, it appears that global action focused primarily on the economic aspects of environmental problems is not enough. In some regions and nations, ecosystem services have deteriorated despite economic advancement. Also, it was sometimes difficult to adjust large-scale environmental policies for local and regional issues. Despite some significant environmental disasters, this lesson has not yet been learned. As we look to 2100 and beyond, multiscale management of ecosystem services is a top challenge for environmental policy.*

At the beginning of the twenty-first century, poverty and inequality, together with environmental degradation and climate change, were pressing problems on the agendas of global and national decision-makers. Concerns about social tensions arising from inequalities in and uneven access to global markets were growing, as these tensions were often seen as the un-

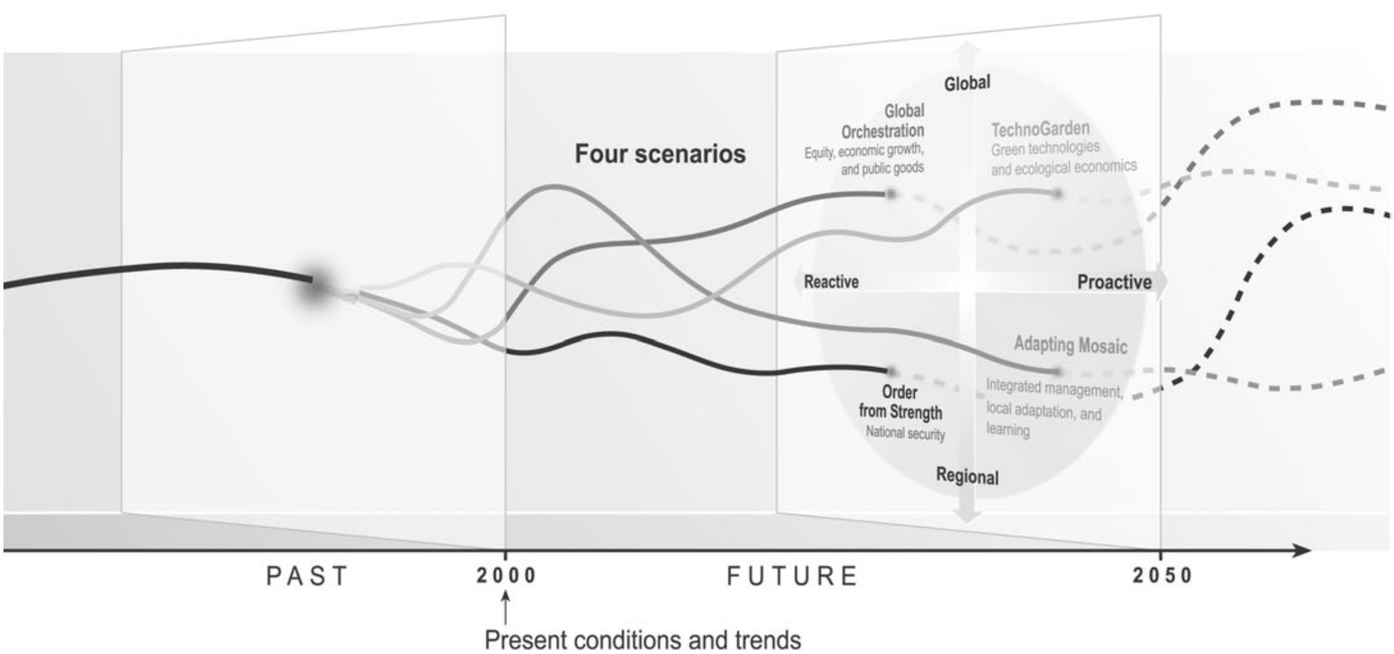


**Figure 5.2. Contrasting Approaches among MA Scenarios.** The scenario differences are based on the approaches pursued toward governance and economic development (regionalized versus globalized) and ecosystem service management (reactive versus proactive).

**Table 5.1. Comparison of Variables across Scenarios**

| Variables | Order from Strength | Global Orchestration | TechnoGarden | Adapting Mosaic |
|---|---|---|---|---|
| Priorities for investment in (and consumption of ) natural (N), human (H), manufactured (M), and social (S) capitals | high investment in H, M, and S among elites within and between societies; low investment in H and S of non-elites by elites | high investments in M, H, and S, but not with respect to ecosystem goods and services; investment in N or in environmental research or education only to the extent it matters for development | balanced investment in all forms of capital | strong investment in S, through encouragement of local institutions, and H, through investment in environmental research and education; these lead to investments in N, through both protection and repair |
| Perspective on ecosystem services and socioecological systems | ecosystem services will be maintained by local or national actions to conserve representative ecosystems | ecosystem services can be sustained by global social economic policies; ecological systems are either resilient (and will remain so) or resilience will be enhanced as a consequence of social policies | ecosystem services can be sustained by technologies, including methods of ecological engineering and ecological economics | ecosystem services are an evolving aspect of socioecological interactions; ability to control and predict ecosystem services is limited, so continual learning and adaptation are necessary to sustain ecosystem services |
| Changes in connectivity of socioecological systems | variability in socioecological links among nations | loosening of socioecological links | tightening of socioecological links driven by social and economic objectives | exploring and adjusting socioecological links |
| Root of unexpected breakdowns in ecosystem services | lack of consideration of the impact of slowly changing variables; feedbacks emerge as surprising due to lack of monitoring | lack of consideration of the impact of slowly changing variables; feedbacks emerge as surprises due to lack of monitoring | over-engineering; some ecological systems are more complex than expected; lack of understanding of how technological innovation interacts with ecological complexity, including long-term dynamics and spatial connectedness of ecosystem processes | risks of experimentation 9or inaction0 lead to some localized breakdowns, while global ecosystem services diminish due to limited capacity to address global ecosystem issues |

| | | | | |
|---|---|---|---|---|
| Response to unexpected breakdowns of ecosystem services | elites assume that local and national management of ecosystem services is sustainable | it is assumed that global policies, markets, substitution, and adaptation are sufficient to maintain ecosystem services; little strategic planning as there is little investment in research or monitoring | proactive in the sense that ecosystems are engineered to provide specific ecosystem goods and services and avoid cross-scale ecological feedbacks; assumption that technologies will prepare managers to deal with unexpected feedbacks | adaptive, innovative, and proactive for local, national, or regional ecosystem services, but global coordination of ecosystem management is lacking |
| Investment in learning about the environment | lowest of the four scenarios | low, motivated by breakdowns in ecosystem services | high investment in ecosystem research motivated by technological development | variable; high in some locales; learning by comparing regional experiences, but little investment in understanding of global ecosystem services |
| Approach to global commons | action on global issues that affect elites | strong global action on global issues if and when they affect social and economic goals | coordinated and proactive action on global issues, emphasizing technological solutions | little attention to global issues that affect ecosystem services |
| Programs for multiscale resources management | sometimes exist in wealthier regions; in other regions, institutions for multiscale resource management are slow to develop | focus on global emissions with little emphasis on multiscale coordination; global practices sometimes overlook regional variation in resource issues | scale of intervention tends to be driven by technological capability and opportunity | variable among regions; growing attention to multiscale management of ecosystem services emerges by ∼2050 |
| Institutions, incentives, property rights for ecosystems management | regulatory control by elites, who have greater access to ecosystem services | weak institutions for ecosystem services, except for global commons issues; ecosystem services not seen as fundamental to wealth creation; property rights often discounted from benefits of ecosystem services | property rights and market mechanisms are emphasized to align private incentives with sustainability of ecosystem services | high variability of institutions among regions; exploration of practices to build resilience of ecosystem services |
| Emphasis on development of environmental technology | low; in wealthy regions, some progress on environmental technology in response to recognition of novel environmental problems | moderate, in response to emergence of novel environmental problems | rapid development of advanced environmental technologies that support ecological design; technologies are used to decrease the dependency of economic growth and consumption | moderate; variable among regions |

