Introduction to the Pilot Analysis of Global Ecosystems

PEOPLE AND ECOSYSTEMS

The world's economies are based on the goods and services derived from ecosystems. Human life itself depends on the continuing capacity of biological processes to provide their multitude of benefits. Yet, for too long in both rich and poor countries, development priorities have focused on how much humanity can take from ecosystems, and too little attention has been paid to the impact of our actions. We are now experiencing the effects of ecosystem decline in numerous ways: water shortages in the Punjab, India; soil erosion in Tuva, Russia; fish kills off the coast of North Carolina in the United States; landslides on the deforested slopes of Honduras; fires in the forests of Borneo and Sumatra in Indonesia. The poor, who often depend directly on ecosystems for their livelihoods, suffer most when ecosystems are degraded.

A critical step in managing our ecosystems is to take stock of their extent, their condition, and their capacity to continue to provide what we need. Although the information available today is more comprehensive than at any time previously, it does not provide a complete picture of the state of the world's ecosystems and falls far short of management and policy needs. Information is being collected in abundance but efforts are often poorly coordinated. Scales are noncomparable, baseline data are lacking, time series are incomplete, differing measures defy integration, and different information sources may not know of each other's relevant findings.

OBJECTIVES

The Pilot Analysis of Global Ecosystems (PAGE) is the first attempt to synthesize information from national, regional, and global assessments. Information sources include state of the environment reports; sectoral assessments of agriculture, forestry, biodiversity, water, and fisheries, as well as national and global assessments of ecosystem extent and change; scientific research articles; and various national and international datasets. The study reports on five major categories of ecosystems:

- Agroecosystems;
- Coastal ecosystems;
- Forest ecosystems;
- Freshwater systems;
- Grassland ecosystems.

These ecosystems account for about 90 percent of the earth's land surface, excluding Greenland and Antarctica. PAGE results are being published as a series of five technical reports, each covering one ecosystem. Electronic versions of the reports are posted on the Website of the World Resources Institute [http://www.wri.org/wr2000] and the agroecosystems report also is available on the Website of the International Food Policy Research Institute [http://www/ifpri.org].

The primary objective of the pilot analysis is to provide an overview of ecosystem condition at the global and continental levels. The analysis documents the extent and distribution of the five major ecosystem types and identifies ecosystem change over time. It analyzes the quantity and quality of ecosystem goods and services and, where data exist, reviews trends relevant to the production of these goods and services over the past 30 to 40 years. Finally, PAGE attempts to assess the capacity of ecosystems to continue to provide goods and services, using measures of biological productivity, including soil and water conditions, biodiversity, and land use. Wherever possible, information is presented in the form of indicators and maps.

A second objective of PAGE is to identify the most serious information gaps that limit our current understanding of ecosystem condition. The information base necessary to assess ecosystem condition and productive capacity has not improved in recent years, and may even be shrinking as funding for environmental monitoring and record-keeping diminishes in some regions.

Most importantly, PAGE supports the launch of a Millennium Ecosystem Assessment, a more ambitious, detailed, and integrated assessment of global ecosystems that will provide a firmer basis for policy- and decision-making at the national and subnational scale.

AN INTEGRATED APPROACH TO ASSESSING ECOSYSTEM GOODS AND SERVICES

Ecosystems provide humans with a wealth of goods and services, including food, building and clothing materials, medicines, climate regulation, water purification, nutrient cycling, recreation opportunities, and amenity value. At present, we tend to manage ecosystems for one dominant good or service, such as grain, fish, timber, or hydropower, without fully realizing the trade-offs we are making. In so doing, we may be sacrificing goods or services more valuable than those we receive — often those goods and services that are not yet valued in the market, such as biodiversity and flood control. An integrated ecosystem approach considers the entire range of possible goods and services a given ecosystem provides and attempts to optimize the benefits that society can derive from that ecosystem and across ecosystems. Its purpose is to help make trade-offs efficient, transparent, and sustainable.

Such an approach, however, presents significant methodological challenges. Unlike a living organism, which might be either healthy or unhealthy but cannot be both simultaneously, ecosystems can be in good condition for producing certain goods and services but in poor condition for others. PAGE attempts to evaluate the condition of ecosystems by assessing separately their capacity to provide a variety of goods and services and examining the trade-offs humans have made among those goods and services. As one example, analysis of a particular region might reveal that food production is high but, because of irrigation and heavy fertilizer application, the ability of the system to provide clean water has been diminished.

