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Research, part of a Special Feature on Scenarios of global ecosystem services

Scenarios for Ecosystem Services: An Overview

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ABSTRACT. The Millennium Ecosystem Assessment (MA) scenarios address changes in ecosystem services and their implications for human well-being. Ecological changes pose special challenges for long-term thinking, because of the possibility of regime shifts that occur rapidly yet alter the availability of ecosystem services for generations. Moreover, ecological feedbacks can intensify human modification of ecosystems, creating a spiral of poverty and ecosystem degradation. Such complex dynamics were evaluated by a mixture of qualitative and quantitative analyses in the MA scenarios. Collectively, the scenarios explore problems such as the connections of poverty reduction and ecosystem services, and trade-offs among ecosystem services. Several promising approaches are considered by the scenarios, including uses of biodiversity to build resilience of ecosystem services, actively adaptive management, and green technology. Although the scenarios do not prescribe an optimal path, they illuminate the consequences of different policies toward ecosystem services.

Key Words: *adaptive governance; ambiguity; ecological change; ecosystem services; poverty reduction; regime shift; resilience; response diversity; scenarios, uncertainty*

INTRODUCTION

The world is changing fast, and current trends do not point to an obvious outcome. Consider a few examples. The proportion of people living in poverty has declined, but the absolute numbers of the impoverished are roughly constant (Millenium Ecosystem Assessment (MA) 2005a, Kates and Parris 2003). Wealth inequity has increased among countries, and among citizens within many countries, both rich and poor (Kates and Parris 2003). Yet, more people than ever before live in democratic or quasi-democratic political regimes (Kates and Parris 2003). Only a small percentage of the Earth's people live outside the country of their birth, but many people have migrated to urban areas (Kates and Parris 2003). By 2007, for the first time in human history, Earth's urban population will equal its rural population (Kates and Parris 2003). Urban migrants will consume ecosystem services via longer supply chains, and they will experience greater separation from nature. However, the growth of urban infrastructure offers an opportunity to implement efficient, environmentally friendly technology on an unprecedented scale. Natural disasters that affect at least 1 million people per event have increased fourfold in frequency since 1960 (MA 2005b). This trend is likely to continue as a growing population occupies more vulnerable areas. Natural disasters may overtake armed conflict as a threat to lives and livelihoods. Although conflict is widespread, the number of nations engaged in armed conflict has decreased substantially from the peak of the past two centuries, suggesting a time of opportunity for multinational efforts to broker peace (Sarkees et al. 2003). These somewhat contradictory trends suggest turbulence and unpredictable change, rather than a smooth track to a knowable future.

In humanity's relationship with nature, change is equally rapid. Human action is changing the climate, land cover, oceans, and the biogeochemistry of the fundamental cycles that sustain life, and the diversity of life itself (Steffen et al. 2004, MA 2005b). These changes threaten the future availability of ecosystem services, defined as the benefits that people obtain from nature (MA 2003). Although people are buffered from the natural environment by culture and technology, ultimately our livelihoods, health, and even survival are completely dependent on ecosystem services.

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The future of ecosystem services needs to be better understood. As a step toward understanding the future prospects for ecosystem services, the Scenarios Working Group (a team of 95 experts from 25 countries) undertook an assessment of possible future scenarios for ecosystem services, under the auspices of the Millennium Ecosystem Assessment (MA). The Scenarios Working Group sought to build understanding of ecosystem management by considering a set of possible future paths. The four MA 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. They also consider the consequences of different approaches to ecosystem management, and explore the trade-offs that are faced by decision makers as they consider choices that affect future flows of ecosystem services.

The MA scenarios were designed to incorporate more realistic and detailed ecological dynamics than previous global scenario exercises (Raskin 2005, MA 2005a). Although people modify ecosystems, there are also significant feedbacks from ecosystem change to livelihoods, health, economies, and societies that lead to changes in human systems, engendering further ecosystem change. Our understanding of these feedbacks is in its infancy. At the same time, it is clear that the skill of societies in managing social–ecological feedbacks has powerful implications for whether and how some societies persist (Diamond 2005). Therefore, the MA scenarios consider social–ecological feedbacks.

This paper discusses the unique challenges posed by feedbacks and regime shifts in ecosystem services, and the implications for uncertainty and ambiguity in the MA scenarios. We then explain how the overarching structure of the four MA scenarios was selected. We close by presenting some of the cross-cutting findings that emerge from the set of scenarios.

