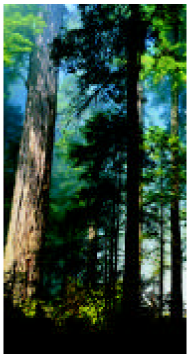
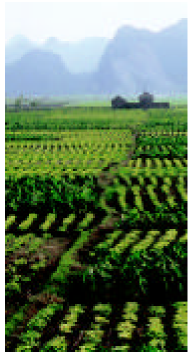
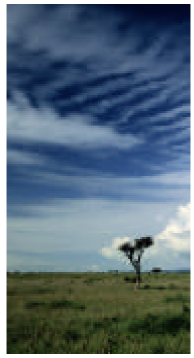
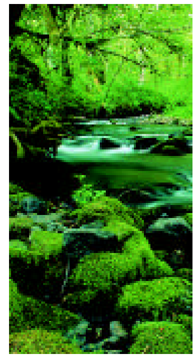
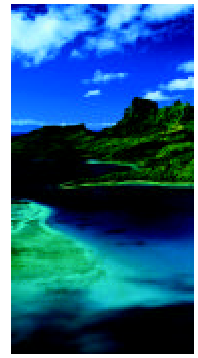

Pilot Analysis of Global Ecosystems

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PILOT ANALYSIS OF GLOBAL ECOSYSTEMS

Grassland Ecosystems

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The agroecosystem report is also available at http://www.ifpri.org. Printed copies may be ordered by mail from the International Food Policy Research Institute, Communications Service, 2033 K Street, NW, Washington, D.C. 20006-5670, USA.

Contents

Foreword

Earth's ecosystems and its peoples are bound together in a grand and complex symbiosis. We depend on ecosystems to sustain us, but the continued health of ecosystems depends, in turn, on our use and care. Ecosystems are the productive engines of the planet, providing us with everything from the water we drink to the food we eat and the fiber we use for clothing, paper, or lumber. Yet, nearly every measure we use to assess the health of ecosystems tells us we are drawing on them more than ever and degrading them, in some cases at an accelerating pace.

Our knowledge of ecosystems has increased dramatically in recent decades, but it has not kept pace with our ability to alter them. Economic development and human well-being will depend in large part on our ability to manage ecosystems more sustainably. We must learn to evaluate our decisions on land and resource use in terms of how they affect the capacity of ecosystems to sustain life — not only human life, but also the health and productive potential of plants, animals, and natural systems.

A critical step in improving the way we manage the earth's ecosystems is to take stock of their extent, their condition, and their capacity to provide the goods and services we will need in years to come. To date, no such comprehensive assessment of the state of the world's ecosystems has been undertaken.

The Pilot Analysis of Global Ecosystems (PAGE) begins to address this gap. This study is the result of a remarkable collaborative effort between the World Resources Institute (WRI), the International Food Policy Research Institute (IFPRI), intergovernmental organizations, agencies, research institutes, and individual experts in more than 25 countries worldwide. The PAGE compares information already available on a global scale about the condition of five major classes of ecosystems: agroecosystems, coastal areas, forests, freshwater systems, and grasslands. IFPRI led the agroecosystem analysis, while the others were led by WRI. The pilot analysis examines not only the quantity and quality of outputs but also the biological basis for production, including soil and water condition, biodiversity, and changes in land use over time. Rather than looking just at marketed products, such as food and timber, the study also analyzes the condition of a broad array of ecosystem goods and services that people need, or enjoy, but do not buy in the marketplace.

The five PAGE reports show that human action has profoundly changed the extent, condition, and capacity 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. Human activities have adversely altered the earth's most important biogeochemical cycles — the water, carbon, and nitrogen cycles — on which all life forms depend. Intensive management regimes and infrastructure development have contributed positively to providing some goods and services, such as food and fiber from forest plantations. They have also led to habitat fragmentation, pollution, and increased ecosystem vulnerability to pest attack, fires, and invasion by non-native species. Information is often incomplete and the picture confused, but there are many signs that the overall capacity of ecosystems to continue to produce many of the goods and services on which we depend is declining.

The results of the PAGE are summarized in *World Resources 2000–2001,* a biennial report on the global environment published by the World Resources Institute in partnership with the United Nations Development Programme, the United Nations Environment Programme, and the World Bank. These institutions have affirmed their commitment to making the viability of the world's ecosystems a critical development priority for the 21st century. WRI and its partners began work with a conviction that the challenge of managing earth's ecosystems — and the consequences of failure — will increase significantly in coming decades. We end with a keen awareness that the scientific knowledge and political will required to meet this challenge are often lacking today. To make sound ecosystem management decisions in the future, significant changes are needed in the way we use the knowledge and experience at hand, as well as the range of information brought to bear on resource management decisions.

A truly comprehensive and integrated assessment of global ecosystems that goes well beyond our pilot analysis is necessary to meet information needs and to catalyze regional and local assessments. Planning for such a Millennium Ecosystem Assessment is already under way. In 1998, representatives from international scientific and political bodies began to explore the merits of, and recommend the structure for, such an assessment. After consulting for a year and considering the preliminary findings of the PAGE report, they concluded that an international scientific assessment of the present and likely future condition of the world's ecosystems was both feasible and urgently needed. They urged local, national, and international institutions to support the effort as stakeholders, users, and sources of expertise. If concluded successfully, the Millennium Ecosystem Assessment will generate new information, integrate current knowledge, develop methodological tools, and increase public understanding.

Human dominance of the earth's productive systems gives us enormous responsibilities, but great opportunities as well. The challenge for the 21st century is to understand the vulnerabilities and resilience of ecosystems, so that we can find ways to reconcile the demands of human development with the tolerances of nature.

We deeply appreciate support for this project from the Australian Centre for International Agricultural Research, The David and Lucile Packard Foundation, The Netherlands Ministry of Foreign Affairs, the Swedish International Development Cooperation Agency, the United Nations Development Programme, the United Nations Environment Programme, the Global Bureau of the United States Agency for International Development, and The World Bank.

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Jonathan Lash
President
World Resources Institute

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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.

GRASSLANDS: EXECUTIVE SUMMARY

Scope of Analysis

This study, or Pilot Analysis of Global Ecosystems (PAGE), examines grassland ecosystems of the world using a large collection of spatial and temporal data. We analyze datasets primarily at the global level, presenting quantitative indicators and qualitative information on the condition of the world's grasslands. Grassland condition is defined in terms of the current and future capacity of these ecosystems to provide goods and services important to humans.

GRASSLAND EXTENT, CHANGE, AND HUMAN MODIFICATION

PAGE analysts define grasslands as terrestrial ecosystems dominated by herbaceous and shrub vegetation and maintained by fire, grazing, drought and/or freezing temperatures. This definition includes vegetation covers with an abundance of non-woody plants and thus lumps together some savannas, woodlands, shrublands, and tundra, as well as more conventional grasslands. Our comprehensive view of grasslands allows us to make use of a variety of global datasets and to avoid somewhat arbitrary distinctions among different land cover types. We examine the spatial extent of grasslands and modifications that have altered their extent, structure, and composition over time. Modifications include human-induced changes such as cultivation, urbanization, desertification, fire, livestock grazing, fragmentation, and introduction of invasive species.

GRASSLAND GOODS AND SERVICES

This analysis focuses on a selected set of grassland goods and services. Our choice was determined partly in consultation with grassland experts worldwide and partly by availability of data. Our goal was to use global datasets, preferably in electronic form, available spatially and with time-series. Where global data were not available, we used regional, national, and sometimes sub-national studies. The data and indicators presented in this report address the condition of the following goods and services provided by grasslands:

- Food, forage, and livestock;
- Biodiversity;
- Carbon storage; and
- Tourism and recreation.

Each good or service is discussed in terms of its current status, trends over time, and modifications that have changed its condition. The good or service also is discussed in terms of the type of data required to expand our knowledge about the ecosystem's ability to provide the service. When quantitative indicators are available, we explore the potential to use them to evaluate the condition of grasslands. In other cases we present qualitative measures of condition, sometimes based entirely on expert opinion.

This study attempts to locate and draw together global, spatially represented databases on grassland ecosystems. It is not an exhaustive review of literature available on grassland types. Nor is it complete in its search for spatial datasets related to grassland ecosystems. Some important goods and services provided by grasslands also have not been covered. For example, woodfuel, often collected from shrublands or savannas, is not discussed in this report (but see the PAGE analysis on forest ecosystems), nor are the important services that grasslands provide in terms of water and nutrient cycling. Rather, we present an examination of many of the global datasets most readily accessible, and of quantitative and qualitative indicators that can be used as starting points for a more comprehensive, international effort to evaluate the condition of grassland ecosystems worldwide.

Key Findings and Information Issues

The following tables (pp. 2-5) summarize key findings of the study regarding grassland condition and trends and the quality and availability of data.

Grassland Extent and Change

PAGE Measures and Indicators	Data Sources and Comments
Extent of current grasslands	Land cover characterization developed by International Geosphere/Biosphere Program (IGBP) using global satellite data at l-km resolution (GLCCD 1998), modified by WRI using Olson (1994a and b); WRI global, electronic dataset of watersheds of the world (Revenga et al. 1998).
Extent of dry grasslands	Aridity zones of the world mapped by United Nations Environment Programme according to the ratio of mean annual precipitation to mean annual potential evapotranspiration (UNEP 1992, 1997).
Extent of woody vegetation	Land cover characterization developed by University of Maryland Geography Department identifying percent woody and herbaceous cover across the world's terrestrial surface (DeFries et al. 2000).
Extent of historical grassland	Major habitat types of the world representing geographic areas of similar environmental conditions before major modification by humans (WWF-U.S. 1999).
Trends in grassland conversion	Regional data reported by United States Geological Survey (USGS) and the Nature Conservancy (TNC) for North America; IUCN – The World Conservation Union for Europe; State of the Environment Advisory Council for Australia; United States Agency for International Development (USAID) for Kenya.
Modification of grasslands	
Agriculture	GLCCD (1998) land cover characterization as modified by PAGE; methodology may over-represent grassland modification in some parts of the world, such as southern Africa.
Urbanization/ Human settlements	Population data from inventory of national censuses (CIESIN 2000); see also see below for road fragmentation using Digital Chart of the World road's database (ESRI 1993).
Desertification	Use of aridity zones and human population data to describe effects of land degradation in dry areas as presented in the World Atlas of Desertification (UNEP 1992, 1997)
Fire	Satellite data from European Space Agency (ESA) for fires in Africa, Latin America, SE Asia, and Oceania detected during 1993 (Arino and Melinotte 1997).
Domestic livestock	Various studies in scientific literature; datasets from FAO and ILRI described in chapter on food, forage and livestock.
Fragmentation	Fragmentation index developed by the World Wildlife Fund (Dinerstein et al. 1995; Ricketts et al 1997); spatial, electronic database of road networks worldwide from Digital Chart of the World (DCW) (ESRI 1993) presented in chapter on biodiversity.
Non-Native Species	Dataset for North America compiled by WWF-US (Ricketts et al. 1997), described in chapter on biodiversity.

Conditions and Trends

- Grasslands cover some 40 percent of the earth's surface (excluding Greenland and Antarctica).
- Grasslands are found in every region of the world; Sub-Saharan Africa and Asia have the largest total area in grassland, 14.5 and 8.9 million km^2 respectively.
- The five countries with the largest grassland area are Australia, the Russian Federation, China, the United States, and Canada.
- The five countries with the highest percentage of grassland area, all in Sub-Saharan Africa, are Benin, Central African Republic, Botswana, Togo, and Somalia.
- Twenty-five of the 145 major watersheds of the world are made up of at least 50 percent grassland. Sub-Saharan Africa has the most extensive grassland watersheds; Europe, the least.
- Grasslands are found most commonly in semi-arid zones (28 percent of the world's grasslands), followed by humid (23 percent), cold (20 percent), and arid zones (19 percent).
- Human populations are highest in the dry grasslands (arid, semi-arid, and dry sub-humid) of Sub-Saharan Africa followed by Asia. Human populations are lowest in the dry grasslands of Oceania.
- Temperate grasslands, savannas, and shrublands have experienced heavy conversion to agriculture, more so than other grassland types including tropical and subtropical grasslands, savannas, and woodlands.

Information Status and Needs

- Global estimates of grasslands are complicated by diverse definitions of grassland, and variability in the designation of boundaries between land cover types.
- Higher-resolution satellite data, available now and expected to become more accessible within the next few years, could improve the information base. These data, however, will most likely remain expensive to obtain, especially for extensive areas.
- Expansion of our knowledge of grassland condition is hindered by disagreement on the characteristics of a healthy grassland ecosystem and the difficulty of identifying the best methods to determine ecosystem health.
- Various satellite sources primarily from the U.S. and Europe are being perfected to better detect, monitor and analyze fires over time. NASA's website presents current (1999-2000) fire counts and additional fire information at 4km resolution in monthly intervals but these data are not yet available for general analysis. Studies using these data are required to analyze the long-term effects of frequent fires on grassland systems.

Food, Forage, and Livestock

PAGE Measures and Indicators	Data Sources and Comments
Soil degradation	Global Assessment of the Status of Human-Induced Soil Degradation (GLASOD), spatial, electronic data at 1:10 million; Soil Degradation Assessment for South and Southeast Asia (ASSOD) at 1:5 million (UNEP 1992 and 1997).
Vegetation change	Global satellite imagery; surface reflectance data from NOAA/AVHRR that provides the Normalized Difference Vegetation Index (NDVI); various models using climate and vegetation data to analyze Net Primary Productivity (NPP); University of Maryland Geography Department's Global Production Efficiency Model (GLOPEM); Rain-Use Efficiency (RUE) Index using data from rainfall stations to indicate regional trends (UNEP 1997; Cramer and Field 1999; Prince et al 1998; Goetz et al 1999).
Livestock densities	Spatial, electronic data on livestock populations of the world (Lerner and Matthews 1988); regional spatial coverage of Africa by country and other administrative units from the International Livestock Research Institute (ILRI) (Kruska et al.1995).

Conditions and Trends

- Although much of the PAGE grassland area does not coincide with mapping units that are degraded according to GLASOD extent and degree classes, nearly 49 percent are lightly to moderately degraded and at least 5 percent are considered strongly to extremely degraded.
- Satellite imagery has greatly expanded our ability to measure grassland vegetation. Promising measures for determining grassland condition are long-term trends in NDVI, NPP, and RUE.
- Trends in RUE provide a potential method of separating vegetation declines due to lack of rainfall from declines associated with degradation. Combining this index with other measures, such as livestock densities, may increase our ability to more accurately evaluate grassland condition.
- While some grasslands support high livestock densities, association of grassland condition with specific livestock densities must be based in part on information about geographic location and management practices as well as on characteristics of the soil, vegetation, and wildlife.

Information Status and Needs

- Soil condition is key to evaluating grassland condition; GLASOD provides the only global database on soil degradation. It is heavily criticized, however, for relying on qualitative data interpreted in different ways and produced at too large a scale for assessing degradation at the national level. ASSOD is an improvement over GLASOD, but its 1:5 million scale is still too coarse on which to base national policies. We need a worldwide digital database of soil degradation at 1:1 million backed up by field reconnaissance.
- To take advantage of improved satellite data for monitoring vegetation change, we need continued evaluation of NPP models, compilation of long-term trends, and further evaluation of the use of additional indicators (such as RUE) in the assessment of grassland ecosystem condition.
- Relationships among meat production, livestock densities, and rangeland condition must be assessed with caution. They require worldwide spatial data that differentiate feedlot from range-fed livestock, identify management practices, and report population levels of all livestock—domestic and wild.