Given data inadequacies, this systematic approach was not always feasible. For each of the five ecosystems, PAGE researchers, therefore, focus on documenting the extent and distribution of ecosystems and changes over time. We develop indicators of ecosystem condition — indicators that inform us about the current provision of goods and services and the likely capacity of the ecosystem to continue providing those goods and services. Goods and services are selected on the basis of their perceived importance to human development. Most of the ecosystem studies examine food production, water quality and quantity, biodiversity, and carbon sequestration. The analysis of forests also studies timber and woodfuel production; coastal and grassland studies examine recreational and tourism services; and the agroecosystem study reviews the soil resource as an indicator of both agricultural potential and its current condition.

PARTNERS AND THE RESEARCH PROCESS

The Pilot Analysis of Global Ecosystems was a truly international collaborative effort. The World Resources Institute and the International Food Policy Research Institute carried out their research in partnership with numerous institutions worldwide (see *Acknowledgments*). In addition to these partnerships, PAGE researchers relied on a network of international experts for ideas, comments, and formal reviews. The research process included meetings in Washington, D.C., attended by more than 50 experts from developed and developing countries. The meetings proved invaluable in developing the conceptual approach and guiding the research program toward the most promising indicators given time, budget, and data constraints. Drafts of PAGE reports were sent to over 70 experts worldwide, presented and critiqued at a technical meeting of the Convention on Biological Diversity in Montreal (June, 1999) and discussed at a Millennium Assessment planning meeting in Kuala Lumpur, Malaysia (September, 1999). Draft PAGE materials and indicators were also presented and discussed at a Millennium Assessment planning meeting in Winnipeg, Canada, (September, 1999) and at the meeting of the Parties to the Convention to Combat Desertification, held in Recife, Brazil (November, 1999).

KEY FINDINGS

Key findings of PAGE relate both to ecosystem condition and the information base that supported our conclusions.

The Current State of Ecosystems

The PAGE reports show that human action has profoundly changed the extent, distribution, and condition of all major ecosystem types. Agriculture has expanded at the expense of grasslands and forests, engineering projects have altered the hydrological regime of most of the world's major rivers, settlement and other forms of development have converted habitats around the world's coastlines.

The picture we get from PAGE results is complex. Ecosystems are in good condition for producing some goods and services but in poor condition for producing others. Overall, however, there are many signs that the capacity of ecosystems to continue to produce many of the goods and services on which we depend is declining. Human activities have significantly disturbed the global water, carbon, and nitrogen cycles on which all life depends. Agriculture, industry, and the spread of human settlements have permanently converted extensive areas of natural habitat and contributed to ecosystem degradation through fragmentation, pollution, and increased incidence of pest attacks, fires, and invasion by non-native species.

The following paragraphs look across ecosystems to summarize trends in production of the most important goods and services and the outlook for ecosystem productivity in the future.

Food Production
Food production has more than kept pace with global population growth. On average, food supplies are 24 percent higher per person than in 1961 and real prices are 40 percent lower. Production is likely to continue to rise as demand increases in the short to medium term. Long-term productivity, however, is threatened by increasing water scarcity and soil degradation, which is now severe enough to reduce yields on about 16 percent of agricultural land, especially cropland in Africa and Central America and pastures in Africa. Irrigated agriculture, an important component in the productivity gains of the Green Revolution, has contributed to waterlogging and salinization, as well as to the depletion and chemical contamination of surface and groundwater supplies. Widespread use of pesticides on crops has lead to the emergence of many pesticide-resistant pests and pathogens, and intensive livestock production has created problems of manure disposal and water pollution. Food production from marine fisheries has risen sixfold since 1950 but the rate of increase has slowed dramatically as fisheries have been overexploited. More than 70 percent of the world's fishery resources for which there is information are now fully fished or overfished (yields are static or declining). Coastal fisheries are under threat from pollution, development, and degradation of coral reef and mangrove habitats. Future increases in production are expected to come largely from aquaculture.

Water Quantity
Dams, diversions, and other engineering works have transformed the quantity and location of freshwater available for human use and sustaining aquatic ecosystems. Water engineering has profoundly improved living standards, by providing fresh drinking water, water for irrigation, energy, transport, and flood control. In the twentieth century, water withdrawals have risen at more than double the rate of population increase and surface and groundwater sources in many parts of Asia, North Africa, and North America are being depleted. About 70 percent of water is used in irrigation systems where efficiency is often so low that, on average, less than half the water withdrawn reaches crops. On almost every continent, river modification has affected the flow of rivers to the point where some no longer reach the ocean during the dry season. Freshwater wetlands, which store water, reduce flooding, and provide specialized biodiversity habitat, have been reduced by as much as 50 percent worldwide. Currently almost 40 percent of the world's population experience serious water shortages. Water scarcity is expected to grow dramatically in some regions as competition for water grows between agricultural, urban, and commercial sectors.