derlying causes of uncontrolled migration, conflicts, and even terrorism. Leaders were also concerned about inequalities among people, including differential access to technology and education and other drivers of inequality. There were great debates about the best approach to solving these problems.

Eventually, globally orchestrated policy reforms took hold as the dominant strategy. Policy reforms were used to reshape the world's economic and governance systems. The emphasis of these reforms was on creating markets that allowed equal participation and provided equal access to goods and services. The reforms also targeted the creation of more transparent governance systems worldwide as the necessary foundation of economic growth. As the world became increasingly connected financially, it was necessary to create global policies to deal with problems arising from the connections. Thus, one result of globalized economic systems was a strengthening of global and regional standard-setting bodies such as the World Trade Organization. The focus on policy reforms and faith in global institutions also led to strengthening of the United Nations and some other multinational alliances.

At about this same time, governments found themselves making decisions about how to handle terrorism and conflicts among nations. Should rich countries focus on borders and protection or should they assist with development in poorer countries to spread goodwill? Generally, rich nations leaned toward helping poor nations meet their basic needs, as this was thought to be the better long-term solution. Trade practices that had hindered economic development in poor countries were discontinued. These reforms were followed by increased wealth in many poor countries, which led to secondary improvements in governance and democracy. In most regions of the world, governments invested more heavily in public goods, such as education and public transportation.

Trade expanded globally, driven by removal of subsidies and increasing demand for goods and services around the planet. Economies in China, India, and Southeast Asia began to grow rapidly again. A focus on education and, in some cases, political reform helped civil society grow in poorer countries. In countries that profited from increased market access and production opportunities, a wealthier middle class began to develop. Civil society and the growing middle class, in turn, brought about further reforms.

By the 2020s, a growing middle class was demanding cleaner cities, less pollution, and a more beautiful environment. This was particularly true for problems that occurred in and around urban settings and those that directly affected human health. Nevertheless, problems of intensified agricultural systems and the slow loss of wildlands received only limited attention. Environmental problems that were difficult to reverse, such as biodiversity loss, were more or less ignored by the general population because so many other things were going well.

Driven by policies aimed at increasing gross domestic product and human well-being, agricultural area expanded in poor countries, leading to increased human impacts on terrestrial ecosystems. Agricultural specialization increased, driven by the selection of high-yield and commercially valuable crops and livestock. Local ecological knowledge was often replaced by uniform industrial methods. Consequently, by the 2020s, wild varieties of agricultural species existed primarily in gene banks, and the number of domestic varieties in use was greatly reduced. Diverse landraces persisted mostly in marginal areas. By 2025, many small farms had consolidated into large agricultural operations. All farms, small and large, had become more highly mechanized and industrial. By sometime in the 2030s, the rate of increase in agricultural area had begun to slow down due to replacement of traditional agriculture with more-efficient industrial systems.

As the rate of agricultural expansion declined, particularly in rich countries, and as people moved from the countryside into cities, many terrestrial ecosystems began to recover from intensive human use. This recovery was aided by increased productivity of farms, which allowed some reduction in agricultural land area. Recovery of ecosystem function in these areas was aided by replanting and some restoration. Ecosystem restoration was driven by people's interest in increasing the supply of fuelwood and other biomass products, in addition to the expansion of intensively managed spaces for recreation. In contrast to the agricultural land recovery, coastal marine ecosystems and wetlands declined significantly because the increased urban growth was mostly concentrated in a 100-kilometer band along the coastline.

Increases in wealth and in the availability of technology resulted in the continuing improvement of health around the planet. Regional inequalities in health were prevalent until the mid 2020s. Obesity-related diseases remained a threat, particularly in rapidly developing areas, as new food choices became available and societies shifted their eating habits to less healthy diets. Emerging infectious diseases were also a risk. The potential for the origination and spread of novel pathogens was high in areas where ecosystem function was disregarded. It turned out that disruption of ecosystem regulation processes increased the likelihood of exposure to pathogens originating from wild animals and plants, and the movement of exotic species around the world through widespread trade further facilitated the spread of pathogens. While these surprises occurred in rich and poor countries, the capacity to respond was higher in rich countries, and hence the impact was much higher in poorer countries. Positive surprises, such as the success of genetically modified organisms in reducing the agricultural expansion, also occurred.

Despite economic policies designed ultimately to lead to a better environment, the simplification of ecosystems eventually led to a decrease of environmental security as ecological surprises became more common. One surprise of the past 50 years was the high impact that widespread trade had on hastening the spread of invasive species. It seems that reduced diversity limited the options of ecosystems to respond to ever increasing ecological surprises, although it is hard to tell if the problem was this or simply increased population pressure. People in poor countries are generally doing better than they were in 2000, but, looking to 2100, we wonder whether the early policies to increase economic growth will provide the necessary resilience to cope with future surprises.

### 5.5.2 Order from Strength

***Summary:*** *Since 2000, the availability of ecosystem services has fallen below minimal needs for human well-being in some regions of the world while being maintained or even improved in other regions. Widespread loss of faith in global institutions and fear of terrorism led rich countries to favor policies that ensured security and erected boundaries against outsiders. Even in better-off areas, though, there have been some breakdowns of ecosystem services. It turned out that climate change was often more rapid than response capacity, leading to local degradation of ecosystem services in some places, even in rich nations. Overall, the current global condition of ecosystem services is highly variable and declining on average. Even the places in the best condition are at risk, although citizens of wealthy nations enjoy a tolerable level of ecosystem services and human well-being. As we look to 2100 and beyond, Earth's ecosystem services seem fragmented and imperiled. Problems exist at all scales, from global fisheries collapses to regions of the world where ecosystem services are sorely in need of restoration and other regions where ecosystem services are currently fine but threatened. We have learned that it is impossible to build walls that are high enough to keep out all the world's ills, but also that it is sometimes a reasonable policy to focus minimal resources on carefully protecting a few areas rather than only partially protecting everywhere.*

At the beginning of the twenty-first century, terrorism, war, and loss of trust in global institutions led many people to believe that there was a need for powerful nations to maintain peace and achieve equity. Governments of the industrial world reluctantly accepted that militarily and economically strong democratic nations could maintain global order, protect lifestyles in the industrial world, and provide some benefits for any developing countries that elected to become allies. Countries were often unwilling to participate in international and global institutions as they concentrated on building strength as nations. As a result, global institutions began to stagnate as people lost confidence in them and their power eroded.