CHALLENGES POSED BY ECOSYSTEM SERVICES

Previous global scenario studies have addressed ecosystem services only to a limited extent (Cumming et al. 2005, Raskin 2005). The MA Scenarios Working Group took this a step further, by addressing ecosystem services, and the possibility that feedbacks from ecosystem services to other parts of the global system could significantly alter development paths (MA 2005a). In this section, we describe some of the feedbacks and regime shifts that make it difficult to project the future of ecosystem services. We emphasize that many important uncertainties are themselves unknown. Unexpected phenomena have emerged in stressed ecosystems in the past, and this pattern is likely to continue in the future (Bennett et al. 2003). Therefore, scenarios must somehow address the possibility of adapting to completely unexpected events or outcomes.

Ecological Feedbacks May Intensify Human Modifications of Ecosystems

Ecological change can alter the flow and reliability of the supply of ecosystem services that people receive from nature. These changes can, in turn, increase the vulnerability of people and ecosystems to further changes (Cumming et al. 2005). For example, removal of large-bodied predators in coastal areas has decreased the resilience of these ecosystems to cultural eutrophication (Jackson et al. 2001). Degradation of coastal ecosystems has increased vulnerability to storms and tsunamis (Adger et al. 2005). Cascading changes can also occur among ecosystems. Bushmeat hunting in West Africa, for example, has increased following the collapse of coastal fisheries caused by overfishing by international fleets (Brashares et al. 2004).

Drylands provide a striking case of adverse consequences of ecological simplification. Drylands cover about 40% of the Earth’s surface (MA 2005b). They harbor 2 billion people, but have only 8% of the world’s renewable water supply. Of the biomes the MA examined, drylands have the lowest per capita GDP, lowest human well-being, and highest infant mortality rate. Many drylands are overgrazed and overcultivated. These regions are highly vulnerable to changes in rainfall, and this vulnerability is increased when changes in vegetation decrease the capacity of ecosystems to store and regulate water flows. Consequently, human modification of drylands is increasing vulnerability, leading to further modification, and loss of resilience to externally driven changes such as climate change or invasive species (MA 2005b).

Thus, feedbacks and cascading changes can cause major shifts in the availability of ecosystem services, which then alter social dynamics in ways that intensify ecosystem change. The MA working group attempted to incorporate these types of feedbacks into the scenarios.

Regime Shifts

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

Slow losses of resilience set the stage for large changes that occur when the ecosystem crosses a threshold, or is subjected to a random event such as a climate fluctuation (Folke et al. 2005, Groffman et al. 2006). 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).

The MA scenarios considered the risks and consequences of regime shifts. Regime shifts in ecosystems can cause rapid, substantial changes in ecosystem services and human well-being. Regime shifts may be exacerbated by human action. On the other hand, certain kinds of proactive policies may enable people to build resilience against regime shifts, decrease the risk of regime shifts, or even promote regime shifts to create more desirable conditions. These possibilities are explored in the scenarios.