Biodiversity

PAGE Measures and Indicators	Data Sources and Comments
Areas of designated importance	
Centers of Plant Diversity	Compilation of information on centers of plant diversity worldwide through fieldwork and expert judgment from IUCN-The World Conservation Union, spatial, electronic database by World Wildlife Fund (WWF-U.S) (Davis et al 1994 and 1995).
Endemic Bird Areas	Worldwide documentation of breeding ranges of restricted-range bird species developed by Birdlife International through fieldwork and expert judgment (Stattersfield et al 1998).
Global 200 Ecoregions	Designation of 200–plus ecoregions in the world by WWF-U.S., selected as outstanding examples of diverse ecosystems based on expert opinion (Olson and Dinerstein 1998).
Biological Distinctiveness Index	Index of ecoregions based on species richness, species endemism, rarity of habitat type, rare phenomena, and beta diversity developed by WWF-U.S. for North and Latin America (Dinerstein et al. 1995, Ricketts et al 1999).
Protected Areas	Global database of protected areas in management categories I-VI produced by IUCN-World Conservation Union and WCMC (WCMC 1999).
Grassland bird populations	Long-term trend data on breeding birds of North America found along more than 3,500 survey routes over approximately 30 years beginning in 1966, now reported by the U.S. Geological Survey (USGS) (Sauer et al 1997 and 1999).
Large grassland herbivores	Long-term population trend data from the Serengeti (Campbell and Borner 1995).
Key areas for threatened birds in the Neotropics	Dataset for Latin America with extensive documentation, identifying key areas of threatened species through fieldwork and expert judgment, presented by Birdlife International (Wege and Long 1995).
Fragmentation and road densities	Spatial, electronic database of road networks worldwide from Digital Chart of the World (DCW) (ESRI 1993); fragmentation index developed by the World Wildlife Fund (Dinerstein et al. 1995; Ricketts et al 1997) presented in chapter on grassland extent and change.
Non-Native species	Dataset for North America aggregating county-level statistics on non-native species to ecoregions, compiled by WWF-US (Ricketts et al. 1997). County lists do not distinguish invasive or harmful introductions from those that are benign or beneficial.

Conditions and Trends

- Worldwide, almost half of 234 Centers of Plant Diversity (CPDs) include grassland habitat. These CPDs, found in most regions of the world, represent areas with high grassland diversity and where conservation practices could protect a large number of grassland species.
- Approximately 23 of 217 Endemic Bird Areas (EBAs) include grassland as the key habitat type; 3 of these 23 grassland EBAs rank highest for biological importance: the Peruvian Andes, Central Chile, and Southern Patagonia.
- Of 136 terrestrial ecoregions identified as outstanding examples of the world's diverse ecosystems, 35 are grasslands, supporting some of the most important grassland biodiversity in the world today.
- Less than 16 percent of approximately 4,500 relatively large protected areas are at least 50 percent grassland; protected grasslands cover approximately 4 million km^2 or 3 percent of the total land area, just 7.6 percent of the total grassland area.
- The highest densities of 28 breeding grassland bird species of North America are found primarily in three states (North Dakota, South Dakota, and Montana) and two provinces (Saskatchewan and Alberta). Population trend data for a nearly 30-year period show a constant decrease in the numbers of these species.
- Regional data for African herbivores show generally steady long-term population trends within the Serengeti ecosystem. Areas outside the protected area boundaries and with fewer law enforcement activities experienced decreases in densities of already-low wildlife populations.
- Of nearly 600 key areas for threatened bird species in the Neotropics, 42 are grasslands; 12 percent of the threatened birds are specific to grasslands.
- Road networks have led to high grassland fragmentation in some areas: the Great Plains of the United States are highly fragmented with 70 percent of the grasslands less than 1,000 km^2 while in Botswana, 58 percent of grasslands are 10,000 km^2 or greater.
- The introduction of non-native species can negatively affect grassland ecosystems through species competition and can eventually lead to decreases in biodiversity. Some North American grasslands support 10 percent to 20 percent non-native plant species.

Information Status and Needs

- Comprehensive data on grassland biodiversity are not adequate to evaluate global grassland condition; we need to expand efforts to systematically collect data on biodiversity for all grassland types and for all flora and fauna, including both macro- and micro-soil fauna.
- The U.S. Geological Survey supports one of the best programs for collecting status and trends data on grassland birds. Although such expansive programs are not currently feasible in all parts of the world, similar local and regional data collection efforts can be initiated and supported on a gradual basis.
- Data on road networks can provide information on the extent of fragmentation and the potential degradation of grassland ecosystems. The current datasets generally do not reflect road building over the last decade. Systematic, consistent coverage with regular updates of electronic, spatial data on road location, size, and use could help us better measure the effects of ecosystem fragmentation.
- Rapid expansion of invasive species in grassland ecosystems calls for comprehensive, long-term studies and collection of spatial data on invasive plant and animal species.

Carbon Storage

PAGE MEASURES AND INDICATORS	DATA SOURCES AND COMMENTS
Potential carbon stored in grasslands and other terrestrial ecosystems	
Estimates for storage in above- and below-ground live vegetation	Above- and below-ground vegetation carbon storage estimates (Olson et al. 1983) as modified by USGS/EDC (1999).
Estimates for storage in soil	Soil carbon storage estimates based on the International Soil Reference and Information Centre (ISRIC) and World Inventory of Soil Emission Potentials (WISE) global data set of derived soil properties developed by Batjes (1996)and Batjes and Bridges (1994); FAO digital soil map of the world (FAO 1995).
Trends and modifications in storage capacity	Various studies reporting on loss of organic carbon or on a reduction in carbon storage potential based on current practices.

CONDITIONS AND TRENDS

- Grasslands store approximately 34 percent of the global stock of carbon in terrestrial ecosystems while forests store approximately 39 percent and agroecosystems approximately 17 percent.
- Unlike tropical forests, where vegetation is the primary source of carbon storage, most of the grassland carbon stocks are in the soil.
- Cultivation and urbanization of grasslands, and other modifications of grasslands through desertification and livestock grazing can be a significant source of carbon emissions.
- Biomass burning, especially from tropical savannas, contributes over 40 percent of gross global carbon dioxide emissions.
- Some exotic grassland plant species may decrease total carbon storage because they have less extensive below-ground root networks for storing organic matter than native grassland plants.

INFORMATION STATUS AND NEEDS

- Estimates of carbon storage in terrestrial ecosystems worldwide vary widely; we need continued updating of models to refine estimates of carbon storage in grassland vegetation and soils.
- Carbon storage estimates need to reflect the influence of different vegetation and soil types and conditions and management practices.
- Soil greatly affects the storage potential of grasslands; comprehensive soil studies are needed to improve the accuracy of estimates of that potential.

Tourism and Recreation

PAGE MEASURES AND INDICATORS	DATA SOURCES AND COMMENTS
Tourist numbers and tourism receipts	Annual country-level data compiled by the World Tourism Organization (WTO) and presented by the World Bank (1999).
Safari hunting and animal trophies	Data published by IUCN-World Conservation Union for selected African countries and variable time periods (Leader-Williams et al. 1996).
Wildlife exploitation index	Measure of wildlife exploitation in North America combining data on effects of hunting and poaching, unsustainable extraction of wildlife as commercial products, and harassment and displacement of wildlife by commercial and recreational users, published by WWF (Ricketts 1997).

CONDITIONS AND TRENDS

- In many countries with extensive grassland and for which tourism data are available, the number of international tourists and the international inbound tourism receipts increased over the 10-year period from 1985–87 to 1995–97.
- The economic contribution of grasslands through recreation and tourism, especially safari tours and hunting, can be high. While providing revenues, grassland tourism also can lead to ecosystem degradation.
- Excessive human use and wildlife poaching could decrease the capacity of grasslands to maintain tourism services.

INFORMATION STATUS AND NEEDS

- Data specific to revenues from grassland tourism are rare; we need more systematic collection and reporting of data on grassland tourism revenues.
- To adequately monitor the use and effects of tourism and recreation on grassland ecosystems, we need to systematically collect data on multiple aspects of human use of grassland parks and reserves.

Conclusions

PAGE researchers have found that global-scale analysis of grassland condition is difficult not only because of lack of sufficient data but also because of the variability in definitions of grasslands, inconsistency in scales of reported data, out-of-date information, and data based on expert opinion rather than scientific measurements.

Despite these difficulties, the indicators examined in this pilot analysis show unambiguous declines in the extent of grasslands, especially in the temperate zone. Areas of grassland before major modification by humans are now cultivated or urbanized, especially in North America and Europe. The indicators also suggest that although the major goods and services provided by grasslands are in good to fair condition, the capacity for grassland ecosystems to continue to provide these goods and services is declining.

Indicators of soil condition show that more than half of the grassland area analyzed under PAGE has some degree of soil degradation; over 5 percent of these grasslands are strongly to extremely degraded. Measures for detecting changes in net primary productivity and rain-use efficiency show declines in some grassland areas. Indicators of grassland biodiversity show marked declines in grassland birds of North America, with negative effects from fragmentation and non-native species suggested for this region and others. Although the carbon storage potential for grasslands is large, degraded areas store less carbon and there is heavy burning of some grassland areas, especially the African savannas. Tourism and recreational activities in grasslands appear to make important economic contributions to some countries, with revenues generally increasing. Overuse and declines in wildlife populations, however, suggest possible declines in the capacity to continue to provide these services.

Global scale analysis of grassland condition is further complicated by our limited ability to detect responses of grassland ecosystems to degradation. On the global scale, we rarely detect degradation involving changes in the age structure of plant populations or in the ability of species to reproduce. We might detect a decrease in plant productivity and cover with current satellite data and biomass measures. We can with certainty detect a complete loss of vegetation and evidence of soil erosion through a combination of satellite data, data from meteorological stations, and relationships modeled with NPP and RUE measures. At this stage, however, it may be too late to manage for complete recovery of the degraded ecosystem. This pilot analysis reinforces the importance of establishing indicators that can be used to detect declines in grassland condition with sufficient time to implement changes in management strategies before degradation becomes irreversible.

Recommendations for Future Grassland Assessments

PAGE researchers make several recommendations for future grassland ecosystem assessments. The most important recommendation is to recognize that a global assessment based on systematic measurement would be a large step forward in the field of ecosystem evaluation and monitoring. GLASOD is praised because it collates and generalizes available datasets on the condition of the world's soils. GLASOD is unsatisfactory for global appraisal, however, because it is not built on systematically collected data and thus cannot be used to monitor changes in condition. Another important recommendation is to closely monitor changes of primary concern in land use of grasslands, including conversion of grassland to cropland, and degradation of grasslands in dry areas.

Specific recommendations for future grassland ecosystem assessments include the following:

- Use higher-resolution satellite data to delineate grassland ecosystems.
- Verify classifications of grasslands through field reconnaissance along selected transects of global land cover maps.
- Expand efforts to present time-series data on vegetation condition indicators such as net primary productivity and rain-use efficiency.
- Expand data collection efforts to produce maps of management systems showing extensive and intensive, or static and mobile grazing patterns.
- Use case studies on resilience to identify links between goods and services and changes in ecosystems, and to differentiate between permanent losses and potential recovery.
- Expand systematic data collection on biodiversity.
- Further research the role of carbon in grassland ecosystems, and the potential for both grassland vegetation and soil under different management systems to store carbon.
- Systematically collect data on human use of and revenues collected from grassland parks, reserves, and recreation areas.

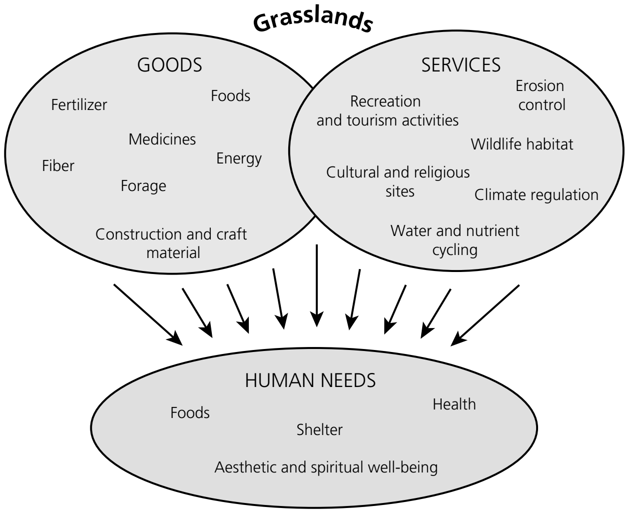
Prologue: Grassland Ecosystems Why They Matter, How They're Doing

Grasslands—as highly dynamic ecosystems—provide goods and services to support flora, fauna, and human populations worldwide. Grasslands have been goldmines of plants used for food. Many of our food grains—wheat, corn, rice, rye, millet, and sorghum—have originated in grasslands. Many grasslands remain the primary source of genetic resources for improving our crops and for increasing the number of pharmaceuticals. Grasslands produce forage for domestic livestock, which in turn support human livelihoods with meat, milk, wool, and leather products. Grasslands provide habitat for breeding, migrating, and wintering birds; ideal conditions for many soil fauna; and rangelands for wild herbivores. These ecosystems cycle water and nutrients, and build and maintain stabilization mechanisms for soil. Grassland vegetation, above and below ground, as well as the soil itself, serve as large storehouses for carbon, helping to limit global warming. Grasslands also supply energy from fuelwood and wind generated from windfarms. These largely open-air landscapes support recreational activities such as hunting, wildlife-watching, and tourism more generally, and offer aesthetic and spiritual gratification **(Figure 1**).

As we enter the 21st century, we still must ask fundamental questions: What is the condition of the world's grasslands? Can grassland ecosystems maintain their current supply of goods and services? Answering these questions is not easy. The difficulty is due in part to the lack of agreement on a definition of grassland condition and on what constitutes a "healthy" grassland ecosystem.

In 1994, the National Research Council (NRC) called for a complete overhaul of the methods for assessing the condition of rangelands in the United States. It stated that rangeland health

Figure 1
Goods and Services Provided by Grasslands



Source: Modified from Campbell et al. 1996:3.

Table 1
Ideal Indicators of Grassland Condition

Grassland Component	Condition Indicator[a]
Extent and Change	Extent of present-day grassland Extent of historical grassland Change in structure and composition
Soil	Soil fertility Soil depth Soil water holding capacity Soil infiltration Soil carbon Soil loss Litter distribution and incorporation
Vegetation	Vegetation productivity Vegetation cover Plant species composition Root distribution
Wildlife	Species abundance Reproductive success
Domestic Livestock	Condition of animals Calving rates Death rates Milk yields
Management System	Grazing patterns Herd size and size of grazing area

Sources: Behnke et al. 1993; Hambly and Angura 1996; NRC 1994.
Notes:
[a.] Data collection and evaluation for each indicator should reflect various spatial and temporal scales.

should be defined as the degree to which the integrity of the soil and ecological processes of rangeland ecosystems are sustained (NRC 1994: 34). In contrast, others describe the condition of grasslands by their ability to provide specific services. For example, Australia's State of the Environment Advisory Council has stated that Australia generally favors evaluation of rangelands according to their potential for pastoralism (State of the Environment Advisory Council 1996: 6–13). Similarly, Abel and Blaikie have described the degradation of grassland condition as a "permanent decline in the rate at which land yields livestock products under a given system of management" (Behnke et al. 1993: 20). In Inner Asia this degradation is described as "the reduction of fine grasses and the increase of poisonous vegetation" (Shan 1996: 111). Emphasizing pastoral productivity, however, means that the available data are less useful for evaluating other aspects of grassland condition, such as the status of biological diversity (State of the Environment Advisory Council 1996: 6–14).

PAGE researchers have used the recommendations of the NRC (1994) and others to compile a list of generally accepted indicators of grassland condition (**Table 1**). These indicators include grassland extent and change, soil, vegetation, domestic and wild animals, and management systems. Importantly, data collected for these indicators would cover various scales, both temporal and spatial. While this pilot study is primarily global in scope, and in some cases uses regional, national, or sub-national data, it would be impossible to find stand or quadrat level data on grasslands aggregated to cover the globe. We can use, nevertheless, the ideal indicators as a guide in our search for global indicators of grassland condition. By juxtaposing these indicators with the major goods and services provided by grassland ecosystems, we have been able to associate the ideal grassland condition indicators with appropriate goods and services and the most important indicators discussed in this report (**Table 2**).

