ECOLOGY

Millennium Ecosystem Assessment: Research Needs

The research community needs to develop analytical tools for projecting future trends and evaluating the success of interventions as well as indicators to monitor biological, physical, and social changes.

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The Millennium Ecosystem Assessment (MA) was designed to meet the needs of decision-makers for scientific information on the consequences of ecosystem change for human well-being (*1–3*). Even though the intended audience is decision-makers, the scientific community is involved as assessments are being made, especially when research and data gaps become apparent. Here we summarize the most important information needs encountered in the MA work.

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Basic Theory

We lack a robust theoretical basis for linking ecological diversity to ecosystem dynamics and, in turn, to ecosystem services underlying human well-being. We all need this information to understand the limits and consequences of biodiversity loss and the actions needed to maintain or restore ecosystem functions.

The most catastrophic changes in ecosystem services identified in the MA involved nonlinear or abrupt shifts. We lack the ability to predict thresholds for such changes, whether or not a change may be reversible, and how individuals and societies will respond. Thus, the risks of ecosystem catastrophes are poorly quantified. Major ecosystem degradation tends to occur as syndromes of simultaneous failure in multiple services. For example, the populous dry lands of the world are facing a combination of failing crops and grazing, declining quality and quantity of fresh water, and loss of tree cover. Similarly, many rivers and lakes have experienced increases in nutrient pollution (eutrophication), toxicity, and biodiversity loss.

Relations between ecosystem services and human well-being are poorly understood. One gap relates to the consequences of changes in ecosystem services for poverty reduction. The poor are most dependent on ecosystem services and vulnerable to their degradation. Empirical studies are needed.

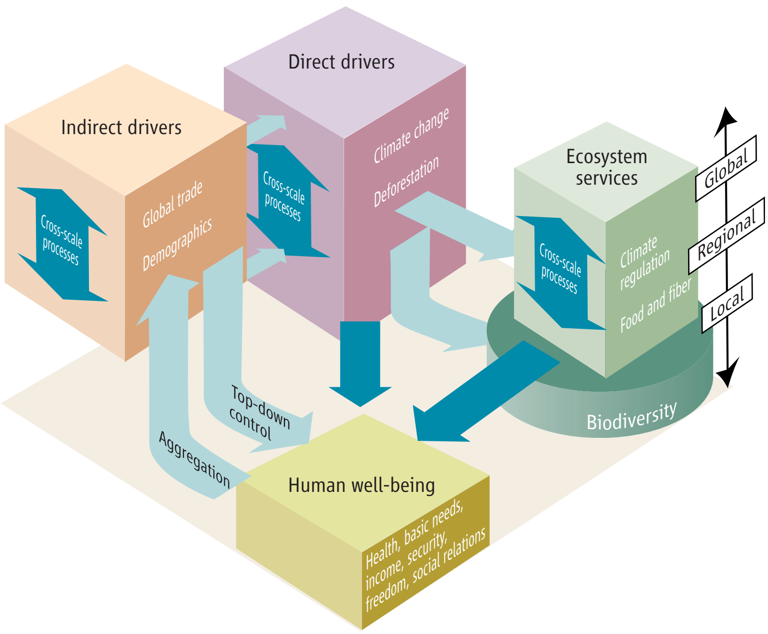
Local to Global Scales

Local processes sometimes spread to become important regionally or globally, but ecosystem services at more aggregated scales are seldom simple summations of the services at finer scales. An example of a cross-scale effect is the loss of buffering coastal ecosystems that exposed extensive regions to catastrophic damage in the 2004 Asian tsunami and the 2005 Gulf of Mexico hurricanes. Conversely, most services are delivered at the local scale, but their supply is influenced by regional or global-scale processes (see figure). Although there are many case studies, our capability of predicting emergence of cross-scale effects and their impacts on ecosystem services is limited. A related problem is the mismatch between the scales at which natural and human systems organize. These lead to failures in feedback, when, for instance, benefits accrue at one scale, but costs are carried at another. We need robust, manageable frameworks for analyzing ecosystem services at multiple scales. Inclusion of "subglobal" assessments in the MA was a tentative step in this direction.

Monitoring and Indicators

Despite advances in monitoring technology, the lack of uninterrupted time series of sufficient length to reflect social-ecological dynamics is a major problem. More disturbingly, the information available today is sometimes of poorer quality than historical information. For example, hydrology monitoring networks in many countries are deteriorating, and institutions to maintain long-term records of Earth observations from satellites are not in place.