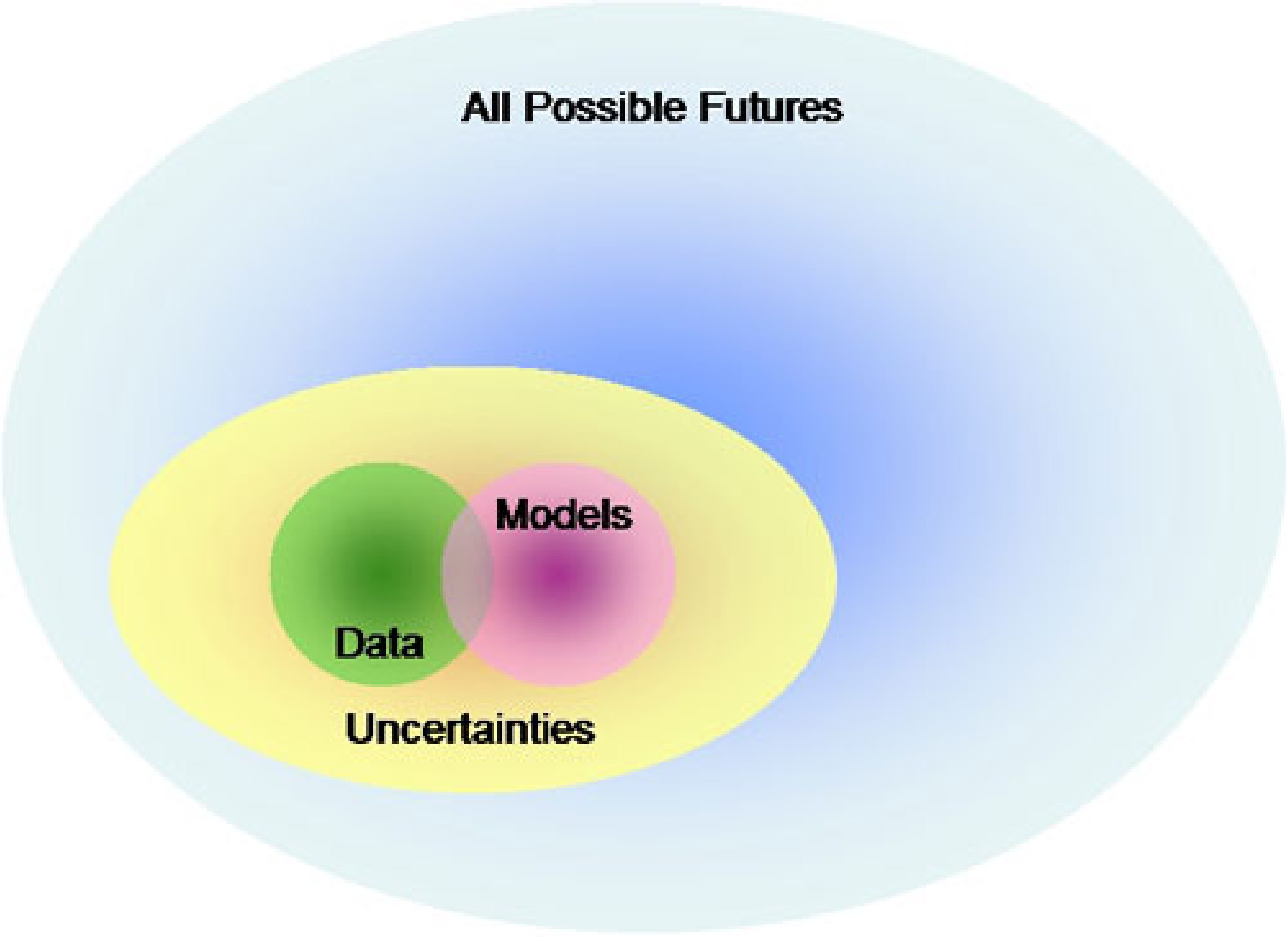
Ambiguity and Uncertainty

The number of plausible trajectories for Earth's ecosystem services is uncountable. This full, and unknown, space of future possibilities is represented by the blue ellipse in Fig. 1. Most people have some useful ideas about how these trajectories might unfold. We also have at our disposal a small number of more formal models for projecting the future (MA 2005a). Collectively, these models, informal and formal, are represented by the magenta circle. We also have access to data (both formal scientific measurements and informal observations by people) represented by the green circle. To some extent, data and models overlap and are mutually reinforcing. Outside the overlap of the circles, there are aspects of models that are not fully tested against data, and aspects of data that are not yet assimilated into models. Together, the circles of data and models represent the information we have to assess and project the future of ecosystem services. Around the circles is a yellow halo of uncertainty, the “known unknowns” that can be inferred from existing information. The blue space beyond the yellow ellipse represents the “unknown unknowns,” the mysteries and surprises that have not yet been imagined (Smith 2002).

The unknown unknowns are likely to be important (MA 2005a). The history of life on earth is one of emerging novelty and surprise, a one-way trip (Gould 1990). The same is true of the climate (Smith 2002), which is only one of many drivers of ecosystem services. Models calibrated on the past can predict only incremental steps toward the future, not the important changes that transform social and ecological systems. Thus, the future of ecosystem services is ambiguous (that is, no probability distribution can be assigned to any particular trajectory (Walley 1991)).

Because the full range of possible trajectories is unknown (blue ellipse of Fig. 1), probabilities cannot be calculated for any given projection of future ecosystem services. In principle, one could calculate probabilities for projections within the yellow ellipse of known unknowns, but these

Fig. 1. The full set of possible futures of ecosystem services (blue ellipse) is only partially represented in available data (green circle) and models (magenta circle). Together, the data and the models allow us to project the uncertainties, or knowable unknowns (yellow ellipse). The unknowable unknowns are the portion of the blue ellipse beyond the edge of the yellow ellipse. The probability of any model projection of future ecosystem services depends on the full set of possible futures, most of which are unknown. This diagram is based on the ideas of L. A. Smith (2002).



probabilities are of little use because the full space of possible outcomes is unaccounted for. Even within the yellow ellipse, it is difficult to compute probabilities for several reasons. The set of extant models is not exhaustive; unknown but important models are missing. Also, the models are not independent (e.g., many ecosystem service models are calibrated from the same data, or from each other). Consequently, probabilities cannot be calculated for any projection of future ecosystem services. It is possible to calculate probabilities for projections *conditional on the models*, but even these calculations require many untested assumptions and fail to address the main question. Also, the results would be obsolete as soon as they were known, because people could act on the results and thereby invalidate the assumptions. Most importantly, such conditional probabilities are irrelevant to the unconditional probabilities needed for decision making (Smith 2002).

