The millennium ecosystem assessment: what is it all about?

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Hundreds of scientists from over 70 nations are now engaged in an intensive effort to assess what we know about the status of the world's ecosystems. Here, we describe the fundamental nature of this assessment, what it hopes to accomplish and how it will go about its work. The results of the Millennium Ecosystem Assessment will serve as a baseline for future assessments, as well as a blueprint for action for sustaining the ecosystem services upon which we all depend for our well being.

The conventional wisdom among biologists is that the ecosystems of the Earth are being massively impacted by human activities and that this is not a positive thing. Although our demands for ecosystem services, such as food and clean water, are increasing, we are simultaneously reducing the capacity of many ecosystems to actually meet these demands. Sound policy and management decisions can often address ecosystem degradation and increase their contributions to our well being, but knowing how and when to intervene requires significant understanding of both the ecological and social systems involved. However, not all members of society subscribe to this viewpoint. A more holistic analysis than has been utilized previously is needed so that both researchers and the public can evaluate for themselves the consequences of what is happening in relation to the values that they hold dear, including attaining social goals, such as the alleviation of poverty. This is the challenge faced by the Millennium Ecosystem Assessment (MA) [1], which is a consortium of hundreds of scientists from over 70 nations who are involved in the most extensive study ever of the links between human well being and the world's ecosystems. The aim is to 'to establish the scientific basis for actions needed to enhance the contribution of ecosystems to human well being without undermining their long-term productivity' [1]. Simply put, 'how can we sustain the capacity of ecosystems to provide for human needs under increasing human demands put upon them?'. This is not a modest goal, but one that is crucial to achieve as the burgeoning human population and uneven human consumption patterns intensify, creating additional demands on the natural resources of the Earth system. To accomplish this goal, scientists are assessing our available knowledge to piece together the many complex threads of information that are needed to document and model trends and interrelationships and to assign degrees of confidence to the information base that is presently available. Additionally, they are using quantitative trends and qualitative modeling techniques to make projections of future world possibilities (see Box 1 of an example of a specific assessment being conducted in southern Africa).

Operationally, the MA focuses on central questions. In simple terms, these are: (i) what is the current status of ecosystems and the services that they provide for human well being and how have they been modified over the recent past?; (ii) Given plausible future trends in drivers such as population and economic growth, technological development and governance structures, how will the supply of ecosystem goods and services be altered, and what will the possible impacts of these be on human well being?; and (iii) what successful responses have we had in the past to conserving and optimizing the delivery of ecosystem goods and services and what do we envision as the possible options for the future?

How is this assessment different?

During recent years, there have been numerous studies of the global impact of humans on the environment (e.g. [2,3]). Furthermore there have been comprehensive overviews by international organizations, such as that by the United Nations Environmental Programme (UNEP), notably the 1992 20-year overview of the State of the Environment [4] and the recent series of GEO (Global Environment Outlook) reports (http://www.unep.org/geo/geo3/). These have generally described the troubling trends of many, but not all, of the global environmental indicators, such as the loss of fishery stocks and the build up of atmospheric trace gases. The recent GEO-3 report further explores plausible future trends in the environment and an analysis of the drivers of change. The MA builds on these traditions, applying the model of the Intergovernmental Panel on Climate Change (IPCC) that involves a global network of experts, coupled with a rigorous and complex review process.

Fundamentally, the MA differs from all of these previous efforts in that it is built on a conceptual framework that considers how ecosystems provide services to society and, in turn, relating these services to human well being (Figure 1). Making the linkage explicit results in this effort being understandable and appealing to a wide

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Box 1. The Southern Africa Millennium Ecosystem Assessment

The approach used in the Millennium Ecosystem Assessment is illustrated in one of its more advanced sub-global components: The Southern Africa Millennium Ecosystem Assessment (SAfMA) (Figure I). SAfMA was carried out over several spatial extents: (i) the Southern Africa Development Community region, encompassing 19 countries; (ii) two large river basins (the Gariep basin and the Zambezi basin); and (iii) more than ten local communities within the river basins. The local level assessments involved participatory research approaches, whereas the basin- and regional-scale assessments made use of quantitative modeling approaches. All SAfMA studies assessed three core services (food, water, and the cluster of services associated with biodiversity), as well as additional services requested by their particular stakeholders.