The EU and the United States turned inward, striving to preserve national security. Trade policies veered toward increasing protectionism. Religious fundamentalism and nationalism were mutually reinforcing in some nations. In some cases, parts of civil society saw this inward focus as dangerous and tried to oppose it, but they were mostly silenced by already strong national governments. Just as the focus of nations was turned to protecting borders, environmental policies concentrated on securing resources for human consumption. Building strong nations was a priority, as many felt that environmental challenges could not be adequately addressed without first strengthening nations and economies. Conservation focused on parks and preserves.

By sometime around 2018, this had increased the separation between the rich, powerful countries and the poverty-stricken ones, with very few countries left in between. Societies were also stratified within nations: rich and powerful people and poor people existed within both rich and poor nations. Within nations, rich and powerful people increasingly turned to gated communities as a way to protect themselves from outsiders.

In the rich world, the drive for security and protection led to privatization of access to many natural resources, as businesses stepped in to help governments assure consistent access to resources. In turn, governments protected the economic interests of these businesses. This led to increasingly tighter connections between governments and business at all scales. There was also very little trade with poor countries.

The world outside the rich people's walls experienced a lot of conflict during this period. The disputes were largely over access to natural resources like water, oil, and fuelwood. Many in poorer countries felt that the way out was to immigrate to a rich country or become part of the elite in their own country, which historians believe entrenched the compartmentalization. With most poor people spending all their time and energy trying to become one of the elites, there were few left to argue for other priorities. Some elites did demand better treatment of the poor and were sometimes able to effect change. Significant economic problems persisted in the poor world due to corruption, disease, and pollution. As poor countries spent most of their time attending to crises of disease and other problems, widespread improvements in economic well-being became rare. Although fertility had been starting to drop in poor countries at the beginning of the twenty-first century, the collapse of nascent social safety nets resulted in increases in fertility; population growth rates reversed course and began to increase.

Powerful countries often coped with problems by shifting the burdens to other, less powerful countries, increasing the gap between the rich and poor. In particular, resource-intensive industries were moved to poorer countries or to poorer parts of wealthy countries. This taxed poor people's environment further, leading to widespread migration from collapsed places to new parts of poorer countries. This migration created stresses that sometimes led to environmental degradation in the new places. For example, refugees who left one place for another increased the pressure on the new area's environment until it collapsed. Disease, particularly contagious diseases, became rampant in poor areas.

Rich nations also attempted to make their lands more livable by moving food production to poor countries. The price of food rose as conflict in poor areas affected their ability to produce food. In some cases, this led rich nations to attempt to stabilize poorer ones through a combination of military and economic intervention. In other cases, rich nations simply produced more of their own food.

The inward focus of wealthier nations did lead to some benefits, including high levels of protection, easy access to goods and services inside the wealthy areas, and pockets of very well preserved wilderness in rich countries and in places that wealthy people wanted to visit on holiday. The spread of invasive species was also a lot lower than researchers had predicted in 2000, a surprise attributed to the decrease in trade among countries. The rate of successful invasions was higher than in 2000, since degraded ecosystems were more susceptible to successful invasion when exotic species were present.

During times when powerful countries became more assured of their security, they did turn somewhat to global issues, particularly those that would obviously affect themselves. Sometimes funding was made available to help poor countries with particularly pressing problems. The focus for this funding was often on conflicts or refugee problems (which were seen as having secondary impacts on rich countries). Generally, when funding was available for poorer areas, the focus was on physical safety rather than social welfare issues. Some global environmental issues that affected rich countries were addressed in the same way, through cautious agreements among rich nations, and this led to some improvements on global environmental issues. However, progress has been slow on those issues that are not of direct concern to the powerful.

As the attention of governments was on economic and military strength, there was less focus on the environment. Global issues (such as climate change) and international issues (such as large river management) were almost always impossible to address as at least one key nation was unwilling to cooperate. Ironically, global climate change increased less than had been expected at the turn of the century, due to a larger than expected proportion of the world's population being forced to live a simpler and less materialistic existence.

Now, in 2050, some poorer regions have finally gained a reasonable amount of stability, and are finding themselves able to form coalitions and trade agreements to better their situation. Generally, these coalitions have worked well to lift some poor areas out of totally abject poverty. This was especially true for nations that had crossed the digital divide. Some Asian, South American, and African nations had established digital networks, which gave their people an advantage in terms of access to global markets and information. These countries in particular were able to gain more stability. As soon as things start getting better, many people want to immigrate to these areas. Thus, countries often are forced to create strong laws against immigration in order to keep their society safe and orderly. The future of these regions is uncertain.

Today, it is apparent that there was not a linear trend toward higher and higher walls, even though it sometimes felt that way. Instead, we saw episodes of rapid change and periods of relative stability. There were some fluctuations of increasing and decreasing compartmentalization as the powerful countries periodically invested in keeping conditions tolerable for the poor in order to reduce illegal immigration and other problems. There were also activist groups and intellectual dissidents in wealthy nations that tried to support the poor and poor nations. Looking forward to 2100, these activist groups are one of the main sources of hope in an otherwise bleak situation. People and ecosystems are generally doing worse than in 2000, but some hope can be found in the activists working to support the poor and improve management.

### 5.5.3 Adapting Mosaic

***Summary:*** *The past 50 years have brought a mix of successes and failures in managing ecosystem services. Approaches to management have been heterogeneous. Some regions strengthened the centralized environmental agencies that emerged late in the twentieth century, while others embarked on novel institutional arrangements. Some approaches turned out to be disastrous, but others proved able to maintain or improve ecosystem services. Many nations have emulated the successes of other nations, and the number of successes has begun to climb by 2050. As a result, the world in 2050 is a diverse mosaic with respect to ecosystem services and human well-being. A considerable variety of approaches still exists, and regrettably some regions still cannot provide adequate ecosystem services for their people. Other regions are doing well, and remarkable successes have occurred on every continent. With respect to global-scale environmental problems, progress has been slow. As we look to 2100 and beyond, policy and ecological science face a twin challenge: to rebuild ecosystem services in the regions where they have collapsed and to transfer the lessons of regional success to problems of the global commons.*

Opportunities for, and interest in, learning about socioecological systems were a defining feature of the early twenty-first century. People had great optimism that they could learn to manage socioecological systems better, but they also retained humility about limits to human control and foresight and the prospects for surprise. Learning to improve socioecological systems came at a great cost. There were failures as well as successes, and learning diverted some of society's resources. Economic growth was probably lower than it could have been had decision-makers put all our investments toward manufactured capital, but economic growth has begun to improve recently as the benefits of better socioecological systems are now slowly being realized.