Thus, the scenarios are not predictions. They are, instead, plausible accounts of the future, selected to represent clusters of informal models held by many people (see following section) that contrast in ways that may be important for decision makers. An important use of scenarios is to understand the consequences of different assumptions about policies. Each of the scenarios addresses a set of assumptions that are currently discussed among decision makers and experts concerned with the future of ecosystem services.

STRUCTURING THE MA SCENARIOS

Although an infinite number of imaginable futures might be explored with the MA scenarios, scenarios are most powerful when presented as a small set with clear and striking differences (van der Heijden 1996). The Scenarios Working Group used interviews with leaders as well as feedback from the MA Board and Convention Secretariats to help identify the main contrasts to be addressed (MA 2005a).

Scientific assessments are most helpful to decision makers when the intended users are active in the assessment process and, especially, when the users directly help shape the questions that the assessment will answer. To this end, the MA team interviewed 59 leaders in non-governmental organizations (NGOs), governments, and industry from five continents to find out their concerns about the next 50 years (Bennett et al. 2005, MA 2005a). We chose leaders from many sectors and nations to gain access to a wide range of concerns and responses (Bennett et al. 2005). Based on methods of previous scenario work (van der Heijden 1996), we asked open-ended questions designed to elicit conversations about those factors that interviewees felt were critical determinants of the world’s future (Table 1).

The leaders were concerned with sustainability. They agreed on many factors that they believed would play a major role in determining the future. Experts disagreed, however, in their beliefs about future trajectories of ecosystem services. Interviewees disagreed on whether humans were on a path to sustainability, and they also disagreed about what actions would put, or keep, us on a sustainable path. Although certain factors came up repeatedly as being important, interviewees disagreed about whether their effects were positive or negative. These factors included: the role of governments in local, national, and global governance; security; resilience and learning; and technology. It was clear that these factors would have to play a major role in the scenarios. But how to integrate these factors into clear and useful stories?

We believed that the scenarios should embrace the diversity of viewpoints held by the interviewees. By organizing diverse viewpoints in scenarios, we hoped to facilitate debate and discussion. Our analyses of the interview results suggested that beliefs about the future tended to cluster in certain ways. We identified four clusters, and developed coherent stories that represented beliefs about the future represented by each cluster (Fig. 2). For example, some interviewees stated that global cooperation to alleviate poverty was the key factor determining whether the future would be sustainable. So we developed a story around global cooperation to alleviate poverty and explored the benefits and risks of this type of approach (Global Orchestration). We did the same for the other themes that emerged from the interviews: green technology (TechnoGarden), locally based learning (Adapting Mosaic), and security (Order from Strength) (Cork et al. 2006).

A complete quantitative analysis of the scenarios was not possible. Quantitative models exist for only a subset of the ecosystem services considered by the MA (MA 2005a). Also, as described above, the future of ecosystem services is ambiguous, and many uncertainties cannot be quantified. Therefore, the MA analysis involved both quantitative and qualitative analyses (Fig. 3). The quantitative and qualitative results were cross-checked to harmonize them. We (and many other participants in the MA process) believe that additional iterations between qualitative and quantitative analyses would have improved the results. Future global scenario projects that address ecosystem services should include more time and funds for iteration between qualitative and quantitative analyses.