Table 2

Grassland Extent, Goods and Services, and Indicators

Grassland Extent and Goods and Services	Ideal Indicators[a]	Condition Indicators (or Proxies)
Land Area	Extent and Change	Extent of current grasslands Extent of dry grasslands Extent of woody vegetation Extent of grassland with agricultural mosaic Extent of historical grassland Recent change in grassland area
Food, Forage, and Livestock	Soil Vegetation Wildlife Domestic Livestock Management System	Soil degradation Net primary productivity Rain-use efficiency Livestock densities
Biodiversity	Soil Vegetation Wildlife Management System	Centers of Plant Diversity Endemic Bird Areas Global 200 Ecoregions Biological Distinctiveness Index Grassland protected areas Bird populations Large herbivores Key Areas for Threatened Birds Fragmentation and road densities Non-native species
Carbon Storage	Soil Vegetation Wildlife Management System	Potential storage capacity Trends in storage capacity Modification of storage capacity
Tourism/Recreation	Vegetation Wildlife	Grassland tourism Grassland hunting Wildlife Exploitation Index

Sources: Behnke et al. 1993; Hambly and Angura 1996; NRC 1994.

Notes:

[a] See Table 1 for ideal indicators.

Grassland Extent and Change

A Working Definition of Grasslands

Definitions for grasslands vary. Some studies classify grasslands by vegetation while others characterize them by climate, soils, and human use of the ecosystem. Bailey (1989) presents a map of ecosystem units or ecoregions of the continents—including dry savanna or steppe, grassy savanna, prairie, and shrub savanna—using climate and vegetation as indicators of the extent of each unit. He qualifies this method by stating that:

> The delineation of ecoregions should properly be based upon the distinctiveness and distribution of various ecological associations. Unfortunately, available data on the associations of the Earth that include both plants and animals are inadequate for this purpose (Bailey 1989: 307).

Savannas often have been described as forming a continuum between tropical forests and grasslands (House and Hall 2000: in press). House and Hall present arbitrary limits and descriptions that have been used to distinguish between forest, grassland, and different structural savanna types (as defined by Scholes and Hall 1996):

- forests: complete tree canopy cover and three or more overlapping vegetation strata;
- woodlands: 50-100 percent tree canopy cover, and a graminaceous layer;
- savannas: 10-15 percent cover by woody plants and well-developed grass;
- grasslands: less than 10 percent tree cover.

House and Hall further describe classification systems that vary as to whether savanna includes dense woodlands or treeless tropical grasslands, and where tropical grasslands may include mixed grass and tree communities as well as rangelands. House and Hall use the term savanna to include the entire range of communities from treeless grasslands to closed-canopy woodlands (with a graminaceous layer).

Graetz suggests that grasslands are defined ecologically by the structure and floristic composition of the vegetation but says that they are “far more commonly defined by the criterion of land use as any open land that is used for livestock production”

(1994: 126). Descriptions of grasslands according to land use include rangelands (NRC 1994) and vegetation that supports grazing systems (McNaughton 1993a, 1985).

In this study, we define grasslands as terrestrial ecosystems dominated by herbaceous and shrub vegetation and maintained by fire, grazing, drought and/or freezing temperatures. According to this definition, grasslands encompass not only non-woody grasslands but also savannas, woodlands, shrublands, and tundra. This broad definition has allowed PAGE analysts to highlight many of the important goods and services provided by this ecosystem: livestock production as well as grassland biodiversity, carbon storage, and tourism and recreation. No global mapping effort has delineated boundaries of the world's grasslands using all of these vegetation types. Thus, in the next section, we present three datasets that capture important aspects of this definition: land cover type, aridity zones, and woody vegetation cover.

Extent of Global Grassland Cover

Several major studies have presented estimates of the extent of the world's land area in grasslands. These estimates vary, in part, because of differences in land cover characterizations of grasslands. The estimates range from approximately 41 to 56 million km^2, or 31 to 43 percent of the earth's surface (Whittaker and Likens 1975: 306; Atjay et al. 1979: 132; Olson et al. 1983: 20–21) (**Table 3**).

The most recent global dataset based on satellite imagery of land cover and vegetation types is the International Geosphere-Biosphere Project (IGBP) 1-km Advanced Very High Resolution Radiometer (AVHRR) land cover classification (GLCCD 1998). In this study, we have included from the IGBP legend, land characterized as closed and open shrubland, woody savanna, savanna, and non-woody grassland. PAGE analysts have made two modifications to the IGBP land cover classification (**Map 1**). First, we distinguished tundra from areas classified by the IGBP as shrubland, barren land, and snow or ice and included tundra in our extent of grassland. We used the legend from Olson's Global Ecosystem Classification to identify the extent of tundra (Olson et al. 1983). Second, we subtracted urban area from the grassland area. We identified urban areas using the Nighttime Lights of the World database, a 1-km resolution map derived from nighttime imagery provided by the Defense Meteorological Satellite Program, Operational Linescan System of the United States (NOAA-NGDC 1998). This database identifies the locations of stable lights that indicate built-up areas. To calculate the total area of grasslands, PAGE researchers subtracted the area of these urbanized locations from the total area of grassland according to the IGBP dataset. This calculation decreased the total global grassland area by approximately 1 million km^2 (**Table 4**).

According to the modified IGBP land cover map, or PAGE land area, approximately 13.8 percent of the global land area

Table 3

Extent of the World's Grasslands

	Whittaker and Likens (1973)[a]		Atlay et al. (1970)[a]		Olson et al. (1983)	
Grassland Type	**Million km^2**	**Percent[b]**	**Million km^2**	**Percent[b]**	**Million km^2**	**Percent[b]**
Savanna	15.0	11.6	12.0	9.3	X	X
Tropical woodland and savanna	X	X	X	X	7.3	5.6
Dry savanna and woodland	8.5[c]	6.6	3.5	2.7	13.2[d]	10.2
Shrublands[e]	X	X	7.0	5.4	X	X
Non-woody grassland and shrubland	X	X	X	X	21.4	16.5
Temperate grassland	9.0	7.0	12.5	9.7	X	X
Tundra	8.0	6.2	9.5	7.3	13.6	10.5
Total grassland	**40.5**	**31.3**	**44.5**	**34.4**	**55.5**	**42.8**

Sources: Atjay et al. 1979; Olson et al. 1983; Whittaker and Likens 1975.

Notes:
"X" signifies data are not available or have been combined with other categories.
[a] Desert and semidesert scrub not included.
[b] Total land area used for the world is 129,476,000 km^2–excludes Greenland and Antarctica.
[c] Includes woodland and shrubland.
[d] Includes dry forest and woodland.
[e] Includes warm, hot, or cool shrublands.

Table 4

Ecosystem Area and Population

Ecosystem/Country	IGBP Land Area (000 km^2)	Urban Area[a] (000 km^2)	Agricultural Mosaic Area[b] (000 km^2)	PAGE Area (000 km^2)[c]	Population (000)[d]
GRASSLANDS	**53,544**	**1,010**	**7,172**	**52,544**	**792,711**
Asia (Excl. Middle East)	9,033	141	1,281	8,892	249,495
Europe	7,072	116	189	6,956	20,491
Middle East & N. Africa	3,031	161	159	2,871	111,882
Sub-Saharan Africa	14,546	83	3,531	14,464	312,935
North America	6,816	238	518	6,583	6,032
C. America & Caribbean	1,130	82	24	1,048	30,533
South America	5,017	150	1,416	4,867	57,529
Oceania	6,898	40	54	6,859	3,814
FORESTS	**29,905**	**930**	**1,727**	**28,974**	**446,470**
Asia (Excl. Middle East)	3,812	91	192	3,721	231,782
Europe	6,957	226	338	6,731	43,713
Middle East & N. Africa	100	10	44	90	6,724
Sub-Saharan Africa	2,672	13	162	2,659	53,823
North America	7,564	449	965	7,115	30,764
C. America & Caribbean	997	59	1	939	33,940
South America	6,928	67	26	6,861	39,860
Oceania	874	17	0	857	5,864
AGRICULTURE	**27,890**	**2,407**	**X**	**36,234**	**2,790,582**
Asia (Excl. Middle East)	8,874	683	X	10,370	1,991,214
Europe	6,840	763	X	7,448	311,923
Middle East & N. Africa	1,025	136	X	1,230	99,662
Sub-Saharan Africa	2,141	38	X	5,837	204,901
North America	2,867	511	X	4,406	47,927
C. America & Caribbean	517	48	X	611	26,973
South America	4,991	216	X	5,642	105,083
Oceania	635	13	X	690	2,899
OTHER[e]	**18,136**	**395**	**180**	**22,343**	**1,812,688**
ECOSYSTEM TOTALS[f]	**129,476**	**4,745**	**9,079**	**X**	**X**

Sources: PAGE calculations based on CIESIN 2000; GLCCD 1998; NOAA NGDC 1998; Olson 1994a and b.

Notes:

[a] Urban area is defined by the NOAA/NGDC database within each IGBP ecosystem category (i.e., grassland, forest, other). The data set contains the location of stable lights and is used as an indicator of the spatial distribution of settlements and infrastructure.

[b] Agricultural mosaic area is area classified as 30-40 percent cropland within each IGBP ecosystem category (i.e., grasslands, forests, other).

[c] Boundaries for each PAGE ecosystem category are defined independently resulting in an overlap of agriculture ecosystem area with grassland and forest ecosystem area. Area estimates for grasslands and forests exclude the stable lights extent. The PAGE estimates for agriculture ecosystem extent are based on the seasonal land cover regions (SLCRs) which roughly equals the IGBP agriculture extent plus the agricultural mosaic area for grasslands and forests but includes urban areas since an explicit urban class was not assigned in the SLCR map units.

[d] Population data are from an inventory of national censuses compiled by administrative units. These data were standardized to 1995 to derive estimates for the PAGE ecosystem areas.

[e] The "Other" category includes wetlands, barren land, and human settlements.

[f] Global totals cannot be calculated for PAGE categories because the agriculture ecosystem area overlaps with the grassland and forest ecosystem areas.

(excluding Greenland and Antarctica) is woody savanna and savanna; 12.7 percent is open and closed shrub; 8.3 percent is non-woody grassland; and 5.7 percent is tundra (**Table 5**). Thus, approximately 40.5 percent of terrestrial area is grassland. This estimate of 52.5 million km^2 for total grassland area falls within the range of previous estimates: 40.5 to 55.5 million km^2.

Regionally, grasslands are found on every continent. Commonly recognized grasslands include the savannas of Africa, the steppes of Central Asia, the llanos and cerrados of South America, the prairies of North America, and the hummock grasslands or spinifex of Australia. Using the PAGE land area, we determined the extent of grasslands within each geographic region (**Table 6**):

- Sub-Saharan Africa and Asia (excluding the Middle East) have the largest total amount of grassland: 14.5 and 8.9 million km^2, respectively.
- The Middle East and Central America have the least grassland: 2.9 and 1.0 million km^2, respectively.
- Sub-Saharan Africa has the largest amount of savanna: 10.3 million km^2.
- Oceania and Asia have the largest amount of shrubland: close to 4 million km^2 each.
- Asia has most non-woody grassland: 4 million km^2.
- Europe has the most tundra: nearly 4 million km^2.

At the country level, 28 countries have more than 500,000 km^2 of grassland and 11 have more than one million km^2 (**Table 7**). The countries with more than 500,000 km^2 of grassland are found in all eight regions of the globe; more than half of them are in Sub-Saharan Africa. The countries with more than 1 million km^2 of grassland are found in six regions:

- two in Sub-Saharan Africa: the Sudan and Angola;
- three in Asia: China, Kazakhstan, and Mongolia;
- two in South America: Brazil and Argentina:
- two in North America: the United States and Canada:
- one in Europe: the Russian Federation; and
- one in Oceania: Australia.

The five countries with the most grassland are Australia, the Russian Federation, China, the United States, and Canada; each supporting over 3 million km^2 of grassland.

The land cover in 28 countries is more than 60 percent grassland (**Table 8**). The five countries with the highest percent of grassland area (all in Sub-Saharan Africa) are Benin, the Central African Republic, Botswana, Togo, and Somalia. Additionally, 25 countries have at least 60 percent and more than 100,000 km^2 of grassland; the majority are found in Sub-Saharan Africa (Angola, Benin, Botswana, Burkino Faso, Central African Republic, Cote d'Ivoire, Ethiopia, Ghana, Guinea, Kenya, Madagascar, Mozambique, Nigeria, Senegal, Somalia, South Africa, Tanzania, Zambia, and Zimbabwe); 3 are in Asia (Mongolia, Kazakhstan, and Turkmenistan), 1 in the Middle East (Afghanistan), and 1 in Oceania (Australia). Six countries support at least 60 percent grassland area and contain more than 1 million km^2 of grassland: Australia, Mongolia, Kazakhstan, Angola, South Africa, and Ethiopia.

Another way to designate the extent of grassland area is to draw boundaries around watersheds and calculate the amount of grassland within each basin. In a study of watersheds of the worlds, the World Resources Institute (WRI) mapped 145 watersheds and analyzed global data at the watershed level (Revenga et al. 1998). Watersheds were defined as the entire area drained by a major river system or by one of its main tributaries. The selected watersheds, modeled from elevation data using geographic information systems (GIS) software, represented 55 percent of the world's land area (excluding Greenland and Antarctica).

For this study, PAGE researchers used the PAGE land cover map as an overlay to determine the percent of total basin area classified as grassland. Within the previously mapped 145 watersheds, we identified basins that fall within three categories:

Table 5
Grassland Types of the World

Grassland Type	PAGE Land Area[a] Area (million km^2)	PAGE Land Area[a] Percent of Total Land Area[b]
Savanna	17.9	13.8
Shrubland	16.5	12.7
Non-woody Grassland[c]	10.7	8.3
Tundra	7.4	5.7
World Total	**52.5**	**40.5**

Sources: PAGE calculations based on GLCCD 1998; Olson 1994a and b.
Notes:
[a] PAGE land area is the IGBP land cover classifications for savanna, woody savanna, closed and open shrubland, and non-woody grassland, plus the Olson's category for tundra.
[b] Total land area used for the world is 129,476,000 km^2—excludes Greenland and Antarctica.
[c] Includes non-woody grassland.

Table 6

World Regions, PAGE Grassland Area, and Population[a]

Region	Savanna Area (Million km²)	Savanna Population (000)	Shrubland Area (Million km²)	Shrubland Population (000)	Non-woody Grassland Area (Million km²)	Non-woody Grassland Population (000)
Asia[b]	0.90	79,993	3.76	112,482	4.03	53,064
Europe	1.83	8,243	0.49	7,675	0.70	2,169
Middle East & N. Africa	0.17	10,719	2.11	68,129	0.57	31,421
Sub-Saharan Africa	10.33	266,258	2.35	17.354	1.79	28,558
North America	0.32	1,725	2.02	1,766	1.22	2,530
C. America & the Caribbean	0.30	15,622	0.44	5,705	0.30	8,999
South America	1.57	18,051	1.40	17.997	1.63	17,128
Oceania	2.45	2,546	3.91	333	0.50	882
World	**17.87**	**412,767**	**16.48**	**239,044**	**10.74**	**149,232**

Region	Tundra Area (Million km²)	Tundra Population (000)	Global Grassland Area (Million km²)	Global Grassland Population (000)
Asia[b]	0.21	4,231	8.89	249,771
Europe	3.93	2,734	6.96	20,821
Middle East & N. Africa	0.02	457	2.87	110,725
Sub-Saharan Africa	0.00	0	14.46	312,170
North America	3.02	104	6.58	6,125
C. America & the Caribbean	0.00	20	1.05	30,347
South America	0.26	3098	4.87	56,273
Oceania	0.00	0	6.86	3,761
World	**7.44**	**11,550**	**52.53**	**789,992**

Sources: PAGE calculations based on CIESIN 2000; ESRI 1993; GLCCD 1998; Olson 1994a and b.