At the turn of the century, some people in the rich world held beliefs that promoted regionalization of trade, nationalism, and local or regional management of natural resources. Global trade barriers for goods and products were increased, but trade barriers decreased within regional blocs such as ASEAN, NAFTA, and the EU. In contrast, global barriers for information flow nearly disappeared due to improving communication technologies and the rapidly decreasing cost of information access. Political focus followed the economic emphasis on regional or national trade.

The regionalization of markets and politics was associated with a decline in the relative power of global international institutions. The decline was partly linked to loss of confidence in the effectiveness of global governance and dissatisfaction with distortions of global markets. But the strengthening of interactions within nations and within regional blocs was also an important factor in the relative deemphasis of global institutions. Dissatisfaction with the results of global environmental summits and other global approaches led many people to perceive global institutions to be ineffective at environmental management. Climate change negotiations had broken down by 2010. International agreements failed to prevent the depletion of most marine fisheries, and regulation of transboundary pollutants proved ineffective.

Within some nations, power devolved to local authorities. There was variation among nations and regions in styles of management, including natural resource management. Some managed with rigid centralized bureaucracies. Others focused on market incentives or other economic measures. Still others attempted some form of adaptive management for the nation or region as a whole. Some local areas explored actively adaptive management, investigating alternatives through experimentation. Some were passively adaptive, investing in a certain amount of monitoring but dealing with change in a reactive way. Still other locales largely ignored the environment, dealing with crises only as they arose.

There was great diversity in the outcome of these varied approaches to managing socioecological systems. Some notable disasters were poorly handled. Sometimes, methods that succeeded in one region failed when imported to another region because of unforeseen differences in social practices, politics, or ecosystems. Reactions to resource breakdowns were also diverse. Perversely, failed practices were sometimes sustained by subsidies from other regions or other sectors of the economy. In other cases, breakdowns were followed by innovations that eventually made things better.

Groups began to experiment with innovative local and regional management practices that put special emphasis on investments into human and social capital, such as education and training. Information about success stories was shared among locations. Information sharing was facilitated by cheap communication tools such as the Internet. The experiments varied in their success. As more and more experience and knowledge were collected, the conditions for success were better understood and experiments became more successful on average. Food production became more localized, feeding into national or regional markets that valued clean, green production processes. Environmental technologies were developed based on local needs and conditions, leading to a gradual improvement in management of socioecological systems and natural resources.

By the 2020s, global tourism had begun to encourage development and application of local learning as a celebration of diversity in reaction against global homogenization and the sameness of products. Traveling was seen as a means to experience heterogeneity, but, in the end, had negative feedbacks due to increased transportation and human impact on poorer regions.

Throughout this period of varied learning, there was relatively little focus on global commons problems such as climate change, marine fisheries, and transboundary pollution. Crucial ecological feedbacks were acting over spatial extents that were too large to be noticed by local institutions. As a result, large-scale environmental crises eventually became more frequent. Technological disasters occurred in some natural resource systems. Climate shifts led to more storm surges in coastal areas. Top predators vanished from most marine ecosystems, leaving jellyfish as the apex predator for vast areas of the world. Coastal pollution increased drastically, which led to further degradation of coastal fisheries and severe health risks to humans from eating shellfish, shrimp, and other filter feeders. There were also outbreaks of new diseases, such as rapidly evolving bacteria resistant to antibiotics. Luckily, climate change was not as bad as it could have been because people were trying to curtail local pollutants like nitrogen oxides and sulfur dioxide, which also act as agents of climate change. But sometimes the global phenomena affected local socioecological systems in severe ways.

At about the same time, businesses became more interested in finding new markets in other parts of the world and consumers began to demand a greater diversity of choices. The renaissance of global business led to greater internationalization of governance and negotiation of new international trade agreements. Some global barriers to trade started to erode, and the economy gradually became more globalized.

The negative large-scale environmental events were largely seen as being caused by inadequate management of the global environmental commons. The growing international framework of trade and political institutions provided a foundation on which global environmental management institutions could be rebuilt. The rebuilding was slow and tenuous, due to slowly changing institutions that often needed disaster as a goad to action. Nevertheless, renewal began. The emerging institutions for international environmental management drew on decades of local and regional experience, including a rich history of successes and failures. The emerging institutions were more focused on ecosystem units than in the early decades of the century. Watersheds, air basins, and coastal regions, rather than states or nations, became the basis for management. New large-scale management was also more cautious, focused on learning while managing, based on the successes that learning had brought to many locales earlier. When two or more regions came together to manage a jointly shared problem, they often participated in deliberate small-scale trials to determine the best management practices.

In the year 2050, Earth's socioecological systems seem poised at a branch point. Local ecosystem management is varied and improving in many regions. While problems exist, the situation is better than in 2000. On the other hand, global environmental problems have become more pressing. It seems possible that new approaches will emerge for addressing them, built in part on the varied experiments of preceding decades. This hope beckons at the dawn of the second half of the twenty-first century.

### 5.5.4 TechnoGarden

**Summary:** *Significant investments in environmental technology seem to be paying off. At the beginning of the century, doomsayers felt that Earth's ecosystem services were breaking* *down. As we look back over the past 50 years, however, we see many successes in managing ecosystem services through continually improving technology. Investment in technology was accompanied by significant economic development and education, improving people's lives and helping them understand the ecosystems that make their lives possible. On the other hand, not every problem has succumbed to technological innovation. In some cases, we seem to be barely ahead of the next threat to global life support. Even worse, new environmental problems often seem to emerge from the most recent technological solution, and the costs of managing the environment are continually rising. Many wonder if we are in fact on a downward spiral, where new problems arise before the last one is really solved. As we look to 2100 and beyond, we need to cope with a situation in which problems are multiplying faster than solutions. The science and policy challenge for the next 50 years is to learn how to organize socioecological systems so that ecosystem services are maintained without taxing society's ability to invent and pay for solutions to novel, emergent problems.*

Early in the twenty-first century, increased recognition of the importance of ecosystem services led to increasingly formalized patterns of human/ecological interactions. The trend to formalization led to definition of a wide variety of ecological property rights, which were assigned to a variety of communal groups, states, individuals, and corporations. These rights often prompted ecosystem engineering to maintain provision of the desired ecosystem services. Investment in ecological understanding and natural capital meant that environmental problems were often identified before they became severe.