SOME CROSS-CUTTING INSIGHTS FROM THE SCENARIOS

The MA Scenarios technical volume presents a rich, detailed, and lengthy analysis of the scenarios (MA 2005a). The papers in this special feature aim to provide an accessible entry point to the scenarios

Table 1. Questions asked in the MA Interviews (from Bennett et al. 2005)

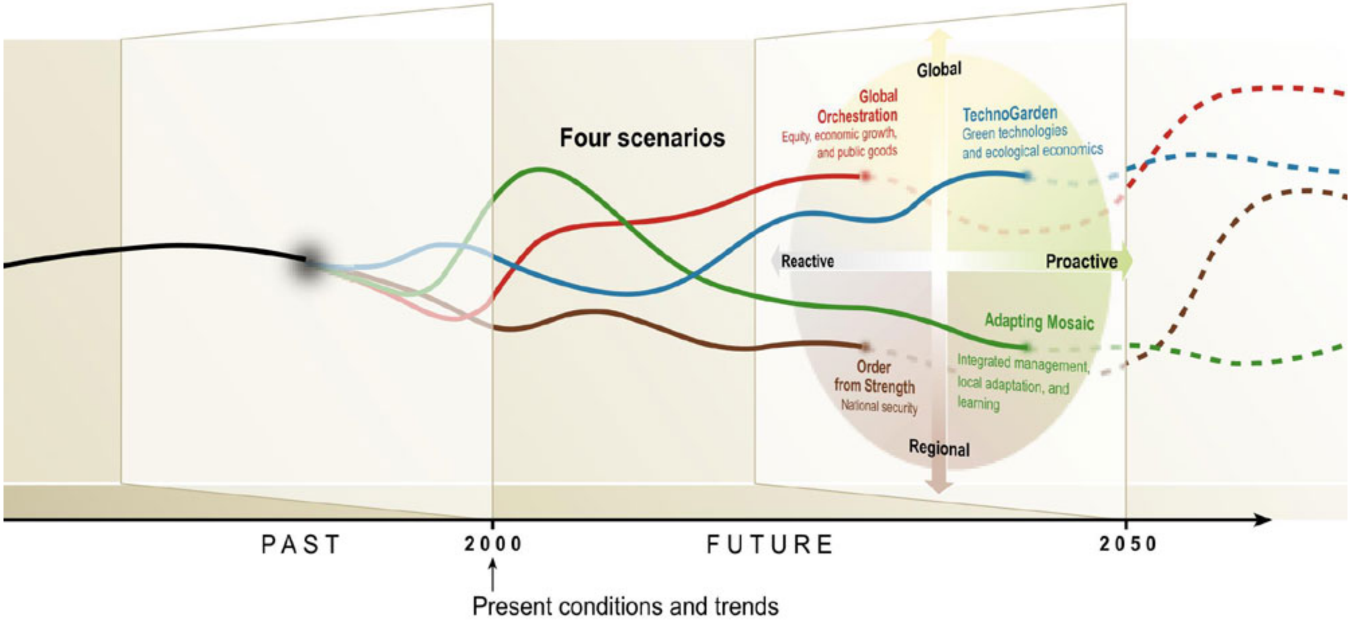
What words would you use to describe the current state of the Earth’s natural and human systems?
What words would you use to describe the ideal state of the Earth’s natural and human systems in 2050?
What obstacles do you envision to achieving this ideal world?
If you could talk to someone who visited 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?

by selecting highlights. In that spirit, this section of our paper selects five synthetic findings that emerge from considering the MA scenarios as a whole. These are not the only cross-cutting insights from the MA scenarios, but they do illustrate ways in which the scenarios illuminate dynamics of ecosystem services. First, we discuss two cross-cutting challenges that emerge from the scenarios—the connection between poverty reduction and ecosystem services, and the difficult choices involved in trade-offs among ecosystem services. We close by discussing three approaches that offer hope for the future: building resilience through regulating ecosystem services, actively adaptive ecosystem management, and investment in green technology.

Poverty Reduction and Ecosystem Services

Poverty and ecosystem degradation are closely associated and exacerbate one another (Biggs et al. 2004). The feedbacks that produce the spiral of poverty and ecosystem degradation are incompletely understood. The alleviation of poverty often depends upon access to a reliable supply of ecosystem services (Martinez-Alier 2002). Yet, although growing wealth may increase demand for cleanup of certain aspects of the environment, other aspects of ecosystem degradation seem to be tolerated by wealthy people (Stern 1998, Khanna and Plassmann 2004, Gergel et al. 2004). The scenarios show that economic growth, expansion of education, and access to technology increase the capacity of people to mitigate and adapt to environmental change. At the same time, however, the growth of human, social, and manufactured capital can degrade natural capital and ecosystem services.