Notes:
[a] Total land area used for the world is 129,476,000 km²—excludes Greenland and Antarctica.
[b] Asia excludes Middle East countries.

less than 25 percent grassland, between 25 and 50 percent grassland, and more that 50 percent grassland. Twenty-five of the 145 watersheds have more than 50 percent grassland (**Figure 2**). These watersheds are scattered throughout the world in six regions: 13 in Africa, 5 in Asia, 3 in South America, 2 in North America, 1 shared by North and Central America, and 1 in Oceania. The 13 watersheds with more than 50 percent grassland in Africa include the Senegal, Niger, Volta, Nile, Turkana, Shaballe, Jubba, Zambezi, Okavango, Orange, Limpopo, Mangoky, and Mania. Two additional large watersheds on the African continent, the Congo and Lake Chad, are adjacent to several of the largely grassland basins, and are at least 25 percent grassland. None of the 27 mapped watersheds in Europe are more than 25 percent grassland.

Examination of grasslands according to watershed boundaries can facilitate integrated resource management. Grasslands provide services to watersheds in the form of rainfall absorption, aquifer recharge, soil stabilization, and moderation of runoff. Many physical and biological features of grasslands can be managed effectively in the context of watersheds. At a minimum, the grassland watershed map can be used to visually highlight watersheds with large grassland areas and, with overlays of additional environmental data, to identify those that may deserve special conservation attention. For example, the 17 mapped watersheds in Africa could be ranked according to percent of grassland cover. Additional data could be used to pinpoint threats to grassland soil, vegetation, and wildlife within each watershed.

ARIDITY ZONES

The world has been divided into a set of six aridity zones on the basis of the ratio of mean annual precipitation to mean annual potential evapotranspiration (ratios less than .05 indicate hyperaid zones, whereas ratios of .65 or greater identify humid zones) (UNEP 1992) (**Map 2**). (As a note of caution, use of annual means can be misleading because rainfall and evapotranspiration vary greatly according to season in these zones.) UNSO (1997: 5) cites Ahrens' (1982) definition of potential evapotranspiration as the "amount of moisture that, if it were available, would be removed from a given land area by evaporation and transpiration." This evapotranspiration can be estimated from temperature and photoperiod. Thus, climate statistics for the three dryland zones—arid, semi-arid, and dry sub-humid—translate to an aridity index of .05–.65. Woody savannas and savannas found in the humid zone have an aridity index of .65 or greater.

Table 7

Top Countries for Grassland Area[a]

Country	Region[b]	Total Land Area (km^2)	Total Grassland Area (km^2)
Australia	Oceania	7,704,716	6,576,417
Russian Federation	Europe	16,851,600	6,256,518
China	Asia	9,336,856	3,919,452
United States	North America	9,453,224	3,384,086
Canada	North America	9,908,913	3,167,559
Kazakhstan	Asia	2,715,317	1,670,581
Brazil	South America	8,506,268	1,528,305
Argentina	South America	2,781,237	1,462,884
Mongolia	Asia	1,558,853	1,307,746
Sudan	Sub-Saharan Africa	2,490,706	1,292,163
Angola	Sub-Saharan Africa	1,252,365	1,000,087
Mexico	C. America & Carib.	1,962,065	944,751
South Africa	Sub-Saharan Africa	1,223,084	898,712
Ethiopia	Sub-Saharan Africa	1,132,213	824,795
Congo, Dem. Rep.	Sub-Saharan Africa	2,336,888	807,310
Iran	Middle East & N. Africa	1,624,255	748,429
Nigeria	Sub-Saharan Africa	912,351	700,158
Namibia	Sub-Saharan Africa	825,606	665,697
Tanzania, United Republic	Sub-Saharan Africa	945,226	658,563
Mozambique	Sub-Saharan Africa	788,938	643,632
Chad	Sub-Saharan Africa	1,167,685	632,071
Mali	Sub-Saharan Africa	1,256,296	567,140
Central African Republic	Sub-Saharan Africa	621,192	554,103
Somalia	Sub-Saharan Africa	639,004	553,963
India	Asia	3,090,846	535,441
Zambia	Sub-Saharan Africa	754,676	526,843
Botswana	Sub-Saharan Africa	579,948	508,920
Saudi Arabia	Middle East & N. Africa	1,958,974	502,935

Sources: PAGE calculations based on ESRI 1993; GLCCD 1998; Olson 1994a and b.

Notes:

a. Includes all countries with greater than 500,000 km^2 of grassland.

b. Asia excludes Middle East countries.

Aridity, as described in the *World Atlas of Desertification* (UNEP 1997), represents a lack of moisture in average climatic conditions. This lack of moisture can be attributed to atmospheric stability (especially in zones of stable, moisture-deficient air in the tropics and subtropics), the distance of oceans from continental interiors, the creation of rain shadow zones by mountains, and cold ocean currents. Grasslands are found in all of these situations, although those found in areas affected by cold ocean currents (which lead primarily to hyper-arid, desert areas) are not considered grasslands under the definition used in this study.

Twenty-eight percent of the world's grasslands are found in the semi-arid zones, 23 percent in the humid zone, 20 percent in the cold zone, and 19 percent in the arid zone (**Table 9**). Montane grasslands and shrublands are found primarily in the cold aridity zones in mid-latitude, high-altitude areas; tundra is found primarily in the cold aridity zones at northern latitudes. Grasslands are least represented in the dry sub-humid zone and the hyper-arid zone, which is dominated by the Sahara Desert and Arabian Peninsula. Among the world's regions, Africa has the largest amount of total grassland area in each aridity zone. Most of this area is in the semi-arid, dry sub-humid, and humid zones. Asia has the most grassland in the arid zone, as well as considerable grassland in the semi-arid, humid, and cold zones.

The United Nations Convention to Combat Desertification (UNCCD) provides a framework for sustainable development of

Table 8

Top Countries for Percent of Grassland Area[a]

Country	Region[b]	Total Land Area (km^2)	Grassland Area (percent)
Benin	Sub-Saharan Africa	116,689	93.1
Central African Republic	Sub-Saharan Africa	621,192	89.2
Botswana	Sub-Saharan Africa	579,948	87.8
Togo	Sub-Saharan Africa	57,386	87.2
Somalia	Sub-Saharan Africa	639,004	86.7
Australia	Oceania	7,704,716	85.4
Burkina Faso	Sub-Saharan Africa	273,320	84.7
Mongolia	Asia	1,558,853	83.9
Guinea	Sub-Saharan Africa	246,104	83.5
Mozambique	Sub-Saharan Africa	788,938	81.6
Namibia	Sub-Saharan Africa	825,606	80.6
Angola	Sub-Saharan Africa	1,252,365	79.9
Zimbabwe	Sub-Saharan Africa	391,052	76.8
Nigeria	Sub-Saharan Africa	912,351	76.7
Guinea-Bissau	Sub-Saharan Africa	34,117	73.9
Senegal	Sub-Saharan Africa	196,699	73.5
South Africa	Sub-Saharan Africa	1,223,084	73.5
Lesotho	Sub-Saharan Africa	30,533	73.5
Afghanistan	Middle East & N. Africa	642,146	73.4
Ethiopia	Sub-Saharan Africa	1,132,213	72.9
Zambia	Sub-Saharan Africa	754,676	69.8
Tanzania, United Republic	Sub-Saharan Africa	945,226	69.7
Madagascar	Sub-Saharan Africa	594,816	69.4
Kenya	Sub-Saharan Africa	584,453	68.6
Ghana	Sub-Saharan Africa	240,055	64.2
Cote d'Ivoire	Sub-Saharan Africa	322,693	62.3
Turkmenistan	Asia	471,216	62.1
Kazakhstan	Asia	2,715,317	61.5

Sources: PAGE calculations based on ESRI 1993; GLCCD 1998; Olson 1994a and b.

Notes:

[a.] Includes all countries with greater than 60 percent grassland.

[b.] Asia excludes Middle East countries.

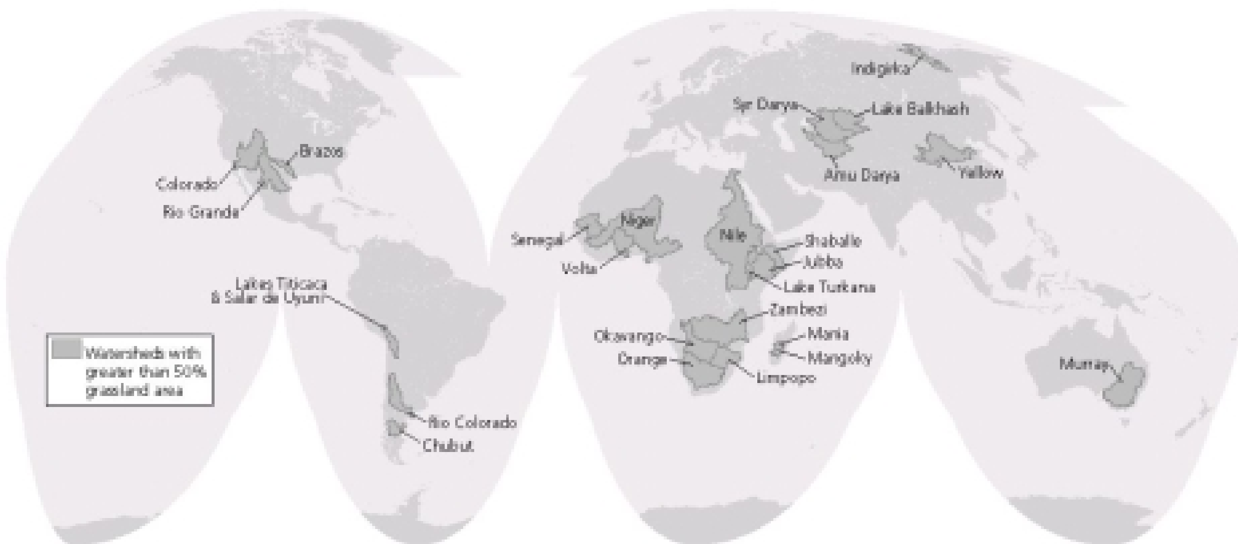
drylands; with help from national and international partners, the CCD focuses attention on dryland populations in its attempts to find solutions to problems of desertification (UNSO 1997). The Office to Combat Desertification and Drought (UNSO), in a collaborative study with WRI, found that drylands are inhabited by approximately 2 billion people; an estimated 1.7 billion inhabitants are threatened by desertification in developing countries (UNSO 1997: 3). PAGE analysts have determined human population levels in grasslands within each aridity zone. Populations are highest in the dry grasslands (arid, semi-arid, and dry sub-humid grasslands) of Sub-Saharan Africa, followed by the dry grasslands of Asia and the Middle East. Population densities are lowest in the dry grasslands of Oceania, North America, and Europe.

In addition to defining grassland ecosystems by land cover types and aridity zones, we can analyze grassland extent using several supplementary approaches. One approach distinguishes forest from grassland by using the percent of woody vegetation cover. Another approach estimates the amount of agricultural land within a specified mapping unit of grassland. These approaches are described below.

WOODY VEGETATION COVER

Using AVHRR data with 1-km spatial resolution, the Geography Department at the University of Maryland (UMD) gener-

Figure 2
Grassland Watersheds of the World



Source: Revenga et al., 1998; GLCCD 1998.

Table 9
Grasslands within Aridity Zones

Aridity Zone	Aridity Index [a]	Percent of Total Land Area [b] (percent)	PAGE Grassland Area in Each Aridity Zone [c] (percent)
Cold		13.6	20
Hyper-arid	< 0.05	7.5	2
Arid	0.05 - < 0.20	12.1	19
Semi-arid	0.20 - < 0.5	17.7	28
Dry Sub-humid	0.5 - < 0.65	9.9	8
Humid	0.65 and greater	39.2	23

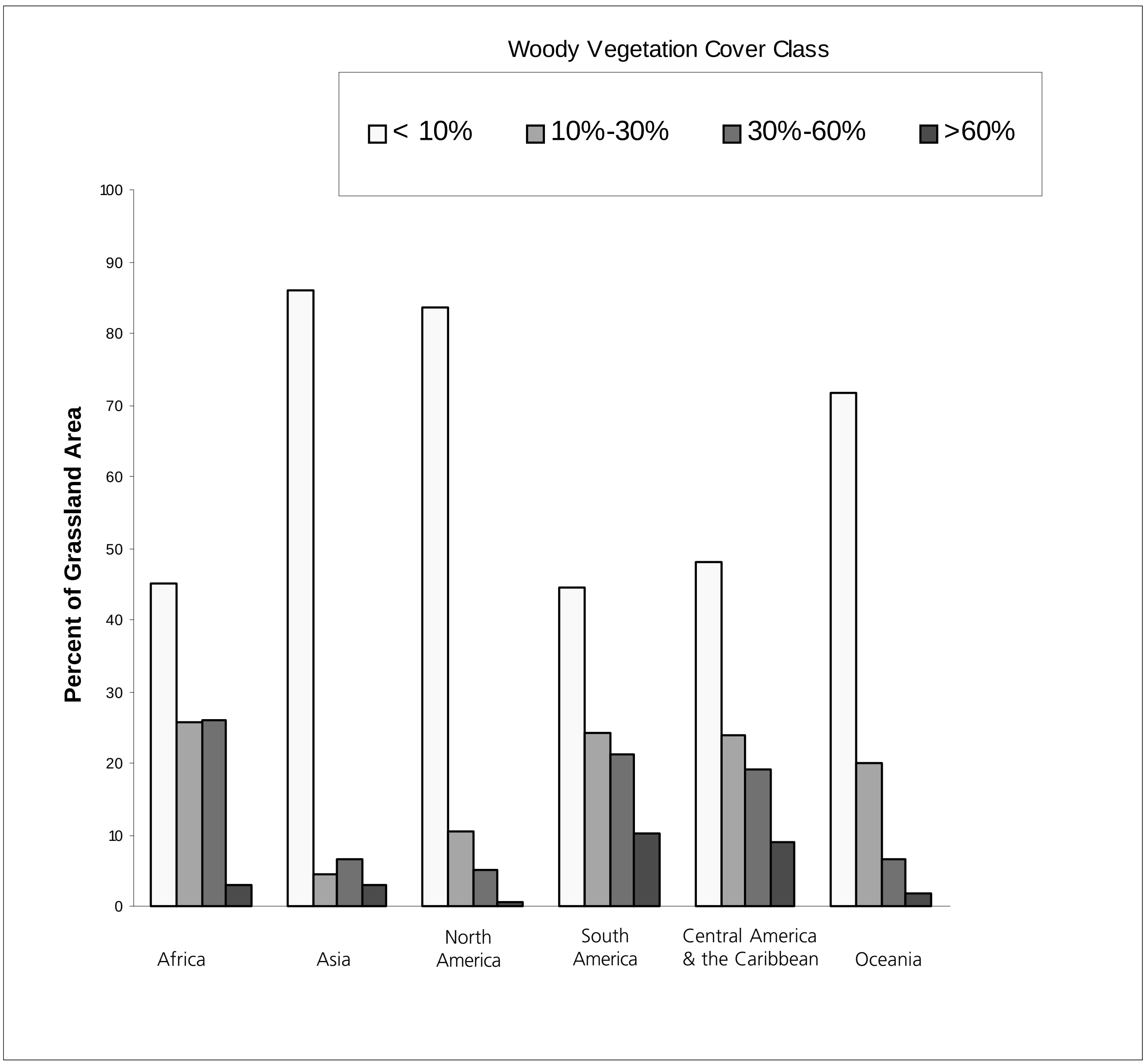
Sources: PAGE calculations based on GLCCD 1998; Olson 1994a and b; UNEP 1997.

Notes:
[a] Aridity index is the ratio of mean annual precipitation to potential evapotranspiration.
[b] Total land area used for the world is 129,476,000 km^2—excludes Greenland and Antarctica.
[c] Total grassland area used is 52,554,000 km^2.

ated a global map depicting percent of woody vegetation cover on a scale of 0 to 100 percent (DeFries et al. 2000). Woody vegetation is defined as mature vegetation with an approximate height of greater than five meters. PAGE analysts modified the UMD map by separating bare ground from the "less than 10 percent woody vegetation" category on the basis of the IGBP bare ground classification. Using this technique, we were able to map the percent of woody and herbaceous cover across the world's terrestrial surface (**Map 3**). This mapping method results in a more continuous representation of grassland extent than that used by IGBP, with boundaries between grassland types less defined.