Specific data gaps that posed serious constraints in the MA analysis include the lack of (i) global time-series information on land cover change; (ii) adequate information on location and rate of desertification; (iii) global maps of wetlands distribution; (iv) systematic information



The MA conceptual framework (*2*), modified to illustrate connections among local, regional, and global scales for a few processes. Light blue arrows indicate actions that are amenable to policy interventions.

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on stocks, flows, and economic values of many ecosystem services (e.g., freshwater fisheries, natural hazard regulation, groundwater, and pollination); (v) knowledge of trends in human reliance on ecosystem services, particularly services without market values (e.g., domestic fuel wood and fodder); (vi) systematic local and regional assessments of the value of ecosystem services; and (vii) connections between data on human systems and ecosystems. Trends in ecosystem services are often most effectively communicated through indicators that simplify and synthesize the underlying complexity (*4*). Many ecosystem indicators have been proposed [e.g. (*4*, *5*)], but there is no consensus on a manageably small set that can be consistently applied and serves the needs of decision-makers and researchers.

There are challenges to developing indicators of ecosystem services. How can observable attributes of ecosystems and human well-being be linked? How can indicators be aggregated across spatial scales without smoothing out important heterogeneity? How can indicators reflect future consequences for human well-being? What is the minimal set of indicators to represent multiple facets of ecosystem services? Assessments must convey the confidence attached to particular indicators. In most cases, the MA was unable to quantify uncertainty. Work is needed to improve identification, quantification, and communication of uncertainties (*6*–*9*).

Attributes used for monitoring social and economic variables, such as gross domestic product or population, have been collected over long periods and have an established role in decision-making, but their spatial resolution is coarse. Biophysical observations typically have great spatial detail, but short records and little political traction. Integrating both types of data into policy discussions is a key challenge.

Policy Assessment

Existing policies constitute "experiments" from which we can learn (*10*). For example, there has been a proliferation of biodiversity conservation strategies designed to increase local incentives for conservation. Yet, McNeely *et al*. (*11*) conclude that "A key constraint in identifying what works and what does not work to create economic incentives for ecosystem conservation is the lack of empirical data supporting or refuting the success of *any* approach." We already have evidence that sustained interdisciplinary effort can yield sound science and practical guidance (*12*).

We need to understand how the effects of response strategies vary among ecological and social contexts. We don't know what conditions must be met or how to tailor planning and decision-making to local circumstances. Even in the few cases where research has explored options to maximize individual services (such as crop production), there is limited research into trade-offs with other ecosystem services (such as water resources or biodiversity). Understanding of the costs and benefits of alternative management approaches for the entire range of ecosystem services is essential. The few examples that assess the bundle of ecosystem services provided by a region show that a single-service analysis misses key trade-offs (*13*).

Linking Social to Ecosystem Change

Most research related to ecosystem services focuses on direct drivers, such as land use change or invasive species. Yet, effective management requires more attention to indirect drivers such as demographic, economic, sociopolitical, and cultural factors. In their assessment of forest responses, Sizer *et al*. (*14*) conclude that "[Forest sector] outcomes tend to be shaped as much or more by policies and institutions related to trade, macroeconomics, agriculture, infrastructure, energy, mining, and a range of other 'sectors' than by processes and instruments within the forest sector itself." In some cases, indirect drivers may provide better leverage points for policy than the direct drivers (*15*).

People have enormous capacity to adapt. Thus, investments in education and technology have substantial implications for future ecosystem services. However, we have limited capacity to project the effects on ecosystem services of investments in education or development of green technology.

Economic Instruments and Valuation

The MA found potential in economic incentives to improve ecosystem management, but little research on the effectiveness of different approaches. At present, most ecosystem services are not marketed. The resulting lack of information about prices that reflect social value is an impediment to design and implementation of economic policy instruments. The gap is particularly acute for "regulating services," such as disease and flood regulation and climate control, which are rarely priced, yet have strong effects.

Valuation translates ecosystem services into terms that decision-makers and the general public can readily understand (*16*). The MA attempted to provide a systematic accounting of the value of changes in ecosystem services but was limited in its ability to do so. Often, the ecological production functions that describe the relation between ecosystem condition and the provision of ecosystem services have not been quantified. Too often, ecological and economic studies are carried out separately; as a result, the most reliable ecological and economic information cannot be brought together.

Conclusions

Meeting the research needs described will require new coalitions among disciplines that traditionally have been isolated and funded by programs that are discipline-specific. It also requires much greater interaction among resource-based institutions and their policy processes. Achieving a sustainable world depends on a full understanding of the connections between ecosystems and human well-being and the drivers and responders to change. The MA has provided a road map; now, we need to start the journey.

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