At the regional scale, SAfMA examined the state of knowledge concerning the trends and status of the production, sustainability, and resilience of food, water, and biomass fuel, as well as air quality (particularly emissions of NO_x and SO_x) and nature-based tourism through the use of remotely sensed data and published literature. For these services, they assessed knowledge concerning the contribution of the services to human needs, including economic, social and health considerations. The team then developed two scenarios for changes in driving forces in the region ('African Patchwork' and 'African Partnership') and, using models where possible and qualitative reasoning where models did not exist, explored how the various ecosystem services would change in the region under the two scenarios. For each of these services, the team then examined various policy interventions being proposed to address needs related to the service and the consequences of those policies for other ecosystem services.

At the scale of the Gariep Basin, the same basic analysis was undertaken, but for a larger number of ecosystem services (now including mineral services and a larger array of cultural services) and often with more fine-grained sources of information, and typically better data concerning the human uses of various ecosystem services. Within the Basin, assessments were undertaken within three communities. Through community workshops, scenarios were again developed to describe plausible changes in ecosystems and their services in the future years. A similar process is underway in the Zambezi Basin. The teams of researchers involved in each of the three scales of SAfMA are now preparing an integrated assessment product, drawing from the information at all scales.

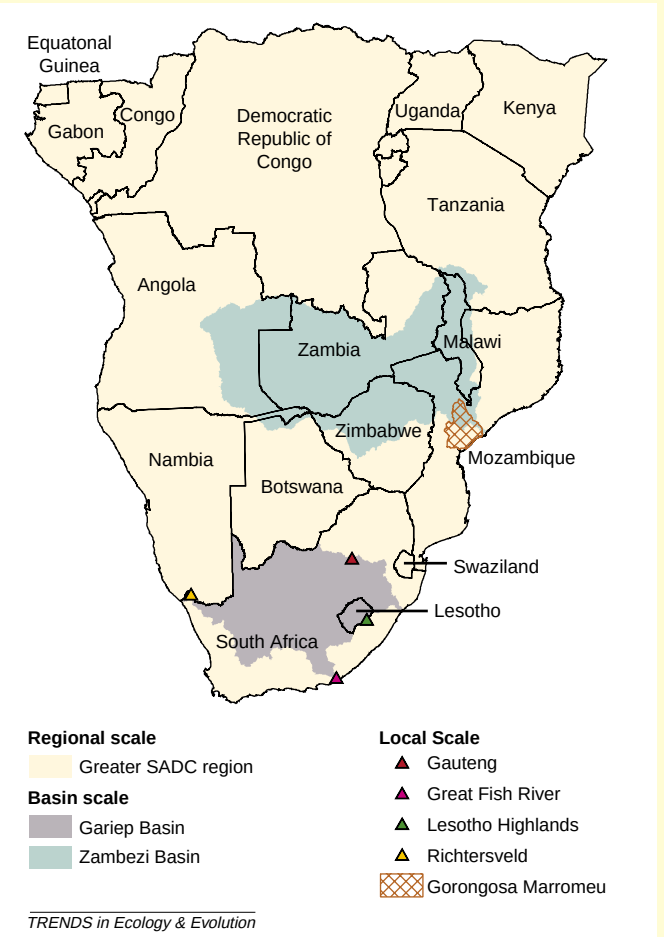

Figure I. The three geographic scales of the Southern Africa Millennium Ecosystem Assessment. Reproduced with permission from R. Scholes and O. Biggs.

range of audiences. The delivery of ecosystem services is being evaluated in a quantitative manner so that their losses or gains can be evaluated under different management practices. Because all services will be evaluated, the consequences of the enhancement of the delivery of one service can be seen on the delivery of all others. The ecosystem service focus and the consideration of tradeoffs in their delivery is therefore an important innovation in environmental assessment. This approach provides us with the information necessary to evaluate quantitatively the benefit in services gained, for example, by agriculture, against the notable losses of water and impacts on air quality.

For the MA analysis, ecosystem services have been grouped into those that are provisioning, such as food and water, those that regulate the human environment, such as provided by those organisms that influence climate or control diseases, those that provide cultural services, such spiritual and cultural values and, finally, those that are essential for supporting ecosystem functioning itself, such as primary productivity and the cycling of minerals. Some of these services are easily valued in monetary terms, such as the provisioning services, but others are generally valued in non-economic terms. To sustain, recover or augment the delivery of services, we must fully understand what are, and have been, the drivers of change that operate directly, such as climate change, and indirectly, such as trade policy, on service delivery. Whereas other assessments have focused on a single resource, such as water or forests, the MA focuses on the total bundle of resources provided by ecosystems. Additionally, the MA addresses goods and services at the global as well as at regional and local levels. In the MA, there is a global assessment being conducted simultaneously with sub-global assessments, which are spread over many regions of the world. There is, therefore, a need to use local knowledge about how resources are evaluated, utilized and monitored, now and in the past. Thus, traditional and local knowledge will be vitally important to the assessment and the guideline for the assessors is that this information must be clearly traceable.