Worldwide, the percent of grassland within each woody vegetation cover class ranges from approximately 66 percent in the non-woody class (this class represents less than 10 percent woody vegetation), 17 percent in the 10–30 percent woody vegetation class, 14 percent in the 30–60 percent woody vegetation class, and 3 percent in the greater than 60 percent woody vegetation class. Histograms of the percent of area within each class in each region show that the grasslands in Asia, North America, and Oceania are largely non-woody (primarily in the less than 10 percent woody vegetation class). In contrast, the grasslands in Africa, South America, and Central America and the Caribbean contain larger amounts of woody vegetation (**Figure 3**).

Figure 3
Percent Woody Vegetation in Grasslands



Source: DeFries et al. 2000; GLCCD 1998.

By indicating percentage of woody vegetation, the UMD map provides a view of grasslands as part of a continuum of global land cover. Generally, classification schemes employ seemingly rigid boundaries between classes. These boundaries tend to imply homogeneity within land cover types when in reality land cover is often heterogeneous. The UMD map avoids rigid distinctions between land cover types and provides an alternative perspective on grassland extent and the complexities of ecological and land cover variation.

Change in Grassland Extent

HISTORICAL CHANGE IN GRASSLAND EXTENT

The World Wildlife Fund–US (WWF–US) has mapped the world's major types of habitat representing geographic areas that share environmental conditions, habitat structure, patterns of biological complexity, and species complexes with similar guild structures and adaptations (Olson and Dinerstein 1997: 4). The grassland major habitat types (MHTs) are divided into six categories:

- tropical and subtropical grasslands, savannas, and shrublands;
- temperate grasslands, savannas, and shrublands;
- flooded grasslands and savannas;
- montane grasslands and shrublands;
- Mediterranean shrublands; and
- tundra.

Boundaries for the MHTs were drawn on the basis of expert opinion and existing classification systems for vegetation and climate. The MHTs depict potential extent and location of grasslands before major modification by humans.

PAGE analysts have compared the area of grassland MHTs to current land cover (**Table 10**). From this analysis, it is apparent that much of the temperate non-woody grassland, savanna, and shrublands have been cultivated—41 percent of this MHT is now classified as agricultural land. Conversion of grassland to agricultural land also has occurred in other MHTs, but to a lesser extent: flooded grasslands are now 22 percent agriculture; tropical and subtropical grassland 15 percent agriculture; Mediterranean shrublands 11 percent, and montane grasslands 8 percent. Tundra is the only grassland MHT with minimal reported cultivation (0.1 percent).

In addition to identifying MHTs, WWF–US has described ecoregions of the world. Ecoregions are defined as "a relatively large unit of land or water containing a characteristic set of natural communities that share a large majority of their species, dynamics, and environmental conditions "(Dinerstein et al. 1995: 4). Ecoregions, when aggregated, form the MHTs and represent the approximate original extent of their natural communities (Olson and Dinerstein 1997: 4).

PAGE analysts assessed land cover change in five ecoregions: one each in North America, South America, Africa, Asia, and Australia. Each shows varying percents of habitat change—primarily from grassland to cropland but also from grassland to urban areas (**Table 11**). Within these ecoregions, the Tallgrass Prairie ecoregion of North America, by far, shows the largest change: retaining only 9 percent grassland area with 71 percent cropland and 19 percent urban area. The Cerrado Woodland and Savanna ecoregion of South America follows with a similar amount of land as cropland (71 percent), 21 percent grassland, and 5 percent urban. The last three ecoregions—one each in Asia, Africa, and Australia—retain at least 50 percent of their grasslands. Cropland ranges from 19 to 37 percent and urban areas make up less than 2 percent of these ecoregions (**Map 4**).

Table 10

Conversion of Historical Grassland Areas[a]

Major Habitat Type	PAGE Grassland (percent)	Agriculture (percent)	Urban (percent)	Other[b] (percent)
Tropical and Subtropical Grasslands, Savannas, and Shrublands	71.3	15.4	0.8	11.8
Temperate Grasslands, Savannas, and Shrublands	43.4	41.4	6.1	7.4
Flooded Grasslands and Savannas	48.2	21.7	2.9	24.4
Montane Grasslands and Shrublands	70.6	7.7	1.4	18.7
Mediterranean Shrublands	48.0	11.9	4.4	34.9
Tundra	71.2	0.1	0.1	23.7

Sources: PAGE calculations based on GLCCD 1998; Olson 1994a and b; WWF-US 1999.

Notes:

[a] Historical grassland areas refer to the Major Habitat Types (MHTs) as defined by the World Wildlife Fund (WWF) which represent the potential extent of grasslands before major modification by humans.

[b] The "Other" category represents other IGBP/PAGE land cover classifications such as deciduous broadleaf forests or mixed forests.

Table 11

Conversion of Grassland Ecoregions

Ecoregion	Current Grassland Extent (percent)	Estimated Conversion: Cropland Extent (percent)	Urban Extent (percent)	Other[a] (percent)
North American Tallgrass Prairie[b]	9.4	71.2	18.7	0.7
South American Cerrado Woodland and Savanna[c]	21.0	71.0	5.0	3.0
Asian/Daurian Steppe[d]	71.7	19.9	1.5	6.9
Central and Eastern Mopane and Miombo Woodlands[e]	73.3	19.1	0.4	7.2
Southwest Australian Shrublands and Woodlands[f]	56.7	37.2	1.8	4.4

Sources: PAGE calculations based on GLCCD 1998; Olson 1994a and b; WWF-US 1999.

Notes:
[a] The "Other" category represents other PAGE land cover classification such as deciduous broadleaf forests or mixed forests.
[b] Ecoregion is in North America: United States.
[c] Ecoregion is in South America: Brazil, Paraguay, and Bolivia.
[d] Ecoregion is in Asia: Mongolia, Russia, and China.
[e] Ecoregion is in Sub-Saharan Africa: Tanzania, Rwanda, Burundi, Dem. Rep. Congo, Zambia, Botswana, Zimbabwe, and Mozambique.
[f] Ecoregion is in Oceania: Australia.

RECENT CHANGE IN GRASSLAND EXTENT

Exact figures for recent change in grassland extent are not readily available. In general, however, native grasslands have decreased. In some areas, total area classified as grassland may have increased due to clearing of forests. In addition, data that are published for different countries or regions often are difficult to compare because definitions of grassland are so variable.

The Food and Agriculture Organization of the United Nations (FAO) does not provide estimates of the extent of grassland in each country. In the past, FAO has reported on permanent pasture (defined as land used for at least five years for herbaceous forage crops, either cultivated or growing wild) and included shrubs and savanna in either the permanent pasture category or the forests and woodlands category. Grassland not used for forage was included in the category "other land." This "other land" category could not be used to determine ungrazed pasture, however, because it combined grassland not used for pasture with uncultivated land, built-up areas, wetlands, wasteland, and roads. Because of the inexact method for defining permanent pasture, data in this category has not been reported by FAO since 1994.

The U.S. Geological Survey has reported on the change in extent of North American grasslands over the last 170 years (Samson et al. 1998: 439). The data are based on estimates from state and provincial conservation organizations, and show that since 1830, the tall-grass prairie of North America has decreased by nearly 97 percent (**Table 12**). Mixed-grass prairie has decreased by 64 percent, from approximately 628,000 km^2 to 225,803 km^2. Short-grass prairie has decreased by nearly 66 percent, from approximately 181,790 km^2 to 62,115 km^2. These prairies are described as the most threatened ecological community in North America (Samson and Knopf 1994: 418). Considered in their entirety, the prairies of central North America have declined by an average of 79 percent since the early 1800s.

Change in the extent of grassland also can be analyzed through the use of Landsat TM (Thematic Mapper) imagery with a ground resolution of 30 meters. The Nature Conservancy (TNC) has identified 15 ecoregions in the Great Plains of North America for developing ecoregional conservation plans (Ostlie and Haferman 1999: 138). TNC delineated the Great Plains as a 2.6 million km^2 bioregion that encompasses 15 ecoregions adapted from Bailey (1995) and the Ecological Stratification Working Group (1995). Using TM imagery, TNC identified relatively large, untilled areas (exceeding 65–130 km^2) in each of the Great Plains ecoregions that have initiated ecoregional conservation (**Figure 4**). These areas generally have not been tilled and 80 percent of the land is expected to be in native vegetation (Wayne Ostlie, TNC, Boulder, CO; personal communication, May 1999). Other portions of these landscapes may include tilled land, land set aside in the Conservation Reserve Program, or lands tilled in the past (typically after the 1930s) but not revegetated. These largely untilled areas are more likely to maintain large-scale ecological processes than smaller areas and to enhance the potential for long-term viability of species and natural communities (Ostlie and Haferman 1999: 143).

Although the eastern Great Plains and its tall-grass ecosystem has been nearly completely converted to agriculture or urban areas, the western Great Plains ecoregions retain areas of

Table 12

Decline in Prairies of Central North America

Prairie Type/Location	Past area (km^2)[a]	Current area (km^2)[a]	Decline (percent)
Tall-grass Prairie	**677,300**	**21,548**	**96.8**
Manitoba	6,000	3	99.9
Illinois	85,000	9	99.9
Indiana	28,000	4	99.9
Iowa	120,000	121	99.9
Kansas	69,000	12,000	82.6
Minnesota	73,000	450[b]	99.3[b]
Missouri	60,000	320	99.5
Nebraska	61,000	1,230	98.0
North Dakota	1,300	1	99.9
Oklahoma	52,000	N/a	N/a
South Dakota	26,000	200	99.2
Texas	72,000	7,200	90.0
Wisconsin	24,000	10	99.9
Mixed-grass Prairie	**628,000**	**225,803**	**64.0**
Alberta	87,000	34,000	60.9
Manitoba	6,000	3	99.9
Saskatchewan	134,000	25,000	81.3
Nebraska	77,000	19,000	75.3
North Dakota	142,000	45,000	68.3
Oklahoma	25,000	N/a	N/a
South Dakota	16,000	4,800	70.0
Texas	141,000	98,000	30.5
Colorado	N/a	N/a	N/a
Kansas	N/a	N/a	N/a
Montana	N/a	N/a	N/a
Wyoming	N/a	N/a	N/a
Short-grass Prairie	**181,790**	**62,115**	**65.8**
Saskatchewan	59,000	8,400	85.8
Oklahoma	13,000	N/a	N/a
New Mexico	N/a	12,552	N/a
South Dakota	1,790	1,163	35.0
Texas	78,000	16,000	79.5
Wyoming	30,000	24,000	20.0
Colorado	N/a	N/a	N/a
Kansas	N/a	N/a	N/a
Montana	N/a	N/a	N/a
Nebraska	N/a	N/a	N/a
TOTAL	**1,487,090**	**309,467**	**79.2**

Source: Samson et al. 1998.

Notes:

[a] Estimates of past and current area are based on information from The Nature Conservancy's Natural Heritage Data Center Network; the provinces of Alberta, Manitoba, and Saskatchewan; universities, and state conservation organizations.

[b] Original data reported as a range: 300–600 km^2 at 99.2–99.6 percent.

Figure 4
Untilled Landscapes in the Great Plains

Source: Ostlie and Haferman 1999.

untilled lands. These short-grass prairie areas have not been as exploited for agriculture because their soils are shallow, rocky, or sandy, and their precipitation unreliable. The Nature Conservancy points out, however, that the resource inventory of natural communities has been sparse in these areas, and the distribution of untilled tracts within the ecoregions is not uniform (Ostlie and Haferman 1999: 146). For example, in the Central Short-grass Prairie, a single community—sandsage—dominates the majority of the untilled landscapes, and much of the prairie is undergoing conversion to agriculture.

Outside of North America, the extent of grassland may be increasing as forests are cleared, or decreasing as urban and agricultural areas expand. With a few exceptions, records on the rate and extent of change are not well documented. Data presented by the IUCN-World Conservation Union in 1991 summarize the extent of and change in the lowland grasslands of central and eastern Europe (IUCN 1991). Grassland status, distribution, and recent losses are presented for 14 countries: Albania; Bulgaria; Czechoslovakia (pre-breakup); Germany (portion); Hungary; Poland; Romania; the former western Soviet Republics of Ukraine, Belarus, Lithuania, Moldova, Latvia, and Estonia; and Yugoslavia (pre-breakup). IUCN data on permanent pasture, an inexact category for defining grassland, reveals that over the ten-year period from 1976 to 1986 extent of change in this pasture in eight of these countries (data for each of the former Soviet Republics are not reported) ranged from a 7.7 percent decrease for the Federal Republic of Germany to a 13.5 percent increase for Bulgaria. This relatively large increase for Bulgaria may be misleading, however, as it is primarily ascribed to the conversion of meadow to pasture (IUCN 1991:13).

Data on change in land cover in Australia over the last 200 years reveal an increase in grassland area. According to the State of the Environment Advisory Council (1996: 6–14), rangelands occupy about 75 percent of the continent (approximately 6 million km^2). Shrubland occupies 46 percent of the continent; woodland, 42 percent; and tussock grasslands, 9 percent. From 1788 to 1988, forests were thinned to woodland and cleared for grazing, woodland was thinned to open woodland and cleared for pasture and cropland, and shrubland was thinned (State of the Environment Advisory Council 1996: 6–11). Grassland (without an overstory of woody vegetation) increased from 7 percent to almost 16 percent of the continent's surface. Major changes include an increase of 3 percent in tussock grasslands and an increase of 6 percent in sown pasture grasses. Although there has been a 9 percent increase in grassland area, 8 percent of the native grassland present in 1788 is now open woodland.

Data on land use change in Africa suggest conversion of dry grassland areas to agriculture. According to the United States Agency for International Development (USAID) Famine Early Warning System (FEWS), over the period 1976–1996, people in Kenya moved from lands with high agricultural potential to semi-arid lands with lower agricultural potential (FEWS 1996). FEWS reports that Kenya increased maize production by 4.8 percent per year during the 1970s. By the mid-1980s, land in the zones with high agricultural potential was scarce, and planting increased in marginal areas, which (along with decreases in yields from improved varieties of maize) led to stagnating trends in production. The amount of marginal land turned to agriculture is not documented but these areas reflect recent conversion of dry grassland areas to cropland.

Human Modification of Grassland Cover

A variety of modifications influence the functioning of grassland ecosystems. The major modifications addressed in this report are conversion of land to agriculture, urbanization/human settlement, desertification, fire, grazing of domestic livestock, fragmentation, and the introduction of non-native species.

AGRICULTURE

Change in grasslands has been brought about primarily by conversion of these ecosystems to agriculture. The effects of this conversion can be dramatic: native vegetation is removed and replaced with seed for crops; soil is exposed and becomes vulnerable to wind and water erosion; fertilizers and pesticides are added, changing soil composition; and water-holding capacity is altered, changing the moisture regime for plants and animals. Some native grassland species are able to survive the changes and continue to reproduce in the agricultural environment. Most species fail to reproduce successfully, or they migrate to more suitable habitat.

Graetz (1994: 132–145) presents an historical depiction of grassland use driven by human population growth, affluence, and technology. Grasslands may first be used by hunter-gatherers and later by nomads (who herd domesticated livestock) and sedentary pastoralists. Later still, agriculturists might turn productive areas into croplands. Wealth and technology developments, as well as climate and soil changes, influence the scale and extent of the grassland transformation.

Variations of this conversion process can be traced in the Great Plains of North America and the African Sahel. Managed agriculture began in the eastern Great Plains in the 1850s, reducing vegetative cover and destabilizing the soil (Samson et al. 1998: 443). In the 1930s, large dust storms brought on by climatic drought devastated the area of exposed, cultivated prairie soil. Primarily through use of technology and fossil fuels, the prairies of North America were transformed into croplands producing food for the world. Today, agriculture dominates the region but only with heavy use of fertilizers, chemicals, irrigation, and fossil fuel.