Water Quality
Surface water quality has improved with respect to some pollutants in developed countries but water quality in developing countries, especially near urban and industrial areas, has worsened. Water is degraded directly by chemical or nutrient pollution, and indirectly when land use change increases soil erosion or reduces the capacity of ecosystems to filter water. Nutrient runoff from agriculture is a serious problem around the world, resulting in eutrophication and human health hazards in coastal regions, especially in the Mediterranean, Black Sea, and northwestern Gulf of Mexico. Water-borne diseases caused by fecal contamination of water by untreated sewage are a major source of morbidity and mortality in the developing world. Pollution and the introduction of non-native species to freshwater ecosystems have contributed to serious declines in freshwater biodiversity.

Carbon Storage
The world's plants and soil organisms absorb carbon dioxide (CO_2) during photosynthesis and store it in their tissues, which helps to slow the accumulation of CO_2 in the atmosphere and mitigate climate change. Land use change that has increased production of food and other commodities has reduced the net capacity of ecosystems to sequester and store carbon. Carbon-rich grasslands and forests in the temperate zone have been extensively converted to cropland and pasture, which store less carbon per unit area of land. Deforestation is itself a significant source of carbon emissions, because carbon stored in plant tissue is released by burning and accelerated decomposition. Forests currently store about 40 percent of all the carbon held in terrestrial ecosystems. Forests in the northern hemisphere are slowly increasing their storage capacity as they regrow after historic clearance. This gain, however, is more than offset by deforestation in the tropics. Land use change accounts for about 20 percent of anthropogenic carbon emissions to the atmosphere. Globally, forests today are a net source of carbon.

Biodiversity
Biodiversity provides many direct benefits to humans: genetic material for crop and livestock breeding, chemicals for medicines, and raw materials for industry. Diversity of living organisms and the abundance of populations of many species are also critical to maintaining biological services, such as pollination and nutrient cycling. Less tangibly, but no less importantly, diversity in nature is regarded by most people as valuable in

its own right, a source of aesthetic pleasure, spiritual solace, beauty, and wonder. Alarming losses in global biodiversity have occurred over the past century. Most are the result of habitat destruction. Forests, grasslands, wetlands, and mangroves have been extensively converted to other uses; only tundra, the Poles, and deep-sea ecosystems have experienced relatively little change. Biodiversity has suffered as agricultural land, which supports far less biodiversity than natural forest, has expanded primarily at the expense of forest areas. Biodiversity is also diminished by intensification, which reduces the area allotted to hedgerows, copses, or wildlife corridors and displaces traditional varieties of seeds with modern high-yield, but genetically uniform, crops. Pollution, overexploitation, and competition from invasive species represent further threats to biodiversity. Freshwater ecosystems appear to be the most severely degraded overall, with an estimated 20 percent of freshwater fish species becoming extinct, threatened, or endangered in recent decades.

Information Status and Needs

Ecosystem Extent and Land Use Characterization

Available data proved adequate to map approximate ecosystem extent for most regions and to estimate historic change in grassland and forest area by comparing current with potential vegetation cover. PAGE was able to report only on recent changes in ecosystem extent at the global level for forests and agricultural land.

PAGE provides an overview of human modifications to ecosystems through conversion, cultivation, firesetting, fragmentation by roads and dams, and trawling of continental shelves. The study develops a number of indicators that quantify the degree of human modification but more information is needed to document adequately the nature and rate of human modifications to ecosystems. Relevant data at the global level are incomplete and some existing datasets are out of date.

Perhaps the most urgent need is for better information on the spatial distribution of ecosystems and land uses. Remote sensing has greatly enhanced our knowledge of the global extent of vegetation types. Satellite data can provide invaluable information on the spatial pattern and extent of ecosystems, on their physical structure and attributes, and on rates of change in the landscape. However, while gross spatial changes in vegetation extent can be monitored using coarse-resolution satellite data, quantifying land cover change at the national or subnational level requires high-resolution data with a resolution of tens of meters rather than kilometers.