What are the products and when will they be available?

The findings of the MA will be released in 2005, having been critically reviewed by the scientific, policy and business communities as well as by governments. These

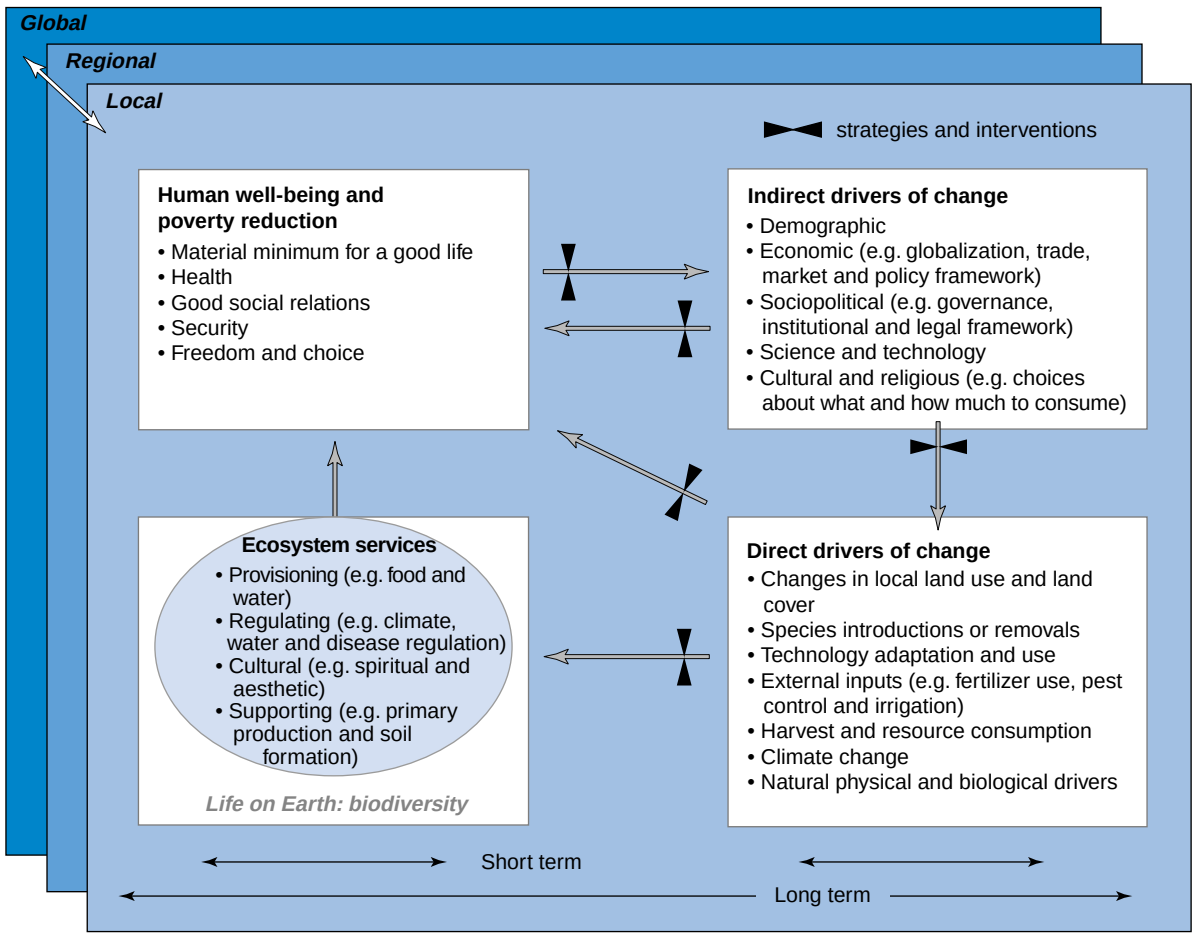

Figure 1. Millennium Ecosystem Assessment conceptual framework, detailing the relationships among the drivers of change to ecosystem services, both direct and indirect, and the capacity of ecosystems to provide services to the support of human well being. The nature of these interactions varies in both time and space. The arrows indicate the directions of interactions and the cross bars the potential for human responses to alter the negative changes and to enhance positive changes. Reproduced, with permission, from [1].

assessment documents will encompass our collective knowledge about the status and past and near-future trends of the ecosystems of the world, their capacity to provide services in a world dominated by different economic, technological and social trajectories. They will also evaluate the kinds of decision-making structures and processes that have and can be utilized to address the choices that we need to make to maximize the continued delivery of ecosystem services. In addition to these global treatments, there will a series of sub-global assessments that will cover all of these issues for a single region, such as southern Africa, or for a country or local area.