In the African Sahel, nomadic pastoralism persisted for a much longer time without major changes (Graetz 1994: 138). Not until the 1950s, with post-World War II aid and other sources providing access to permanent water, did agriculture expand and nomadism decline. With access to medical and veterinary services, human and livestock populations increased. Today, cropland is maintained with low external inputs, although overall production is low and there is evidence of desertification. The grasslands of both regions have been largely altered from their natural condition, primarily through agriculture, but at different rates and with different outcomes.

Using the AVHRR 1-km satellite data, we altered the PAGE classification for grasslands to highlight modification of grasslands by agricultural production. The result is illustrated with a comparison of Map 1 and **Map 5**. On Map 1, mapping units representing areas of greater than 60 percent agriculture are identified as cropland, units representing areas of 40–60 percent agriculture are identified as cropland mosaic, and units representing areas of 30–40 percent agriculture are identified as grassland (or forest, depending on the dominant vegetation type).

On Map 5, mapping units representing 30–40 percent agriculture are identified as "grassland and agriculture mosaic," rather than grassland. When these units are excluded from the total area in grassland, that area decreases by approximately 7.1 million km^2 (**Table 4**). The decrease in grassland in Sub-Saharan Africa is the largest: approximately 3.5 million km^2 (**Table 4** and **Map 5**). South America and Asia also have substantial areas where grasslands may be considerably altered by agriculture; 1.4 million km^2 in South America (especially in northeastern Brazil) and 1.2 million km^2 in Asia (most apparent on the map in Kazakhstan and nearby countries).

Urbanization/Human Settlements

Along with conversion of grassland to agricultural land, human settlements and urbanization of grasslands have greatly modified these ecosystems. The prairies of North America were home to many early European settlers attracted to these large open expanses. Land clearing of trees was not required and the thick prairie sod provided building material for homes. Fuel was readily available from woody vegetation and animal dung. Today these ecosystems continue to support large numbers of people in all regions of the world.

To present human population estimates for grasslands, PAGE analysts used data from an inventory of national censuses compiled by administrative units. The data were standardized to 1995 and translated into a global grid of 4.6-kilometer by 4.6-kilometer cells, each cell reflecting population counts in the respective administrative units intersecting with this cell. The map of PAGE ecosystem extent was scaled to match the resolution of the population data, generalizing from 1-kilometer by 1-kilometer to the 4.6-kilometer by 4.6-kilometer cells. To calculate population according to ecosystem type, the population of each cell was assigned to the majority ecosystem type. For example, population in cells that had 51 percent grassland and 49 percent forest were allocated to grassland ecosystems.

Our analysis shows that more people live in grasslands than forests (nearly 800 million versus 446 million) (**Table 4**). (The population in the agriculture ecosystem is the highest of the three terrestrial PAGE ecosystems, but, because the agriculture PAGE land area includes urban areas [see notes for table 4] this population estimate is not directly comparable with that of the forest and grassland estimates.) Among the four grassland types (savanna, shrubland, non-woody grassland, tundra), most people live in savannas—in Sub-Saharan Africa (approximately 266 million people) (**Table 6**). Shrublands support approximately 239 million people, less than savannas but more than non-woody grassland and tundra. Shrublands in Asia are more heavily populated than the other regions. Non-woody grasslands are less populated with 149.2 million people, those in Asia again support more people than the other regions. Tundra is the least populated grassland type supporting 11.5 million people.

DESERTIFICATION

Desertification may be the most severe modification of grassland ecosystems (Graetz 1994: 132). The United Nations Convention to Combat Desertification (UNCCD) defines desertification as "land degradation in arid, semi-arid, and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (UNCCD 1999: 7). Thus, desertification is "not purely a climatological phenomenon. On the contrary, social, political, economic, and cultural factors that strain the drylands beyond ecologically sustainable limits are often the main driving forces "(UNSO 1997: 4).

Two atlases of desertification have been published by the United Nations Environment Programme to assess desertification on a global scale (UNEP 1992,1997). These atlases address problems associated with desertification in the world's drylands which include grasslands in the arid, semi-arid, and dry sub-humid areas. Global aridity zones and human populations living in them are described above. In a subsequent report, WRI will address the condition of soil and vegetation in drylands, including dry grasslands, and will examine modifications that can lead to their degradation and desertification.

FIRE

Fire is an important factor in maintaining grassland ecosystems. Fire prevents bush encroachment, removes dead herbaceous material, and recycles nutrients. Without fire, organic matter and litter would accumulate and tree densities would increase, leading eventually to forested areas. The timing, frequency, and intensity of fires determine specific effects of these events on the functioning of grassland ecosystems (Andreae 1991).

Natural fires are thought to occur once every 1 to 3 years in humid areas (Frost 1985: 232) and once every 1 to 20 years in dry areas (Walker 1985: 83). Today, the frequency of fires in grasslands varies naturally with climate but also with choice of management objectives. In many African countries, burning clears away dead debris and is highly desirable to maintain good grass conditions for grazing herds of livestock. Large parts of the African savannas are burned annually. The burned areas range from 25 to 50 percent of the total land surface in the arid Sudan Zone and from 60 to 80 percent in the humid Guinea Zone (Menaut et al. 1991: 137). As much as 5 million km^2 of tropical and subtropical savannas, woodlands, and open forests now burn each year (Levine et al. 1999: 4).

Despite providing important services for maintaining natural and human-influenced grasslands, fire can be harmful. Especially when very hot and frequent, fire can destroy vegetation and increase soil erosion. Fire also releases atmospheric pollutants. According to a recent UNEP report analyzing the significance of fire to the global environment, uncontrolled or misused fires can cause "tremendous adverse impacts on the environment and human society" (Levine et al. 1999: 1). Biomass burning is recognized as a significant source of atmospheric emissions and described as the source of nearly 40 percent of gross carbon dioxide and tropospheric ozone (Levine et al. 1999: 2.)

Major components of biomass burning are forests, savannas, agricultural lands after harvest, and wood for cooking, heating, and charcoal production. Burning of tropical savannas "is estimated to destroy three times as much dry matter per year as the burning of tropical forests." The UNEP report notes that most of the biomass burned today is from savannas. Because two-thirds of the world's savannas are in Africa, that continent is now recognized as the 'burn center' of the planet (Levine et al. 1999: 2).

The European Space Agency for Africa, Latin America, and Indo-Malaysia/Oceania has used AVHRR data to map the location of all fires detected during 1993 (Arino and Melinotte 1997) (**Map 6**). (NASA's Earth Observatory website posts fire data acquired by the TRMM VIRS sensor for 1999-2000. NASA is currently developing the capability to provide fire counts and additional fire information at roughly 4 km^2 grid cells at monthly intervals. These data, however, are not yet available for general analysis [Jackie Kendall, Science Systems and Applications, Inc., Lanham, Maryland, personal communication, May 2000]). The fire map shows that fire on the African continent is confined by the Sahara Desert to the north, by the Horn of Africa to the east, and by the Kalahari Desert to the south (Arino and Melinotte 1998: 2022). A comparison of the fire map with the PAGE land cover for Africa, indicates that tropical rainforest, especially in central Africa, is a fire boundary. Fires are greatest in the grasslands on either side of the equator. A somewhat similar pattern is found in South America where the least number of fires occur in the Amazon Basin and southern Patagonia, and the greatest number occur in the grasslands of eastern Brazil and Venezuela.

Although some fires are recognized as critical to the maintenance of grassland ecosystems, and serve as an important management tool, new fire datasets showing broad-scale fire distribution raise new questions. Are the frequency and extent of fires shown in these maps typical or has there been a recent increase? What are the short- and long-term effects of these fires on ecosystem services? Continued monitoring using satellite data as well as field studies should provide answers.

DOMESTIC LIVESTOCK

Wild ungulates are an essential component of energy and nutrient flows in grassland ecosystems. By contrast, domestic livestock generate effects that are disputed as either positive or negative, particularly in relation to different stocking densities and different grassland environments; these topics are discussed in the literature and are mentioned further in the animal forage and products chapter of this report. The focus in this section, is to highlight potential changes that domestic livestock may have on natural grasslands—at the same time recognizing that rangeland livestock production using ecologically sound management practices is essential to supporting human populations and lifestyles (Dodd 1994: 33).

Large populations of herbivores, including bison of North America, wildebeest and zebra of Africa, and Tibetan antelope of Asia have been characteristic of the world's major grasslands. As an integral part of the grassland ecosystem, these herbivores can have a major influence on ecosystem functioning. Through grazing, these animals stimulate regrowth of grasses and remove older, less productive plant tissue. The thinning of older plant tissue in turn leads to increased light absorption and more efficient use by younger plants, and improved soil moisture (Frank et al. 1998: 518).

Grasslands and populations of wild ungulates have coexisted for millions of years, their simultaneous emergence and adaptive radiation described as "among the most thoroughly documented evolutionary patterns in the fossil record" (Frank et al. 1998: 519):

This long coevolutionary history between grasslands and ungulates is testimony to the high sustainability of the grazing ecosystem. Key stabilizing elements of this habitat are the large spatial and temporal variation in mineral-rich forage; the migratory behavior of ungulates, which track high-quality forage across a large region; and the intercalary meristem of grasses, which allows defoliated plants to regrow.

A comparison of the grazing of grasslands by wild ungulates and domestic livestock underline important transformations in grassland ecosystems. Domestic livestock are raised to maximize animal biomass through various techniques, including veterinary care and predator control, as well as water, mineral, and feed supplements. The result is generally higher biomass of domestic animals on pasture and rangelands than biomass of wild ungulates on grasslands (Frank et al. 1998: 519; Oesterheld et al. 1992). In high densities, grazing animals can change floristic composition, structural characteristics of vegetation, reduce biodiversity, and increase soil erosion; in extreme situations, grazing may eliminate much vegetation cover (Evans 1998: 263). The extent to which these changes occur may depend not only on the number of livestock but also on the pattern of their grazing.

Human herding of domestic livestock does not replicate the movements of wild ungulates; use of water pumps and barbed-wire fences have led to more sedentary and concentrated use of grasslands by domestic animals (Frank et al. 1998: 519; McNaughton 1993b). Thus, densities of domestic livestock may be higher than those of wild ungulates, and the grazing patterns of the former may limit the recovery of defoliated grasses.

Some studies have observed complementarities between wildlife and livestock (Steinfeld et al. 1996: 16). Evidence from these studies suggests that raising wildlife and livestock together can support greater biodiversity without lowering incomes for ranchers. The studies indicate that livestock-wildlife combinations may not require large reductions in livestock stocking rates. The studies also suggest that wildlife ranching solely for the purpose of producing game is not financially viable since the market for such meat is small (Steinfeld et al. 1996: 16). Choice of management objectives in raising domestic livestock, in addition to the physical and biological characteristics of the area, play a role in rangeland condition and are discussed later in this report.

FRAGMENTATION

Like forests, grasslands may be fragmented as a result of human or natural causes. Natural causes include geographic features such as rivers and shorelines. Agriculture and road building are the most notable forms of grassland fragmentation caused by humans. Other forms include fencing and woody invasion.

In its assessments of grasslands in North America and Latin America, WWF–US has developed an index for the size and fragmentation of habitat blocks (Ricketts et al. 1997; Dinerstein et al. 1995). The block size index for each ecoregion ranges from 2 (large and numerous habitat blocks) to 25 (small and few blocks). The index varies with the size of the ecoregion, which WWF–US has divided into two categories for North America (greater than 10,000 km^2 and less than 10,000 km^2), and three categories for Latin America (greater than 3,000 km^2, 1–3,000 km^2, and less than 1,000 km^2) as well as with the size of blocks within each ecoregion.

WWF–US relied on regional experts to classify the ecoregions according to broad fragmentation categories, ranging from 0 (relatively contiguous regions where long-distance dispersal along elevational and climatic gradients is still possible) to 20/25 (highly fragmented regions where habitat blocks are small, noncircular, or both, and where edge effects have altered most core habitat).

According to Ricketts et al. (1997: 33), of the 27 ecoregions within the North American grasslands (excluding deserts), 6 have either small and few blocks or high fragmentation. Twelve additional ecoregions have both small and few habitat blocks and high fragmentation: the California Central Valley Grasslands, the Canadian Aspen Forest and Parklands, the Northern Mixed Grasslands, the Northern Tall Grasslands, the Central Tall Grasslands, the Central and Southern Mixed Grasslands, the Central Forest/Grassland Transition Zone, the Edwards Plateau Savannas, the Western Gulf Coastal Grasslands, the California Coastal Sage and Chaparral, the Hawaiian Low Shrublands, and the Tamaulipan Mexquital in Texas and Mexico (**Map 7**). Of the 63 ecoregions within Latin American grasslands (excluding deserts), 11 have either small and few blocks or high fragmentation. Four additional ecoregions have both small and few habitat blocks and high fragmentation: the Leeward Islands Xeric Scrub, the Central Mexican Mexquital, the Pueblan Xeric Scrub in Mexico, and the Motagua Valley Thornscrub in Guatemala (**Map 7**).

These categorizations, based on expert opinion (not actual measurements of block size or degree of fragmentation) suggest that a large percentage of grasslands in the Western Hemisphere may be highly fragmented. In total, nearly 37 percent of the grassland ecoregions identified in the WWF–US study are characterized by small and few habitat blocks, high fragmentation, or both.

NON-NATIVE SPECIES

Small isolated grassland areas are subject to invasion by exotic species (Risser 1996: 267). Although some non-indigenous species such as food crops, pets, ornamentals, and biological control agents are usually considered beneficial, others can cause environmental damage. The Congressional Office of Technology Assessment estimated that at least 4,500 species have been introduced into the United States and that approximately 15 percent of those species have caused severe harm (Office of Technology Assessment 1993: 3–4).

Grasslands are major recipients of foreign species. Of approximately 410 plant species on the Pawnee National Grasslands in eastern Colorado, 70 are exotics; 16 of the 56 grasses in Badlands National Park in southwest South Dakota are non-indigenous (Licht 1997: 72). D'Antinio and Vitousek (1992: 63) describe the human-caused breakdown of dispersal barriers—and resulting spread of non-indigenous species—as responsible for the extinction of more grassland species than any other factor except habitat loss.

The introduction of horses, sheep, and cattle, along with increased agricultural activities, has largely transformed the Argentine pampas from their 16th century state. Charles Darwin noted the great changes effected by these species as early as 1833:

> .few countries have undergone more remarkable changes, since the year 1435, when the first colonists of La Pampa landed with seventy-two horses. The countless herds of horses, cattle and sheep, not only have altered the whole aspect of the vegetation, but they have almost banished the guanaco, deer and ostrich *(sic)* (Soriano et al. 1992: 400).

Since European settlement of Australia, more then 1,900 vascular plant species have been either intentionally or accidentally added to the country's 15,000 indigenous species. More than 220 of these introduced species have been declared as noxious. One of these plants is *Parthenium*, which invades pasture as well as cropland and causes several allergic reactions in livestock and humans (Ricciardi et al. 2000: 239). At least 46 percent of the 220 noxious plants were introduced deliberately.

At several workshops in 1998, invasive species were discussed as an international problem, and databases related to the study"and documentation of such species were reviewed (Ridgway et al. 1999; Ricciardi et al. 2000). The National Biological Information Infrastructure (NBII) website provides information on these databases (http://www.nbii.gov/invasive/workshops/dbsurveys.html). Ricciardi et al. (2000: 239) call for a global information system for invasive species and provide a list of invasive species databases available on the Internet.

Global Grassland Cover: Information Status and Needs

The extent of grasslands is difficult to determine in the absence of (1) a more universally accepted definition or set of definitions of grasslands, and (2) agreement on methods to determine boundaries between forests and grasslands and between agricultural land/permanent pasture and grasslands. Higher resolution satellite data would permit more accurate interpretations of land cover. Field verification with transect checks in selected areas could further improve the accuracy of land cover interpretation. Use of satellite data at l kilometer generally is not of sufficient resolution for country-level analysis. Data of greater than 1 kilometer resolution are collected, for example, Landsat Thematic Mapper (TM) at 30 meters, and SPOT (Systeme Pour l'Observation de la Terre) satellite images at 10 to 20 meters. These remote-sensing platforms, however, are not yet widely available and their use can be expensive.