Much of the information that would allow these needs to be met, at both the national and global levels, already exists, but is not yet in the public domain. New remote sensing techniques and improved capabilities to manage complex global datasets mean that a complete satellite-based global picture of the earth could now be made available, although at significant cost. This information would need to be supplemented by extensive ground-truthing, involving additional costs. If sufficient resources were committed, fundamentally important information on ecosystem extent, land cover, and land use patterns around the world could be provided at the level of detail needed for national planning. Such information would also prove invaluable to international environmental conventions, such as those dealing with wetlands, biological diversity, desertification, and climate change, as well as the international agriculture, forest, and fishery research community.

Ecosystem Condition and Capacity to Provide Goods and Services

In contrast to information on spatial extent, data that can be used to analyze ecosystem condition are often unavailable or incomplete. Indicator development is also beset by methodological difficulties. Traditional indicators, for example, those relating to pressures on environments, environmental status, or societal responses (pressure-state-response model indicators) provide only a partial view and reveal little about the underlying capacity of the ecosystem to deliver desired goods and services. Equally, indicators of human modification tell us about changes in land use or biological parameters, but do not necessarily inform us about potentially positive or negative outcomes.

Ecosystem conditions tend to be highly site-specific. Information on rates of soil erosion or species diversity in one area may have little relevance to an apparently similar system a few miles away. It is expensive and challenging to monitor and synthesize site-specific data and present it in a form suitable for national policy and resource management decisions. Finally, even where data are available, scientific understanding of how changes in biological systems will affect goods and services is limited. For example, experimental evidence shows that loss of biological diversity tends to reduce the resilience of a system to perturbations, such as storms, pest outbreaks, or climate change. But scientists are not yet able to quantify how much resilience is lost as a result of the loss of biodiversity in a particular site or how that loss of resilience might affect the long-term production of goods and services.

Overall, the availability and quality of information tend to match the recognition accorded to various goods and services by markets. Generally good data are available for traded goods, such as grains, fish, meat, and timber products and some of the more basic relevant productivity factors, such as fertilizer application rates, water inputs, and yields. Data on products that are exchanged in informal markets, or consumed directly, are patchy and often modeled. Examples include fish landings from artisanal fisheries, woodfuels, subsistence food crops and livestock, and nonwood forest products. Information on the biological factors that support production of these goods — including size of fish spawning stocks, biomass densities, subsistence food yields, and forest food harvests — are generally absent.

The future capacity (long-term productivity) of ecosystems is influenced by biological processes, such as soil formation, nutrient cycling, pollination, and water purification and cycling. Few of these environmental services have, as yet, been accorded economic value that is recognized in any functioning market. There is a corresponding lack of support for data collection and monitoring. This is changing in the case of carbon storage and cycling. Interest in the possibilities of carbon trading mechanisms has stimulated research and generated much improved data on carbon stores in terrestrial ecosystems and the dimensions of the global carbon cycle. Few comparable datasets exist for elements such as nitrogen or sulfur, despite their fundamental importance in maintaining living systems.

Although the economic value of genetic diversity is growing, information on biodiversity is uniformly poor. Baseline and trend data are largely lacking; only an estimated 15 to 20 percent of the world's species have been identified. The OECD Megascience Forum has launched a new international program to accelerate the identification and cataloging of species around the world. This information will need to be supplemented with improved data on species population trends and the numbers and abundance of invasive species. Developing databases on population trends (and threat status) is likely to be a major challenge, because most countries still need to establish basic monitoring programs.

The PAGE divides the world's ecosystems to examine them at a global scale and think in broad terms about the challenges of managing them sustainably. In reality, ecosystems are linked by countless flows of material and human actions. The PAGE analysis does not make a distinction between natural and managed ecosystems; human intervention affects all ecosystems to some degree. Our aim is to take a first step toward understanding the collective impacts of those interventions on the full range of goods and services that ecosystems provide. We conclude that we lack much of the baseline information necessary to determine ecosystem conditions at a global, regional or, in many instances, even a local scale. We also lack systematic approaches necessary to integrate analyses undertaken at different locations and spatial scales.

Finally, it should be noted that PAGE looks at past trends and current status, but does not try to project future situations where, for example, technological development might increase dramatically the capacity of ecosystems to deliver the goods and services we need. Such considerations were beyond the scope of the study. However, technologies tend to be developed and applied in response to market-related opportunities. A significant challenge is to find those technologies, such as integrated pest management and zero tillage cultivation practices in the case of agriculture, that can simultaneously offer market-related as well as environmental benefits. It has to be recognized, nonetheless, that this type of "win-win" solution may not always be possible. In such cases, we need to understand the nature of the trade-offs we must make when choosing among different combinations of goods and services. At present our knowledge is often insufficient to tell us where and when those trade-offs are occurring and how we might minimize their effects.