Such property rights systems eased industrial countries away from protective subsidies and improved income opportunities for developing countries. They also led to increasing government control through ''green'' taxes and subsidies of research and development. Policies emphasizing research and development led to significant scientific efforts, particularly in the use of technological control to maintain consistent resource flows. There was also a strong belief that ''natural capitalism''—a focus on looking for profits in working with nature—could be profitable for both individuals and society. Big business became interested in research and development of new technologies to produce or enhance production of ecosystem services. The impossibility of maintaining exclusive access to information drove ever more rapid innovation during the early period. It was a time of rapid gain and spread of knowledge around the globe. Global communication, combined with open trade policies, allowed the developing world to apply some of the new technologies and start developing their own.

As population continued to grow and demand for resources intensified, people increasingly pushed ecosystems to their limits of production. This ecological engineering was done privately at local, small, or regional scales by a variety of private, public, and community and individual actors and was done within different types of property rights schemes at different locations. Some areas established property rights schemes based on command and control, common property, or market-based schemes, while others remained open access. This engineering was far more sophisticated, subtle, and adaptive than many traditional attempts at ecological engineering. The new ecological engineers were schooled in the engineering approach of ''fast, cheap, and out of control'' and used advances in computer, communication, and materials sciences to permit human infrastructure to be increasingly flexible, dynamic, and adaptive, like wild ecosystems. Innovations such as pop-up infrastructure allowed people to intervene in ecological dynamics rapidly and flexibly.

In response to negative consequences of intensive agriculture in the industrial world—including land degradation, eutrophication of lakes and estuaries, and disease outbreaks—demand for ecological agriculture began to increase. In the 1990s, governments in several European countries had already begun to change or remove agricultural subsidies following a series of agricultural crises in Europe (mad cow disease, foot-and-mouth disease, swine fever, contamination of food with halogenated organic compounds).

Ecological agriculture unfolded in two intertwined planes. Due to the increasing focus on ecosystem services, people began to realize that agricultural systems were embedded within landscapes and that agriculture could not just produce food or fiber at the expense of all other potential services. This led to policies that encouraged farmers to create a landscape that produced a variety of ecosystem services rather than focusing on food as a single service. The goal of multifunctionality moved government agricultural policy away from a focus on the volume of agriculture production to a focus on agricultural profitability. Despite initial concerns that multifunctional agriculture would destroy farming as a way of life and reduce yields, its profitability and lowered risk encouraged many farmers in Europe and North American to convert their operations. This trend began in the 1990s, and its expansion first in Europe and then North America meant that by 2010 nearly half of European and 10% of North American farms were focusing on a multifunctional existence. By 2025, these numbers had jumped to nearly 90% in Europe and 60% in North America. The diversification of agricultural production and lower yields increased the profitability of farming—particularly smaller-scale farming—and reduced the power of large-scale agribusiness.

Ecological agriculture and the end of widespread subsidies opened the rich world to agricultural inputs from poor countries, and this spurred radical changes in agriculture in Eastern Europe and later in Africa and Latin America. Increased ability of developing countries to export agricultural production encouraged investment in intensification. The demand of industrial countries for at least nominally safe and ecologically friendly production helped stimulate intensification efforts to increase production in environmentally friendly ways. Some of these developments came from the use of genetically modified crops. Despite initial opposition in the EU, the absence of all but a few minor ecological problems led to their widespread use. As crop production for the developing world remained somewhat less sensitive to ecological issues, some local ecological degradation resulted from the agricultural intensification. Water pollution, eutrophication, deforestation, and erosion became significant problems in some locations.

These changes did not happen evenly across the entire world. For example, development of green agriculture spread most rapidly in North European countries. East European countries were well positioned to export agricultural products to the EU and were the first to intensify. In Africa the situation was quite heterogeneous; some countries in southern Africa intensified their agricultural production rapidly, while other African countries were unable to respond to these opportunities due to local problems in governance, lack of infrastructure, or water shortages and droughts.

The engineering approach took hold in urban and suburban areas, too. The best urban management focused on creating low or positive impact on ecosystems using green architecture and on diverse transportation strategies and urban parks as functional ecosystems. In rich countries, new housing developments begin to include rain gardens and wetland areas to clarify runoff and provide wildlife habitat. The specific activities that people engaged in varied by location, based on the ecosystem services they desired and the difficulty of providing those services. In general, rich countries focused on providing water regulation services and cultural services, while developing countries focused more on the production and regulation of water and the production of provisioning services. Regional differences within rich and poor worlds continued to exist due to culture, governance, environmental factors, and the way that property rights were organized.

The highly managed urban garden approach sometimes led to destruction of local, rural, and indigenous cultures. Since the dominant values tended to be functional, culture for culture's sake was not highly valued. The degree of this loss was variable across regions, but some cultural loss was inevitable everywhere. This lowered the adaptive capacity of local ecosystem management by diminishing society's capability to detect subtle changes in local ecological processes, particularly in terms of detecting gradual changes in slow processes. On the other hand, sensitive and cheap ecological monitoring did allow for the rapid accumulation of short-term ecological knowledge.

Highly engineered systems turned out to be very vulnerable to disruptions, however. Even successful management was at risk from loss of process diversity, loss of local knowledge, and people's dependence on stable, consistent supplies of ecosystem services. Ecosystems tended to be simplified because the more obscure and apparently unimportant processes were not supported or maintained. At the same time, increasing social reliance on the provision of ecosystem services led to declines in alternative mechanisms of supplying them. These factors combined to greatly increase the risk of a major breakdown in provision of ecosystem services. The problems were especially severe at the boundaries between ecosystems and across scales, where local effects of management interacted with large-scale fluctuations in ecosystem conditions and function.

Looking back from the year 2050, it seems that we did a pretty good job managing and understanding a rapidly changing world. There are some persistent or growing social and ecological problems, like the loss of local knowledge about ecosystem services and eutrophication of fresh waters and coastal oceans. But in general people around the world have better access to resources and we seem to be thinking more about multifunctionality and systems approaches rather than single goals. Looking forward to 2100, there is great hope for continuing improvement in ecosystem management. We will need to cope with a situation in which problems (caused by new technologies) are sometimes multiplying faster than solutions. The science and policy challenge for the next 50 years is to learn how to organize socioecological systems so that ecosystem services are maintained without taxing society's ability to invent and pay for solutions to novel, emergent problems.

## 5.6 Potential Benefits and Inadvertent Negative Consequences of the Scenarios

Each scenario illustrates the potential benefits and potential risks inherent in the path of each particular storyline. (See Table 5.2.) It is important to note that each scenario emerges from the complex interactions of billions of people and millions of institutions, not from the action of a centralized global controller. The world cannot be directed in one of these four ways, but it could self-organize in one of the ways envisioned by the scenarios or in some hybrid of the four scenarios. At the level of individuals and nations, decisions by people will affect this self-organization of the Earth system.

It is reasonable to consider the relative benefits and negative consequences of the scenarios. These are important for those who are considering their own decisions in the context of the scenarios. Also, there are decisions that could tip the world incrementally toward one scenario or another, and decision-makers may wish to take this into account. Finally, we found that individuals hold contrasting views about the desirability of different paths toward sustainability, and by considering benefits and risks we contribute to the dialogue among contrasting points of view.