Global data for evaluating historical change in grasslands and the effects of major modifications, including conversion to agriculture, urbanization, fire, grazing of domestic livestock, fragmentation, and the introduction of non-native species, are limited in quality but are generally improving. Regional studies in some areas document extensive conversion of grasslands to cropland and human settlements. Fire and the grazing of livestock on open rangelands are becoming better quantified, but documentation of their effects requires further analysis. Fragmentation and the invasion of non-native species are problems that require thorough regional and local study. We need better data to analyze global trends in these phenomena.

Food, Forage, and Livestock

More so than any other human use today, grasslands are used for the production of domestic livestock. From cattle, sheep and goat herds, to horses and water buffalo, grasslands support large numbers of domestic animals, which become the source of meat, milk, wool, and leather products for humans. Grasslands also support large numbers of wild herbivores that depend on grasslands for breeding, migratory, and wintering habitat and share the land with domestic herds.

SOIL ASSESSMENT

The capacity for grasslands to produce forage for livestock is determined, in part, by soil condition. Although long recognized as important for evaluating grassland condition, a credible global assessment of soil degradation has been elusive. The Global Assessment of Human-Induced Soil Degradation (GLASOD) and, more recently, the Assessment of the Status of Human-Induced Soil Degradation in South and Southeast Asia (ASSOD) represent attempts to produce such an assessment.

In 1987, the United Nations Environment Programme (UNEP) requested an expert panel to produce, based on incomplete knowledge and in the shortest time possible, a scientifically credible global assessment of soil degradation. UNEP's recommendation led to the publication of a world map on the status of human-induced soil degradation at a scale of 1:10 million. This map is based on input from more than 250 scientists on soil degradation in the 21 regions into which the world was divided for analytical purposes. UNEP's immediate objective in producing the map was to help decision-makers and policy-makers better understand the dangers of inappropriate land and soil management (Oldeman and van Lynden 1997: 438).

Criticism of GLASOD abounds. Many dismiss the assessment as crude and inaccurate. They assert that its approach is subject to the drawbacks of earlier UN assessments that rely on qualitative interpretations of data from a range of sources, interpreted by many individuals (Thomas 1993: 327). They also assert that aggregation of data from regional soil degradation maps is not appropriate for assessing soil degradation in each country.

The limitations of GLASOD have been acknowledged by its authors, who indicated that the assessment was a compromise between speed of development and scientific credibility (Oldeman and van Lynden 1997: 438). Critics of GLASOD concede that viable alternatives would be difficult to produce (Thomas 1993: 327). UNEP points out that:

> Although GLASOD was by necessity a somewhat subjective assessment it was extremely carefully prepared by leading experts in the field. It remains the only global database on the status of human-induced soil degradation, and no other data set comes as close to defining the extent of desertification at the global scale (UNEP 1997: V).

In 1993, in response to requests for more detailed information on soil degradation, the Asia Network on Problem Soils recommended preparation of a soil degradation assessment for South and Southeast Asia (ASSOD) at a scale of 1:5 million. The methodology of this assessment reflects comments from the peer review of GLASOD. As a result, ASSOD has a more objective cartographic base and uses the internationally endorsed World Soils and Terrain Digital Database (SOTER) to delineate mapping units (Oldeman and van Lynden 1997: 438). Like GLASOD, ASSOD focuses on displacement of soil material by water or wind, and *in-situ* deterioration of soil by physical, chemical, and biological processes. ASSOD, however, places more emphasis on trends of degradation and the effects of degradation on productivity. Unlike GLASOD, it includes some information on conservation and rehabilitation (Oldeman and van Lynden 1997: 432).

Although an improvement over GLASOD, ASSOD is not without problems. The assessment of the degree, extent, and recent past rate of soil degradation is still based on expert opinion, and the scale (1:5 million) is still not adequate to guide national soil improvement policies (Oldeman and van Lynden 1997: 438). Oldeman and van Lynden recommend, as a next step, the preparation of national 1:1 million soil and terrain digital databases that would support a more objective assessment of the status of soils and the risk of human-induced soil degradation.

GRASSLAND SOIL CONDITION

Historical records suggest evidence of large-scale soil degradation in many areas of the world over the past 5,000 years (Scherr 1999:17). GLASOD was designed to provide estimates of the extent and severity of soil degradation for a shorter, more recent time period: from 1945 to 1990. GLASOD divides soil degradation into four categories: water erosion, wind erosion, chemical deterioration, and physical deterioration. For each category, GLASOD advisors estimated the proportional area affected by degradation (extent) and the scale of degradation (degree). GLASOD concluded that approximately 23 percent of the world's used terrestrial area was degraded: 38 percent was lightly degraded; 46 percent moderately degraded; and 16 percent strongly to extremely degraded (Oldeman and van Lynden 1997: 430).

To determine the condition of grassland soils, PAGE analysts superimposed the GLASOD map of soil degradation severity over the map of PAGE grassland extent. The overlay of these two maps, however, tends to overestimate the severity of soil degradation in grasslands; GLASOD mapping units intersecting PAGE grassland extent are large and the assigned degradation severity class may not represent the entire area. For example, an entire GLASOD mapping unit may be assigned a degradation severity class of "very high" if as little as 11 percent of its extent has an extreme degree of erosion. This could mean that while some land within the mapping unit is degraded, other land is not. Thus, we were unable to determine consistently and accurately the amount of overlap between soil degradation severity within the GLASOD mapping units and PAGE grasslands.

To avoid this misrepresentation, PAGE analysts used the extent and degree attributes of GLASOD degradation mapping units rather than the severity class. We tabulated PAGE grassland areas that coincided with different combinations of degradation extent and degree from the GLASOD map (**Table 13**). In terms of degradation extent, nearly 60 percent of PAGE grasslands have 5 percent or less of their area degraded. Over 20 percent of PAGE grassland correspond with GLASOD mapping units that have 25 to 50 percent of their extent degraded; 4.1 percent of PAGE grasslands correspond with degradation units where more than half the area is degraded. In terms of the degree of degradation, about 46 percent of PAGE grasslands are not degraded; almost 49 percent are lightly to moderately degraded, and just over 5 percent are strongly to extremely degraded.

ASSOD assesses soil degradation in 17 countries in South and South-East Asia (UNEP 1997: 77). According to the PAGE classification, the extent of grassland is limited in this area; areas of woody savannas are scattered throughout India, Myanmar, and Thailand, and savannas and non-woody grasslands are found in China. Critics have pointed out that the scale of ASSOD (1:5 million) is too broad to support national-level planning, but compared with GLASOD permits more precise assessments of soil degradation in the 17 countries that it covers (Oldeman and van Lynden 1997; UNEP 1992: 80). Combining the ASSOD data with higher-resolution land cover data may allow better identification of the condition of grassland soils.

GRASSLAND VEGETATION

Characteristics of vegetation can serve as indicators of the condition of grasslands. As noted in Table 1, ideal indicators would include measures of cover, productivity, plant species composition, and root distribution. Aggregation of these measures at the local level to produce credible, global measures is difficult. Global estimates of more general but still useful measures have been made, sometimes through the use of modeled proxies.

Normalized Difference Vegetation Index

Surface reflectance data from NOAA's Advanced Very High Resolution Radiometer (AVHRR) have been used to generate

Table 13

PAGE Grasslands and Soil Degradation Using Extent and Degree Classes from GLASOD

Degree of Degradation	Degradation Extent (percent)[a]						
	0	1-5	6-10	11-25	26-50	>50	All
None	46.3	0.0	0.0	0.0	0.0	0.0	**46.3**
Light	0.0	7.0	6.1	9.3	3.5	1.5	**27.4**
Moderate	0.0	4.0	7.7	5.7	2.4	1.3	**21.1**
Strong	0.0	1.5	0.7	0.9	0.5	1.3	**4.9**
Extreme	0.0	0.1	0.0	0.1	0.0	0.0	**0.3**
All	**46.3**	**12.6**	**14.5**	**16.0**	**6.5**	**4.1**	**100.0**

Sources: PAGE calculations based on Oldeman et al. 1991a; GLCCD 1998; USGS EDC 1999a.

Notes:
Degradation extent refers to the degraded portion of the GLASOD mapping units.

the Normalized Difference Vegetation Index (NDVI). The NDVI provides a direct measure of absorbed, photosynthetically active radiation, or the capacity of vegetation canopies to absorb solar radiation (NRC 2000: 36). To represent the NDVI on a global map, values must be summarized in a meaningful way to avoid problem values, such as days with cloud cover and atmospheric haze. The NASA/NOAA AVHRR Pathfinder Program has made available long-term records of 4-km resolution NDVI data with consistently processed and documented techniques; a complete global record from 1993-1994 at 1-km resolution is available and continues to be collected and processed by NASA and USGS (NRC 2000: 36).

According to UNEP (1997: 52–53), NDVI values vary widely across the world's grasslands. Changes in the condition of grasslands can be charted by noting changes in NDVI values over time (Prince 1991: 1308; Fuller 1998: 2014). Fuller (1998) used NDVI images to identify changes in use of rangeland and cropland in Senegal from 1987 through 1993. Using this 7-year series, Fuller found that maximum NDVI values are strongly related to herbaceous cover and Net Primary Productivity (NPP) in some semiarid environments. Positive trends corresponded to areas with irrigation systems, increased production, and cover of wetland plant species. Negative trends corresponded to rangeland zones and areas with negligible rainfall during the study period.

Caution in interpretation of NDVI values has been advised. For example, it might be assumed that high NDVI values represent relatively luxuriant and beneficial vegetation, but in semiarid rangelands it could represent the replacement of palatable grassland with scrub vegetation or unpalatable forbs; high NDVI values also can occur in disturbed vegetation communities (UNEP 1997: 51). Data on species composition would facilitate interpretation of NDVI values. Such data are not available on a global scale, but in two years NASA plans to launch a sensor (the Vegetation Canopy Lidar or VCL) that will measure plant-height profiles. This instrument will thus allow the monitoring of harvesting and regrowth by measuring above-ground biomass, and the assessment of structural habitat features important to animal species such as distinguishing herbaceous plant growth from taller, woody vegetation (NRC 2000: 41).

Net Primary Productivity

Net Primary Productivity (NPP), and its trend over time, can be used as a measure of grassland condition. Plant productivity is a valuable indicator of many aspects of ecosystem function (NRC 2000: 91). As the amount of organic carbon that plants actually make available to other organisms in an ecosystem, NPP may be a more direct indicator of actual grassland yield than the NDVI, which is a measure of light absorption. Direct observations of NPP are not available globally, but computer models derived from local observations have been developed to represent global NPP (Cramer and Field 1999: iii).

Because global estimates of NPP depend on model simulations, interpretations of these estimates should be made with caution. Moreover, validation of the results of models of these spatial scales is problematic. In a study sponsored by the International Geosphere Biosphere Program (IGBP), the representation of NPP by 17 terrestrial biosphere models was compared (Cramer et al. 1999: 1–15). Some of the models use satellite imagery whereas others rely on climate and soils data. All the models indicate low productivity in dry or cold regions and high productivity in humid tropical forests, but because of the sparse and incomplete database of NPP observations, no model stands out as the best representation of global NPP (Cramer and Fkeld 1999: iii). The National Research Council notes that comparison studies like the IGBP-sponsored study are likely to "lead to a greater understanding of the limitations of both the underlying data and the models themselves" (NRC 2000: 37). This understanding already has resulted in improved NPP models.

One of the models in the IGBP-sponsored study was the Global Production Efficiency Model (GLO-PEM) developed by the University of Maryland's Geography Department (Prince and

Goward 1995; Goetz et al. 1999). Unlike the other models compared in the study, GLO-PEM derives all of its climate and vegetation variables from satellite observations rather than depending on calculations from data collected on the ground, such as precipitation data from widely spaced meteorological stations (Cramer et al. 1999: 6). The NPP values derived from GLO-PEM are based on "global, repetitive, spatially contiguous, and time-specific observations of the actual vegetation." (Prince and Goward 1995: 815).

According to a global map representing GLO-PEM's annual mean NPP estimates for grasslands, NPP values are generally below $7kgCm^{-2}yr^{-1}$. This value decreases in areas near deserts and cooler extremes of grasslands (**Map 8**). Savannas and woodlands have higher NPP values. Variations in NPP estimates most likely indicate the impacts of land use change, such as agricultural development and urbanization (see http://ww.inform.umd.edu/Geography/glopem/ for more information on the GLO-PEM model).

Trends in Grassland Production of Food, Forage, and Livestock

Researchers have used NPP data (1982-1993) from GLO-PEM to analyze interannual variation and to determine the coefficient of variation (ratio of the standard deviation of annual totals to the long-term mean) (Goetz et al. 2000) (**Map 9**). Generally, the regions of lower NPP have the largest percentage variation in productivity from year to year. This variation may influence human behavior and household decisions about whether to migrate on a seasonal or permanent basis or whether to abandon livestock herding for a more sedentary, agrarian existence (Prince et al. 1999: 240).

Researchers also have used GLO-PEM to analyze NPP data for Africa (1982–1993). The resulting interannual mean NPP reveals the complexity of spatial variation in species composition and biomass that is caused by climate, topography, soil types, and human-induced change. Some regions have stable NPP values from year to year, whereas other regions have decreasing NPP values from one year to the next. A long-term decline in NPP might suggest grassland degradation, but on-the-ground observations would be necessary to verify this degradation. Although use of a long time series of data increase the certainty with which determinations of sustained increases or decreases in NPP values are made, field data remain necessary to account for changes in species composition. In addition, because NPP is strongly affected by climate, declines in NPP may be caused by a drop in precipitation or temperature change rather than by degradation of grassland. An increase in precipitation could spur vegetation growth, halting what is then revealed to be a short-term decrease in NPP values rather than long-term grassland degradation.

RAIN-USE EFFICIENCY

One potential method for separating vegetation declines due to lack of rainfall from declines associated with degradation is through the ratio of NPP to precipitation (Prince et al. 1998: 360). The rain-use efficiency index (RUE) is such a ratio. This index is calculated from satellite observations of NPP (modeled with annual integrals of NDVI from NOAA) and rain gauge data.

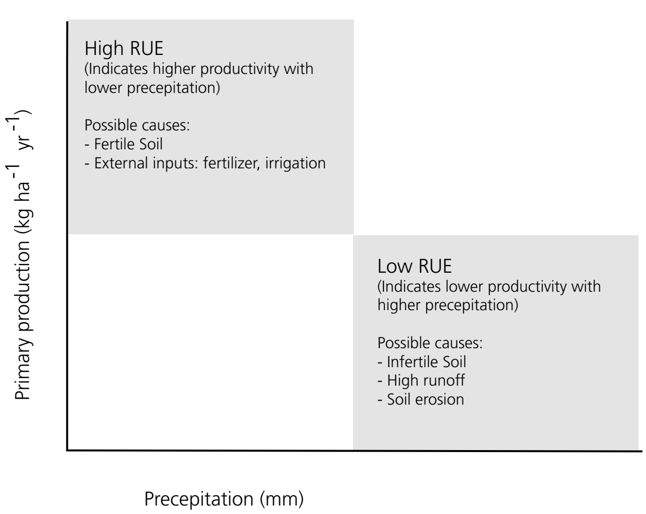
Prince et al. (1998) report that previous studies using local NPP observations have found strong correlations between declines in RUE, increases in livestock, and reductions in rangeland condition. They note that further study is needed to determine whether these local correlations hold on a regional scale (Prince et al. 1998: 370).

Accurate interpretations of the RUE index require information on topography, soil texture, soil fertility, vegetation type, human population, and management regimes (Prince et al. 1998: 370). Decreases in RUE could be due to various factors, including degradation and run-off, soil evaporation, and infertile soils (**Figure 5**). Conversely, increases in RUE may be due to factors such as run-on, fertilizer use, and changes in species composition (for example, replacement of woody C3 vegetation with C4 grassland) (Prince et al.1998: 371).