The mismatch between policymaking and the operation of natural and social systems

Most institutions that deal with natural resources do so in a sectoral manner. Political entities, be they international, national or local, generally have specialized departments that oversee natural resource issues regarding water, timber, food and conservation. Furthermore, there are specialized political units that deal with science, economics and human welfare. These entities generally do not interact and often compete for financial and political support. Of course, the natural world is a complex, yet fully interactive system. Moreover, poor policy decisions can result from the lack of a clear understanding and/or concern about how the actions occurring in once sector can affect other related sectors.

The MA is utilizing the interactions between natural and social systems for its analysis. It considers the interactions among individual resources and the consequences of the tradeoffs that are made in the decision-making process. It is clear that these tradeoffs must be considered as we strive to achieve sustainable forestry, agriculture and fisheries on the one hand, and alleviation of poverty on the other.

Who is doing it?

As is crucial in assessments that will need a wide acceptance, there must be clear indications that those doing the work are the leading experts in their field and that they represent not only different technical expertise, but also the diverse viewpoints and approaches of different nations and cultures. The hundreds of leading experts from around the world engaged in this effort fully represent the many disciplines and nations encompassing

the broad scope of the MA. They were selected by peers from the results of an extensive global call for nominations. The basic work is being conducted by four separate working groups: (i) condition and trends; (ii) scenarios – plausible futures; (iii) response options; and (iv) sub-global assessments. Each of these working groups is co-chaired by a natural and a social scientist. The effort is overseen by an assessment panel and a board that represents diverse user groups. The MA is operationally supported by a globally distributed secretariat and is led by a program director. Funding for this complex undertaking is sponsored by the Global Environment Facility, the United Nations Foundation (through UNEP), the Packard Foundation and the World Bank, among other donors. Full details of the organizational structure of the MA are available at http://www.millenniumassessment.org.

The challenges

The MA faces several hurdles. One is mining the information available that relates to the delivery of ecosystem services and the tradeoffs that are made by societies in relationship to the usage of these services. In the past, information has been gathered principally about the extent and condition of a given ecosystem state (e.g. biodiversity), but not necessarily about the quantification of the delivery of the services provided. Hopefully, the MA will stimulate more research on the ecosystem state, function and service interrelationships. Another challenge is providing a sufficiently robust foundation so that subsequent assessments can clearly document the status of progress in sustaining the biotic systems upon which we all depend.

Where challenges were anticipated, they have not developed. Working simultaneously at both global and sub-global levels appears successful, at this early stage, although there is a temporal mismatch in the tempo of progress owing to differences in approaches and detail. What has been most gratifying, and a hopeful sign for the future, is the very smooth interaction between the social and natural scientists as the work has progressed. Of course, the full measure of success will become evident as the products of the assessment become available and are adopted to the extent that new policies and viewpoints evolve for sustainably managing our life support systems.

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Letters

Sexual selection and animal genitalia

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The timely recent review in *TREE* by Hosken and Stockley [1] highlighted the mechanisms of genital evolution. Central to this paper was the thesis that sexual selection underpins genital evolution. However, two aspects were under-represented in the review, gamete evolution and the roles of females in the evolution of male genital morphology.

After 30 years of study spanning most animal groups [2,3], post-mating sexual selection studies have shown that genital traits are targets of male–male competition and/or female choice. Apart from genitalia, a second set of traits – male sexual cells and accessory fluids – have attracted special attention [3]. For example, sperm properties that are shaped by sexual selection include gamete mobility and morphology, as well as ejaculate size and chemistry. Therefore, when considering the effects of sexual selection on genital traits, reproductive cells and their accessory fluids must be included. Using a hypothetical scenario, if a male with a particular genital morphology is no longer able to remove the sperm stored in a female, he could 'resolve' this problem by producing large ejaculates that supersede those of other males. Conversely, females can manipulate ejaculates by changing both their genital features and glandular secretions. Sexual selection is actually acting on both sets of traits and, therefore, not including the two of them in an analysis of genital evolution is misleading.

To have a complete picture of the evolutionary forces affecting form and function of genitalia, it is widely accepted that the interaction of both sexes should be taken into account [4]. It is wrong, for example, to visualize male genital morphology evolution without teasing apart the properties and morphology of the female genitalia. Hosken and Stockley did not emphasize how much can be gained when females are included in this context. For example, a recent study of *Drosophila melanogaster*

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