Global Orchestration shows some obvious positives. Economic prosperity, global economic growth, and increased equity may lead to higher human well-being around the world. If this wealth leads to increased demand for a better environment or to higher capacity to create a better environment, ecosystems may be restored or better protected. As with all paths to the future, there is the potential for inadvertent negative consequences. Increased wealth may not lead to increased demand for a better environment, but only to increased demand for ecosystem services, which could degrade ecosystems through overuse. The focus on global issues in this scenario and the top-down delivery of globally orchestrated policies comes at the expense of local

**Table 5.2. Benefits and Inadvertent Consequences of Four Scenarios**

| Scenario | Potential Benefits | Inadvertent Consequences |
|---|---|---|
| Order from Strength | increased security for those who can afford it<br>political and trade barriers slow the spread of invasive species and some diseases<br>some regions remain well-endowed with ecosystem services | lower economic growth because of fragmentation, inequality, conflict, and lost human potential<br>risk of security breaches (from middle well-off countries)<br>environmental degradation of the global commons, and losses of ecosystem services in poor regions<br>vulnerability due to fragmentation of ecosystem services |
| Global Orchestration | economic prosperity and increased equality due to more efficient global markets<br>wealth increases demand for a better environment and the capacity to create a better environment | progress on global environmental problems may be insufficient to sustain local and regional ecosystem services<br>breakdowns of ecosystem services create inequality (disproportionate impacts on the poor<br>reactive management may be more costly than preventive or proactive management |
| TechnoGarden | highly efficient management and utilization of ecosystems<br>technological enhancement of ecosystem services<br>forward-looking market mechanisms efficiently allocate ecosystem services | increasing reliance on particular technologies may decrease the diversity of systems for providing ecosystem services, thereby increasing vulnerability to surprising breakdowns<br>some technological innovations create the need for new technological innovations<br>wilderness disappears as "gardening" of nature increases, and people have fewer experiences of nature<br>less economic growth because of diversion of resources to environmental technology |
| Adapting Mosaic | integration of management institutions with ecological processes to improve the resilience of ecosystem services<br>growth of adaptive capacity to sustain ecosystem services in a changing world | little progress on global ecosystem problems<br>less economic growth than maximum possible because of regionalization of economies and inefficiencies of experimentation |

and regional flexibility. Progress on global environmental problems may not be enough to sustain local ecosystem services, and without flexibility, these local issues may not be appropriately addressed. Finally, people and institutions in this scenario are generally reactive to environmental problems rather than proactive. Such reactive management may be more costly than preventive management and may experience costly failures in some cases.

Order from Strength has some adverse outcomes for ecosystem services and human well-being. But there are also some possible positive outcomes for ecosystem services. Lower international trade may mean that fewer invasive species are transported. It may also mean that fewer diseases are spread or that diseases are not spread as quickly or as far as they might be in a more globally connected world. The scenario implies that some wealthy people might have high levels of security and that some ecosystems in wealthy areas might be well protected. The potential inadvertent adverse outcomes are more obvious. Fragmentation, inequality, and conflict may lead to lower economic growth and lost human potential. Security may not be high because pressures from the dispossessed will be extremely high. A globally fragmented world also risks degradation of the global commons and problems caused by fragmentation of ecosystems. Severe losses of ecosystems and their services could occur in some areas.

Adapting Mosaic focuses on flexibility locally and regionally. Local empowerment allows management to be proactive with respect to addressing ecosystem management and to integrate management institutions with ecological processes to improve the resilience of ecosystem services. Because the benefits of ecosystem services are allocated fairly, management institutions tend to focus on the current and future provision of ecosystem services. Also, the focus of most people in the scenario is on adaptive capacity, which may help management institutions approach change more flexibly and better sustain provision of services in a rapidly changing world. However, as with all scenarios, this one has potential for unintentional negatives. The high degree of focus on local and regional management leads to less progress on global problems than in a more globalized world. Also, there is less than the maximum possible economic growth because of the regionalization of economics and the inefficiencies of experimentation.

TechnoGarden uses technology to maintain and improve the provision of ecosystem services. The benefits are a highly efficient utilization of ecosystems for service provision of targeted services and actual enhancement of the services provided. This scenario also includes forward-looking market mechanisms, such as futures markets for ecosystem services and appropriate systems of property rights to allocate and manage ecosystem services efficiently. When conditions are stable and predictable, the provision of services is high and extremely reliable. However, increasing reliance on technologies decreases the diversity of systems that provide any one service and increases the number of connections, thus increasing the vulnerability to unexpected environmental or social changes. Some of these technological innovations will create problems that lead to the need for new technological innovations to solve the problems created by the previous innovation. Finally, the "gardening" approach to natural resource management and provision of ecosystem services may cause wilderness to disappear and people to have fewer experiences of nature and wildness. People who are less familiar with ecosystems may be less likely to understand the processes that build resilient and sustainable ecosystem services.

## 5.7 Breakdowns of Ecosystem Services in the Four Scenarios

Interruptions, breakdowns, and surprising changes in ecosystem services have occurred throughout human history and occur in all plausible scenarios of ecosystem futures. Rapid, potentially irreversible changes are an important feature of ecosystems that can confound human capacity for prediction and control. (See Chapter 3.) Surprises related to ecosystem dynamics were identified by MA interviewees as an area of concern. The different scenarios are associated with varying patterns of disturbance to ecosystem services.

Probability distributions of extreme events are one way of describing the differences among scenarios with respect to surprises. Suppose that all disturbances of ecosystem services were documented during each year for Earth as a whole and ranked in magnitude by the number of people affected by the disturbance. Given such data from many years, a distribution could be constructed showing the likelihood of extreme ecosystem events as a function of their magnitude. Distributions of extreme ecosystem events consistent with each scenario are presented in Figure 5.3. These distributions illustrate our qualitative inferences about extreme events in the scenarios. They are not based on data, because no appropriate data or global models exist. These distributions are integrated to produce the cumulative probability diagrams shown in Figure 5.4.

The scenarios are expected to be different in the frequency and magnitude of surprising changes in ecosystem services. In Figure 5.3A, the magnitude of an ecosystem disturbance is measured by the number of people it affects (x-axis). Because of the great range in event severity, we use a logarithmic (base-10) scale for the x-axis. The likelihood of a disturbance of a given size is given by the corresponding y-axis value.