Fig. 2. The four MA scenarios begin from current conditions and trends. The paths then branch, depending on the extent to which the world is globalized vs. regionalized, and the extent to which ecosystem management is reactive (responding to ecosystem problems after they occur) vs. proactive (deliberately seeking to manage ecosystem services in sustainable ways). In Global Orchestration, there is global economic liberalization with strong policies to reduce poverty and inequality, and substantial investment in public goods such as education. In Order from Strength, economies become more regionalized, and nations emphasize their individual security. Adapting Mosaic also has more regionalized economies, but there is emphasis on multi-scale, cross-sectoral effort to sustain ecosystem services. In TechnoGarden, the economy is globalized, with substantial investments in sound environmental technology, engineered ecosystems, and market-based solutions to environmental problems. Source: MA (2005a).

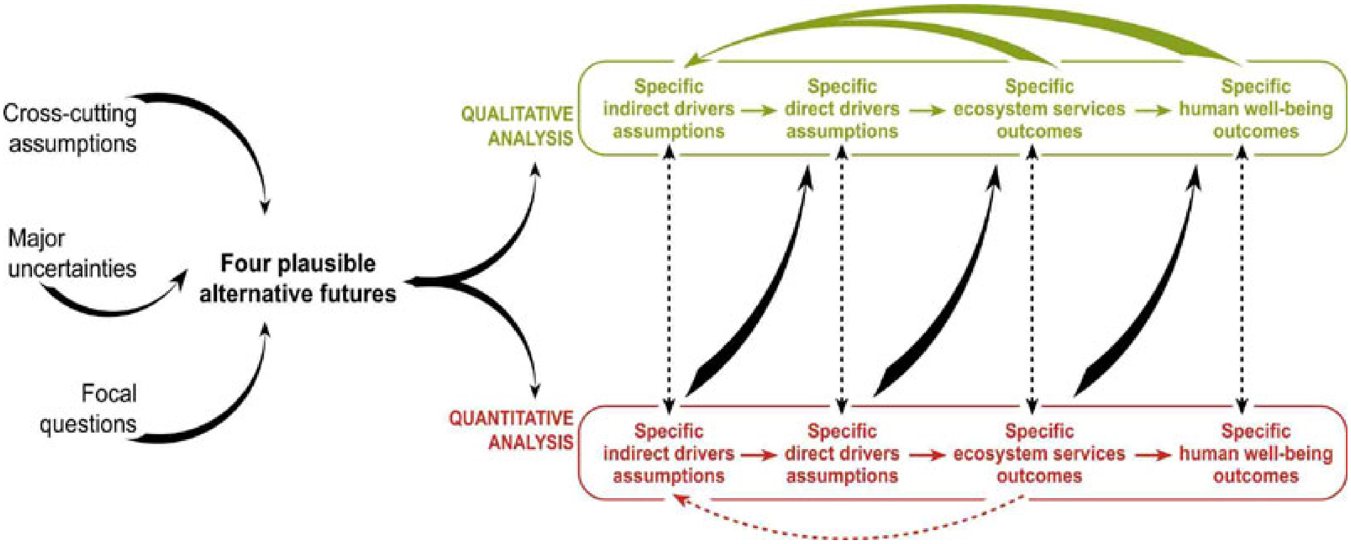


The scenarios indicate that severe and irreversible declines in ecosystem services and human well-being may occur if people do not husband and enhance natural capital at the same time as human, social, and manufactured capital are built. A focus on poverty reduction that erodes the supply of ecosystem services can make poverty alleviation more difficult. Some strategies for achieving poverty and hunger reduction can increase pressures on ecosystems, thereby compromising the capacity to maintain benefits in the long run. In particular, enhancing the supply of a provisioning ecosystem service (e.g., food production) can reduce the supply of other provisioning ecosystem services (e.g., water, fish, or wildlife), thereby removing alternative income sources. Overexploitation of provisioning ecosystem services usually degrades regulating ecosystem services that maintain air, soil, or water quality. This decreases the future yield of provisioning services, and increases vulnerability of people to environmental variability.

Trade-offs among Ecosystem Services

Most decisions about ecosystem services involve trade-offs (Rodriguez et al. 2006). Trade-offs occur between different services as well as between the present and future supply of a service. Agriculture is a nexus of several important trade-offs among ecosystem services. For example, clearing forest land for agriculture improves the provision of food,

Fig. 3. Flowchart of scenario development. The focal questions, major uncertainties, and cross-cutting assumptions were used to develop basic ideas about four plausible alternative futures. These futures were elaborated using qualitative methods (the upper part of the figure) and quantitative methods (the lower part). At each step, quantitative and qualitative results were cross-checked (dotted lines between boxes). Quantitative results of each step were used to help determine qualitative results of the next step (diagonal arrows). Finally, feedbacks from qualitative ecosystem services and human well-being outcomes were used to re-evaluate assumptions about indirect drivers. This feedback procedure was also done in a qualitative way for some quantitative ecosystem services outcomes. Source: MA (2005a).