In Order from Strength, in which people have a reactive and geographically limited approach to sustaining ecosystem services, there is a high chance of extreme disturbances. That is, extreme disturbances of ecosystem services have a moderately wide range with a rather high modal value (see Figure 5.3A). In Figure 5.4, the Order from Strength line is far to the right of all other lines, indicating that there is a high probability of a large disturbance event. Most of the human population inhabits relatively impoverished regions with deteriorating ecosystem services, and this situation is

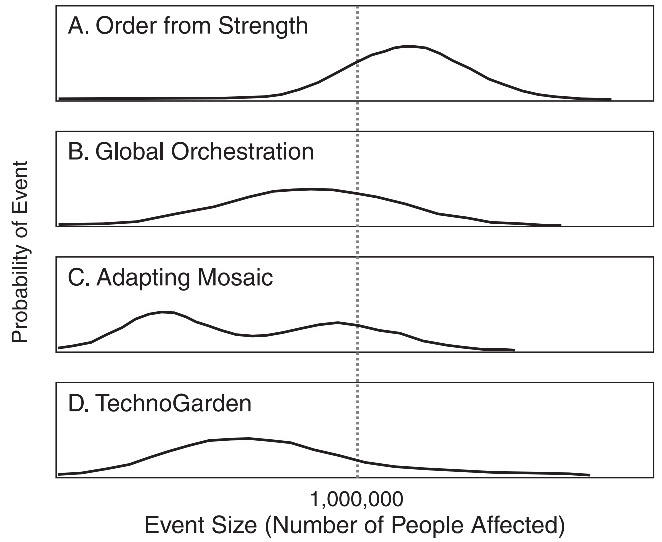


**Figure 5.3. Distributions of Extreme Events during MA Scenarios.** The x-axis is the magnitude of the disturbance of ecosystem services, measured by the number of people affected. The y-axis is the likelihood of an extreme ecosystem event of a given magnitude. The total area under each curve is the same, because for each scenario the probabilities of all event magnitudes must sum to 1. Order from Strength has a very high probability of extreme events affecting just over one million people. Global Orchestration has a moderate probability of extreme events affecting a small number of people due to regional breakdowns in ecosystem services. It has a somewhat lower, but still significant, probability of larger, multi-region breakdowns. TechnoGarden has a moderate to high probability of relatively small events and a low but significant probability of breakdowns that affect extremely large numbers of people.

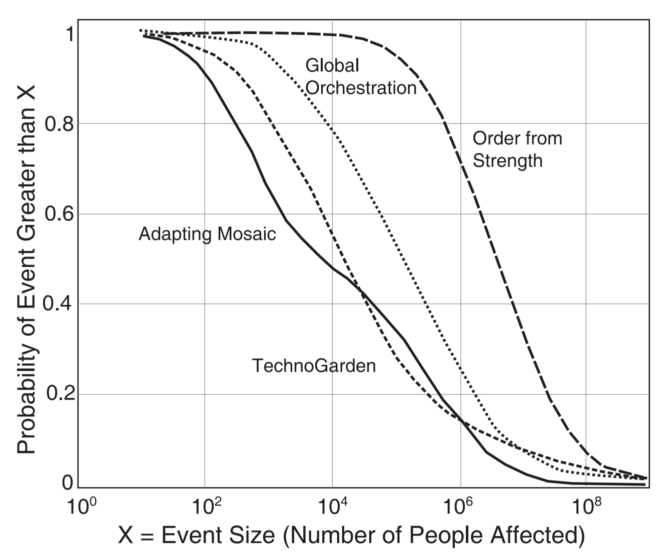


**Figure 5.4. Cumulative Probability Distributions of Extreme Events.** These distributions are derived from the distributions in Figure 5.3. The x-axis is the number of people affected by a given event, and the y-axis is the probability of an event in which more people are affected.

reflected in breakdowns that affect a relatively large number of people.

Global Orchestration, in which the primary approach is fair trade and global policies to ameliorate poverty, has slightly less chance of extreme disturbances because wealth is greater, the world is more connected, and there is greater capacity to react to events when they occur. Also, breakdowns tend to affect fewer people than in Order from Strength. In Figure 5.3B, this is represented in the comparable range but a lower modal value for Global Orchestration. Similarly, in Figure 5.4, the Global Orchestration line is somewhat to the left of the Order from Strength line, indicating that the probability of large events will be somewhat smaller.

In Adapting Mosaic, local vulnerability leads to some extreme events that affect only a small number of people. At the same time, diminished attention to the global commons underlies a small number of extreme events that affect large numbers of people. These large breakdowns are less common than in Order from Strength or Global Orchestration. This is represented as a bimodal distribution of extreme events (see Figure 5.3C). Local adaptation reduces the number of ecosystem service breakdowns that affect large numbers of people. Some regions become vulnerable, and in many years the most extreme breakdowns affect modest numbers of people in these vulnerable regions. At the same time, management of global commons problems, such as the atmosphere and marine pelagic fisheries, tends to be neglected in Adapting Mosaic. Consequently, in some years breakdowns of ecosystem services affect relatively large regions and relatively large numbers of people, thereby creating the second mode in the curve of Figure 5.3C. This bimodal distribution can be seen in the changing slope of the Adapting Mosaic line in Figure 5.4. Also note that the line is to the left of the graph, indicating that most disturbance events affect only a small number of people.

TechnoGarden has the widest distribution of ecosystem event magnitudes (Figure 5.3D). The typical extreme event affects fewer people than Global Orchestration or Order from Strength, but there are many more of these events than in any other scenario. This is also shown in Figure 5.4: the right-side tail of the TechnoGarden line is higher than the lines for all other scenarios. The modal value of extreme breakdowns is lower than the mode for Global Orchestration and lies between the modes for Adapting Mosaic. However, the distribution is widely dispersed; in many years, the most extreme breakdowns of ecosystem services are as large as the upper mode of Adapting Mosaic or the mode in Order from Strength.

The probability of an extreme event that affects more than a given number of people is the area of the curve to the right of that number of people. The vertical dotted line in Figure 5.3 indicates extreme events that affect 1 million people. Thus the area of each curve to the right of the line is the probability of extreme ecosystem events that affect at least a million people. These areas are collected in Figure 5.5. Extreme events that affect at least 1 million people are most common in Order from Strength. They are less common in Global Orchestration. Extreme events are least common in Adapting Mosaic and TechnoGarden, but for different reasons. In Adapting Mosaic, the emphasis of local, not global, commons problems means that there are some large-scale breakdowns of ecosystem services. In TechnoGarden, the emphasis of high efficiency and rigid control makes ecosystem management vulnerable to unexpected events.

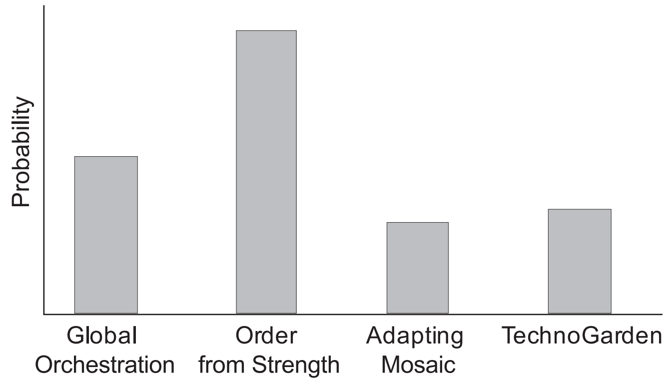


**Figure 5.5. Probabilities of Extreme Ecosystem Events Affecting at Least 1 Million People.** Derived from Figure 5.3.

The impact of an extreme disturbance of ecosystem services will depend on society's capacity to respond, compensate, and adapt to the disturbance. These capacities are expected to differ among the scenarios. In Global Orchestration, there is good capacity to respond to disturbances after the fact, but little attention to addressing underlying causes of ecosystem disturbances. In Order from Strength, rich nations may have considerable capacity to respond to internal disturbances, but the capacity to respond to disturbances in poor nations may be much less. In Adapting Mosaic, local and regional institutions create considerable capacity to address disturbances at those spatial scales, but the Earth system is more vulnerable to global disturbances that affect a relatively large number of people. In TechnoGarden, technology provides a capacity to address some kinds of disturbances, but it also creates new vulnerabilities to the possibility of novel disturbances. The complex interactions of disturbance regimes and capacities to respond or adapt give rise to many of the complex dynamics that are thought to occur in the scenarios.

## 5.8 Transitions among the Scenarios

The scenarios are not predictions. The future of ecosystem services will likely have elements from each of the four scenarios. Indeed, the roots of all four scenarios are evident in the present. Some of our interviewees see tendencies toward Order from Strength in current events. Others see the potential to change the world now through global policies, adaptive local management, and technological innovations. Each scenario proceeds like a river in its own unique channel, but in actuality global dynamics will be more like a braided river, with different channels connecting at some times and diverging at other times. Table 5.3 presents some events that could cause one scenario to branch into another one.

Global Orchestration could branch into Order from Strength if global economic agreements break down, if

**Table 5.3. Potential for Each Scenario to Branch into Another Scenario**

| Scenario | Order from Strength | Global Orchestration | Adapting Mosaic | TechnoGarden |
|---|---|---|---|---|
| Order from Strength | | emergence of strong global institutions; these institutions are recognized as legitimate by most nations, while the derive capacity from the economic, political, and military power of wealthy nations; wealthy nations recognize that their societies cannot be sustained in isolation, and that global reform is necessary | strong regional economic blocs develop; in some regions, there is growing recognition of the importance of ecosystem services and the will to invest in learning to sustain ecosystem services; this recognition spreads, slowly and patchily | same as for Global Orchestration, but more emphasis on environmental technology as the key to building ecosystem services for human well-being |
| Global Orchestration | globalization of the economy stalls; global agreements break down, including those related to the environment; conflict and nationalism spread; wealthy nations look inward | | globalization of the economy gives way to stronger regional blocs; recognition that local ecosystem services are critical for human well-being; devolution of property rights and responsibility for ecosystem services to local authorities | recognition that human well-being depends on ecosystem services and that technology can be used to manage ecosystem services more efficiently; rapid growth of investment in the environmental technology sector |
| Adapting Mosaic | spreading conflict overtakes the collective problem-solving necessary for adaptive management of ecosystem services | increased connectivity of the global economy and expansion of global institutions are driven by growing recognition of the economic opportunities from expanded international trade and by appreciation of common interest in solving global problems of inequity, hunger, disease, and breakdown of global environmental commons | | same as for Global Orchestration, but more emphasis on environmental technology as the key to building ecosystem services for human well-being |
| TechnoGarden | globalization of the economy stalls; global agreements break down, including those related to the environment; conflict and nationalism spread; wealthy nations look inward | environmental technology sector does not compete well economically, so it does not expand to the level envisioned in TechnoGarden | globalization of the economy gives way to stronger regional blocs; recognition that low controllability and low predictability of ecosystem services favor experimental management with multiple approaches and diversified ecosystems; devolution of property rights and responsibility for ecosystem services to local authorities; loss of economies of scale for technological solutions, and loss of confidence in large-scale technological fixes | |

conflict, fundamentalism, and nationalism spread, and if rich nations look inward. Transitions of this type have been considered in previous global scenario exercises. (See Chapter 2.) On the other hand, if globalization gave way to regionalization of economic activity combined with devolution of authority for ecosystem services to institutions at appropriate scales, the resulting system would resemble Adapting Mosaic more than Order from Strength. If in Global Orchestration a strong technological sector emerged, and if society were generally enthusiastic about technological approaches to environmental needs, the system could branch toward TechnoGarden.

It is more difficult to imagine transitions away from Order from Strength, because low economic growth, social breakdown, and environmental degradation would reduce the store of capital necessary for global transformation. If wealthy societies recognized that isolation were no longer sustainable, perhaps they would have the capacity to build global institutions that could move the system toward Global Orchestration. Alternatively, stronger regional economic blocs could develop, at least in some parts of the world. If this economic growth were coupled with investment in human, social, and natural capital and with the development of appropriate institutions for ecosystem management, the system could move toward Adapting Mosaic. This transformation, however, would probably encompass less of the world than envisioned in the global scenario for Adapting Mosaic. In wealthy parts of the world, investments in environmental technology might lead to a sort of TechnoGarden. However, the dispersion of technological innovations globally would probably not occur unless global institutions were expanded. Thus in this family of scenarios, Order from Strength acts like a basin of attraction—it is easier to understand how the global system might move into Order from Strength than it is to understand how the system might move out of it.

The Adapting Mosaic scenario could branch toward Global Orchestration if there were sufficient impetus from transnational economic activity or if global commons problems were perceived as more pressing and urgent. Indeed, a movement toward a more multiscaled sort of Global Orchestration is envisioned near the end of the Adapting Mosaic scenario. On the other hand, Adapting Mosaic could shift toward Order from Strength if slow economic growth exacerbated conflict, fundamentalism, or nationalism. If the diverse approaches to ecosystem management led to successful technological innovations, technology could become an important part of Adapting Mosaic. This would move the system toward TechnoGarden, although the focus would be on local ecosystem management instead of the global focus envisioned in the TechnoGarden scenario.

The TechnoGarden scenario could branch toward Global Orchestration if the environmental technology sector of the economy does not compete well and fails to expand to the level envisioned in the TechnoGarden scenario. The events that could cause TechnoGarden to branch toward Order from Strength are similar to those for Global Orchestration. If globalization stalls, if conflict, fundamentalism, and nationalism expand, and if wealthy nations look inward, the system could move toward Order from Strength. TechnoGarden could move toward Adapting Mosaic if regional trading blocs became stronger. Also, if technological failures led people to think that ecosystems were not predictable and controllable, ecosystem management could move toward diversified adaptive approaches. This would involve devolution of property rights and authority to appropriately scaled institutions. If such changes occurred, the world of TechnoGarden could branch toward that of Adapting Mosaic.

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