but may lead to declines in biodiversity, water purification, and climate regulation provided by the forest. In trade-off decisions, people often prefer, in sequence, provisioning (e.g., food, fiber, and water supply), cultural (e.g., esthetic or spiritual values), and then regulating services (e.g., capacity of ecosystems to purify air or water, or maintain soil fertility). Thus, people tend to undervalue regulating services and the ecosystem processes (or supporting ecosystem services) that create them. Slowly changing ecosystem components, which tend to generate regulating services, are often ignored by policy makers in ways that seriously undermine the long-term existence of provisioning ecosystem services.

There are also trade-offs between use of services now and the use of services in the future. For example, overstocking of pastoral land in the present may decrease the land's capacity to support livestock in the future. Economic discounting is sometimes used to decide trade-offs between the present and the future. Recent analyses show that proper accounting for economic and ecological uncertainties drives discount rates for ecosystem services to low levels, thereby increasing the value of future benefits (Ludwig et al. 2006). Therefore, it is likely that incorrect discounting has driven overexploitation of ecosystem services by undervaluing future benefits (Ludwig et al. 2006).

Trade-offs among ecosystem services pose extraordinary challenges. They are difficult to analyze and anticipate, yet decisions about trade-offs have enormous impact on future ecosystem services.

Building Resilience through Regulating Ecosystem Services and Biodiversity

Impact of extreme events can be moderated by building social–ecological resilience through attention to regulating ecosystem services.

Regulating ecosystem services are associated with the capacity of social–ecological systems to cope with, or adapt to, disturbances of various kinds. However, human action has frequently decreased regulating services, while at the same time increasing the frequency and intensity of shocks. This combination greatly increases the vulnerability of ecosystems and the people who depend upon them. Consequently, maintenance and enhancement of regulating services provide important insurance and adaptability against accelerating human and ecological changes.

Resilience of ecosystem services depends in part upon the species that exist in an ecosystem. Functional groups are sets of species that perform similar ecosystem processes (Walker et al. 1999, Elmqvist et al. 2003). Diversity within functional groups maintains the rate of ecosystem processes despite environmental fluctuations, if the individual species respond differently to environmental fluctuations (Frost et al. 1995, Ives et al. 1999, Cottingham et al. 2001, Elmqvist et al. 2003, Norberg 2004, Folke et al. 2005). This phenomenon is called response diversity. In the face of often novel anthropogenic changes in the environment, preserving the diversity of species and functional groups increases the chance that species are retained that will play a crucial role in the future. 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 change for which diversity may provide insurance is expected. Preserving biodiversity cannot substitute for reducing other kinds of anthropogenic stresses to ecosystems.

Diversity of spatial pattern provides another 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 the dispersal range of the affected patch, then the missing process can be re-established.

Response diversity acts across scales through interspecific differences in the use of space (e.g., dispersal ability, patch size, home range size) and time (e.g., generation time, dormancy period, seasonality). A given ecological disturbance occurs at defined 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 (e.g., highly mobile species) or time scales (e.g., long-lived species or large-bodied generalist predators) are an important element of ecosystem response diversity (Peterson et al. 1998).

The effect of diversity on resilience depends on organization of species among functional groups, response diversity, spatial pattern, and scaling of ecosystem processes in time and space. Response diversity links biodiversity to the resilience of ecosystem services, but changes in species richness may increase or decrease resilience. For example, a species invasion that adds to species richness can decrease the resilience of ecosystem services if it reduces response diversity.

Actions that manipulate species composition to enhance the supply of specific ecosystem services can reduce the resilience of regulating services, thereby decreasing future yield of provisioning ecosystem services or increasing the impact of extreme events. However, scenarios that conserve or enhance response diversity can maintain flows of provisioning ecosystem services and reduce vulnerability to environmental and social shocks.

Actively Adaptive Management and Adaptive Governance

Ecological management and planning have tended to assume that ecological processes are well understood and readily manipulated. In a world in which ecological change occurs quickly, approaches that allow managers to consider uncertainty and learn are more likely to be successful and to improve future management (Peterson 2005). When people make management decisions, they do so based on some expectation, or prediction, of what results their intervention will produce. Unfortunately, in complex social–ecological situations, where connections between people and ecosystems are continually changing, our understanding of ecological and social change is often inadequate to predict what the consequences of our actions will be. In light of this complexity, it is dangerous to view a management action as a solution to a problem. Instead, management actions should be viewed as experiments that can lead to learning. Adaptive environmental management is a structured process that aims to reduce the costs of such experiments, while increasing opportunities for learning. Adaptive environmental management articulates alternative hypotheses that address uncertainties, and develops management plans that evaluate hypotheses by using the human manipulation of ecological processes to strategically probe the functioning of ecosystems (Holling 1978).

Such adaptive approaches can accelerate social learning and provide the capacity to cope with ecological change. However, management that incorporates experimentation has risk, and therefore, cost (Carpenter 2003). These risks are more acceptable when ecosystems have the resilience to cope with surprise, and the people involved in management have some degree of trust in one another. The presence of networks of scientists, managers, technicians, and citizens among different ecosystems helps learning and technological innovation spread among social–ecological systems. Although such networks can be catalyzed by communication technology, they depend upon shared interests, experiences, and trust (Olsson et al. 2006). Because of the critical importance of networks, leadership, and institutional structures in the success or failure of adaptive management, many workers have broadened the scope to consider “adaptive governance” (Dietz et al. 2003). Characteristics of adaptive governance have been addressed by many recent books (e.g., National Research Council 2001, Berkes et al. 2002), as well as the Response Options Working Group of the MA (MA 2005c).

Use of Technology

Technology helps determine what sorts of ecosystem manipulations are possible and what forms of ecosystem governance are tenable. Technology can significantly increase the availability of some ecosystem services. For example, increases in efficiency of use of energy, water, and fertilizer lead to significant improvements in the supply of ecosystem services and human well-being in the scenarios. Although technology has great capacity to improve efficiency of provision, management, and allocation of ecosystem services, its capacity to substitute for ecosystem services is limited. In some cases, such as desalination of sea water, costs of substituting technology for the natural hydrologic cycle are high (Postel and Carpenter 1997). For cultural services, it is difficult to imagine how technology could provide a meaningful substitute—for example, to replace a tiger or wild salmon.

Technology can give people greater latitude to shape the trade-offs among ecosystem services (Rodriguez et al. 2006). For example, rivers can be managed in a fashion that provides flood protection, irrigation, and wildlife habitat. In particular, agricultural technology has important implications for the supply of ecosystem services. The technologies of monitoring, fertilizing, watering, and transporting crops will alter the degree to which agro-ecosystems produce many ecosystem services (food as well as water and wildlife), as well as their impact on other ecosystems to which they are connected. Advances in construction and energy technologies also have great potential to improve ecosystem services.

The development of technology will both shape and be shaped by society’s approaches to ecosystem management. The development of property rights for ecological services, for example, will co-evolve with technologies that augment the ability of people to monitor ecosystems. As a specific case, regulation of offshore fisheries can be enhanced by technological developments in communication and computation that allow the tracking of both fish and fishers. Strengthening of fishers’ property rights will likely stimulate investment in technologies to improve fish management (Repetto 2006).

Technological improvements in agriculture, logistics, energy efficiency, materials, and ecological design have the potential to make substantial improvements in human well-being while decreasing the adverse impact of humanity on its own life support. However, it is important to carefully consider and monitor the potential unintended consequences of new technologies as they are applied. Evidence from the past indicates that even apparently beneficial technologies (e.g., chlorofluorocarbons (CFCs)) can sometimes have major unexpected negative consequences (e.g., the ozone hole). Yet, technology has the potential to move humanity’s effects on the biosphere from being largely adverse, to interactions that nurture the ecosystem services that support human and other life.

CONCLUSIONS

The MA scenarios consider future ecosystem services in the context of global changes in society and the Earth system. This has expanded the richness of global scenarios. The scenarios also draws attention to important analytical challenges, notably the strong reciprocal feedbacks between society and ecosystem services. The connections between poverty alleviation and changes in ecosystem services, and the trade-offs among ecosystem services, are especially challenging. Numerous approaches offer potential benefits, e.g., resilience building through response diversity, actively adaptive management, and green technology, yet in all cases, these benefits must be balanced against costs and risks. Benefits, costs, and risks are incompletely known and hard to predict. Yet, decisions must be made. The MA scenarios are a tool for building understanding in support of these decisions, not a prescription for optimal decision. In this regard, the main contribution of the MA scenarios is to explore logical consequences of different assumptions about policies toward ecosystem services.

Responses to this article can be read online at:
http://www.ecologyandsociety.org/vol11/iss1/art29/responses/

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