Differences in the water balance of various climatic regimes make grasslands influenced by the same climate more meaningful than cross-continental comparisons of RUE. For this reason, the PAGE researchers examined RUE, as calculated by the University of Maryland, for southern Africa and Madagascar (**Map 10**). At this finer resolution, areas of high and low RUE are more easily identified. Several graphs compare sites with similar annual rainfall with trends in RUE (**Figure 6**).

Figure 5

General Representation of the Rain-Use Efficiency Index



Source: Modified from Prince et al. 1988; used with permission from Blackwell Science Ltd.

Some sites appear to maintain fairly constant RUE indexes over this period. Others sites exhibit small, but important declines in RUE. For example, RUE at the Okavango Delta site generally declined over this period, with several ups-and-downs, from an RUE index of approximately 1.1 to 0.9; the Eastern Highlands declined from an RUE index of 1.6 to 0.9. These areas of declining RUE may be good sites to conduct field checks for actual, long-term signs of degradation. Combining the trends in RUE with other measures, such as livestock densities and management practices, could increase the accuracy of map-based evaluations of grassland condition.

Grassland Modification to Produce Food, Forage, and Livestock

Grasslands provide habitat for many of the world's large mammalian herbivores. The effects of wild native herbivores on these ecosystems have been described as beneficial and adaptive to a potentially unpredictable environment, but those of introduced, domestic livestock have been less clearly identified. Both introduced and native herbivores can contribute income to national economies and individual farmers. In addition, native herbivores serve as a major tourist attraction and thus contribute to lucrative tourism operations.

LIVESTOCK DENSITIES

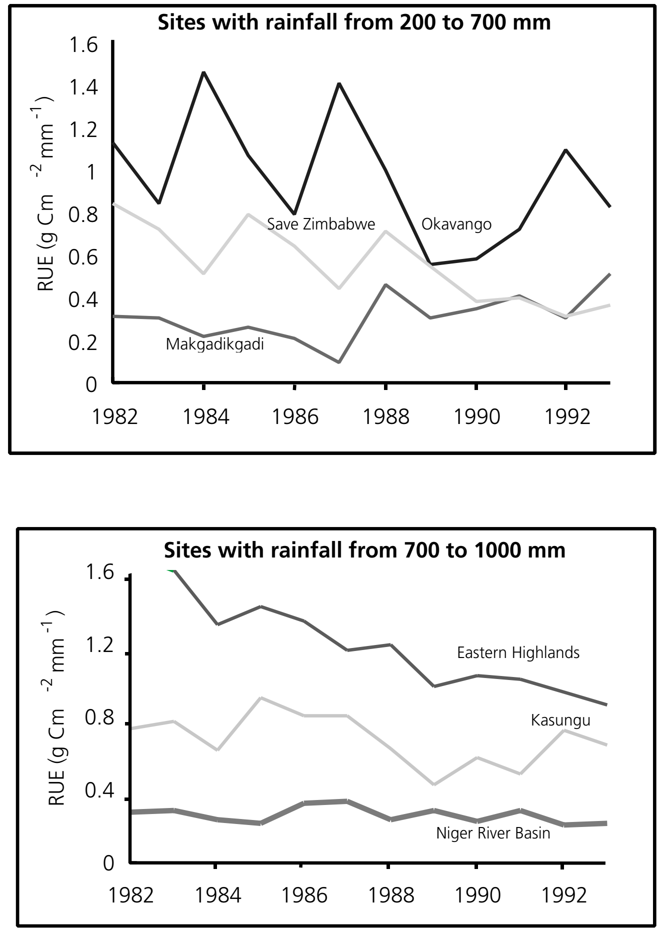
As domestic livestock replace native herbivores in most parts of the world, various views have been expressed on the role of livestock in maintaining healthy grassland ecosystems. To evaluate grassland condition in relation to livestock densities, PAGE analysts have examined a map of global livestock distribution and data on livestock numbers (cattle, sheep, and goats) for developing countries with extensive grassland.

A global map of livestock density, plots the distribution of cattle, sheep and goats, horses, oxen, water buffalo, camels, and caribou (Lerner and Matthews 1988) (**Map 11**). Densities range from less than 1 head to over 100 head of livestock per square kilometer. Some of the highest densities in the world are in the Middle East, Asia, and Australia. In areas where the intensity of livestock production is low, especially in developing regions of Africa and parts of Asia, ranchers presumably rely on native grassland for grazing without many external inputs. Livestock can help maintain soil fertility, increase nutrient retention and water-holding capacity, and create a better climate for microflora and fauna (Delgado et al.1999: 44). If overgrazing does occur, soil compaction and erosion may follow with a decrease in soil fertility, organic matter, and water-holding capacity.

In areas of high intensity livestock production, under industrial and intensive mixed farming systems, high concentrations of animals can cause major environmental problems and have been called "the most severe environmental challenge in the livestock sector" (Delgado et al. 1999: 48). Highly intensive industrial production methods, found near urban agglomerations such as areas of northwestern Europe, the eastern and midwestern United States, and Japan, result in large nutrient surpluses from animal wastes (Steinfeld et al. 1996: 19).

Figure 6

Trends in Rain-Use Efficiency in Southern Africa



Source: Prince, S. D. 2000. University of Maryland, Geography Department.

In addition to this global map of livestock density, PAGE researchers have examined trend data on numbers of livestock by country (FAO 1999) (**Table 14**). Between 1996 and 1998, the total number of cattle, sheep, and goats in three developing countries with extensive grassland—Ethiopia, Nigeria, and South Africa—was more than 50 million head. Other developing countries with relatively high livestock numbers (over 10 million head) in this time interval are Mongolia, Afghanistan, Burkina Faso, Kenya, Madagascar, Senegal, Somalia, and Tanzania. Change in total livestock numbers over the 10-year interval (1986–1988 to 1996–1998) increased in all developing countries with extensive grassland—by as much as 104 percent in Guinea. There are three exceptions: livestock numbers decreased in Mozambique (2.2 percent), Namibia (4 percent), and Somalia (14.2 percent).

Table 14

Livestock in Developing Countries with Extensive Grassland[a]

Region/Country	Cattle		Sheep and Goats		Total Livestock [b]	
	Annual Average (000 head) 1996-1998	Percent Change Since 1986-1988	Annual Average (000 head) 1996-1998	Percent Change Since 1986-1988	Annual Average (000 head) 1996-1998	Percent Change Since 986-1988
WORLD	1,328,037	4.7	1,760,712	5.9	3,388,151	5.6
ASIA (Excl. Middle East)						
Mongolia	**3,469**	**40.4**	**23,122**	**31.5**	**29,722**	**31.4**
MIDDLE EAST & NORTH AFRICA						
Afghanistan	1,500	(0.7)	16,500	16.1	19,748	11.4
SUB-SAHARAN AFRICA						
Angola	3,455	4.7	1,713	0.3	5,174	3.2
Benin	1,383	52.8	1,621	(7.9)	3,011	12.6
Botswana	2,383	2.1	2,090	20.1	4,743	11.7
Burkina Faso	4,492	21.0	13,914	32.4	18,916	29.2
Central African Rep.	2,926	30.2	2,406	91.4	5,332	52.2
Cote d' Ivoire	1,303	39.9	2,380	25.8	3,683	30.5
Ethiopia [c]	29,900	6.8	38,667	(6.5)	78,173	0.1
Ghana	1,183	2.8	4,382	15.6	5,579	12.6
Guinea	2,291	100.0	1,439	110.5	3,735	103.9
Kenya	13,789	8.0	13,133	0.5	27,746	4.2
Madagascar	10,329	1.1	2,093	3.7	12,423	1.5
Mozambique	1,287	(4.7)	508	4.2	1,815	(2.2)
Namibia	2,079	7.6	4,011	(9.4)	6,222	(4.0)
Nigeria	19,300	43.6	38,500	22.4	59,022	28.4
Senegal	2,887	15.6	7,791	46.0	11,565	36.7
Somalia	5,433	13.8	26,533	(19.8)	38,206	(14.2)
South Africa	13,619	9.2	36,139	1.9	50,237	3.8
Tanzania, United Rep.	14,163	10.9	13,640	21.1	27,981	15.6
Zambia	3,150	21.8	669	27.2	3,821	22.7
Zimbabwe	5,429	(7.0)	3,245	18.5	8,806	1.2

Sources: FAO 1999.

Notes:
Negative values are in parentheses.
[a] Countries with extensive grassland have at least 100,000 km^2 of grassland that covers at least 60 percent of the country's total area.
[b] Total livestock refers to head of cattle, sheep and goats combined.
[c] Includes Eritrea.

Can livestock density and variations in livestock numbers be used as proxy indicators for grassland condition—equating high density with poor condition? Answers to this question require a review of findings regarding the relationship between livestock and grassland condition.

Those calling for grazing reform in the United States argue that rangeland decline is due to improper grazing regimes (Riebsame 1996: 7). Others disagree, claiming that the rangelands of the western United States can tolerate livestock grazing without apparent harm. In a report evaluating rangeland health in the United States, the National Research Council found past range quality measurements unreliable (NRC 1994). The NRC report concluded that rangeland health inventories and monitoring systems should be parts of a larger system that examines use and management of rangelands (NRC 1994: 5). Other researchers working in the United States, Asia, and Africa have drawn similar conclusions.

On the basis of research conducted at the Konza Prairie Research Natural Area in Kansas, Knapp et al. (1999) identified key components for conserving and restoring the biotic integrity of tallgrass prairie: fire and ungulate grazing activities that shift across the landscape (Knapp et al.1999: 48). They argue that bison and cattle are functionally similar to large herbivores, and that management strategies such as stocking density and duration are more important to grassland condition than whether cattle or bison are present.

The condition of grazing lands in six regions of Inner Asia (Mongolia, Inner Mongolia, Xinjiang, Buryatia, Chita, and Tuva) has been described in relation to both livestock density and grazing patterns (Sneath 1998) (**Figure 7**). An historical review of land use in these regions shows that in many areas, mobile pastoralism has been largely replaced by more sedentary methods of raising livestock. Comparisons among these regions indicate that the highest levels of degradation are found where

Figure 7
Inner Asia

Source: WRI 2000.

livestock mobility is lowest. According to Sneath (1998: 1148) "mobility indices were a better guide to reported degradation levels than were densities of livestock."

Reports from Africa also support the view that management objectives may offer more clues to rangeland condition than the density of grazing animals. In the context of identifying a workable definition of carrying capacity of grasslands, Behnke and Scoones (1993: 6) state that "there is no single biologically optimal carrying capacity which can be defined independently of the different management objectives associated with different forms of animal exploitation" and conclude that "the only embracing definition of carrying capacity is 'That density of animals and plants that allows the manager to get what he wants out of the system' (Behnke and Scoones 1993: 6; Bell 1985: 153 in Behnke and Scoones). For example, given consumer demand for high-grade meat, some ranchers may choose to raise a few animals on abundant forage. Given a market where meat is sold ungraded by weight, ranchers may seek to maintain higher stocking densities.

When interpreting the effect of livestock densities on rangeland condition in Africa, analysts cannot rely solely on vegetation indicators and declining productivity. Behnke and Scoones (1994: 21) explain: "Large fluctuations in species composition, plant biomass and cover are characteristic of arid and semi-arid rangelands subjected to erratic rainfall." Therefore, analysts must distinguish between drought-induced fluctuations and permanent decline in vegetative cover. The rain-use efficiency index represents a recent attempt to more accurately distinguish between short-term, drought-induced changes, and longer-term, more permanent losses of vegetation.

In an extensive review of the effects of grazing on vegetation and soils, Milchunas and Lauenroth (1993: Appendix 1: 352–362) examined data from 236 sites across 6 regions (Africa, Asia, Australia, Europe, North America, and South America). Included in the analysis were studies comparing species composition, above-ground net primary production, root biomass, and soil nutrients at grazed and ungrazed sites. The analysis revealed that biomass production, species composition, and root development were generally unaffected by long-term grazing. This finding indicates that the geographic location of grazing "may be more important than how many animals are grazed or how intensively an area is grazed" (Milchunas and Lauenroth 1993: 327).

A map constructed by the International Livestock Research Institute (ILRI) in 1998 plots the density of cattle at higher resolution than the global livestock density map (Kruska et al 1995) (**Map 12**). Recorded by administrative unit across the African continent, this map shows the highest densities (between 20 and more than 50 cattle per km^2) across an east–west band of northern grassland, and along a northeast-southwest band of eastern grassland. Countries with the highest densities include Ethiopia, Kenya, Uganda, Tanzania, Zambia, Zimbabwe, South Africa, and Madagascar. One interpretation of this map is that the farmers in these areas are wealthy in terms of the number of cattle that they own. Pastoralists in some African countries are interested in maintaining high stocking densities for security, savings, status, and subsistence (Abel 1993: 194).

Another interpretation is that areas of high density reflect areas of rangeland degradation; areas of low density may be in better condition. As discussed previously, however, to show variation in degradation of rangelands in relation to livestock densities, additional information on management practices and data on soil, vegetation, and biodiversity would be needed. For example, as data to calculate the rain-use efficiency index improves, it will be useful to compare the RUE index map with livestock densities. Locations where RUE is low and livestock density is high may be good starting points for field checks of range condition and degree of degradation. Data revealing trends in the condition of soil and vegetation, and threatened and endangered species, could help researchers better assess the level of ecosystem degradation.

In addition to soil, vegetation, and productivity data, social factors such as education and traditional values that influence management decisions can in turn influence rangeland condition. Tony Whitten of the World Bank has juxtaposed two views of land degradation in Mongolia (**Table 15**). One view holds that sustainable carrying capacity of livestock has been reached or exceeded in many areas and that generally, greater understanding of the ecology of the country's grasslands, such as energy cycles and plant and animal relationships, would lead to better management. An alternative view is that Mongolia's grasslands are rich and livestock herds should be increased at the same time competition with other animals, such as voles, should be eliminated. Whitten diagrams the progression of grassland degradation according to these two views where excessive livestock initiates the decline in one, and high vole populations initiate the decline in the other (**Figure 8**). Whitten's presentation of these different views of land degradation suggest that along with a clear understanding of physical and biological aspects of grassland ecology, we also must consider social and cultural backgrounds when evaluating ecosystem condition and finding explanations and solutions for degradation.

Capacity of Grasslands to Sustain Production of Food, Forage, and Livestock

In our examination of the condition of food production from grassland ecosystems, PAGE analysts reviewed data on soil degradation and measures of vegetation productivity giving special attention to developing countries with extensive grassland—countries in which the total area of grassland is at least 100,000 km^2 and represents at least 60 percent of the total land area according to the PAGE land cover classification. This analysis highlights the importance of being able to consistently distinguish areas of range-fed livestock from those of feed-lot livestock, and those areas of static versus mobile grazing systems.

Using indicators of food, forage, and livestock production to evaluate grassland condition, the PAGE analysts determined that, according to GLASOD, nearly 49 percent of PAGE grasslands are lightly to moderately degraded; at least 5 percent are strongly to extremely degraded. We also detected some declining trends in NPP and RUE, and high livestock densities. As mentioned, however, these findings do not necessarily mean that grasslands in the region have been degraded. Improved data with site-specific field studies are required to make accurate assessments.

Grassland Production of Food, Forage, and Livestock Products: Information Status and Needs

In terms of food production, the condition of grasslands can be indicated by trends in soil condition, vegetation productivity, rain-use efficiency, and numbers and densities of livestock that forage on grasslands. Each dataset has its flaws. GLASOD cannot support estimates on a national scale. Degrees of degrada-

Table 15

Two Views of Grassland Degradation in Mongolia[a]

View One	View Two
Sustainable carrying capacity of livestock has been reached or exceeded in many areas.	The livestock herd should increase from current 30 million to over 60 million.
Large and widespread eruptions of Brandt's vole are indicative of short grass; large numbers of voles would not occur in the tall-grass of the eastern steppe.	Large and widespread numbers of Brandt's voles cause short grass and lower the carrying capacity for livestock; spraying with zinc sulfate is necessary to eradicate the voles.
Livestock share grassland ecosystems with a range of other species.	A major portion of the livestock forage crop is lost to marmots, voles, gazelles, and grasshoppers.
Lichen-bound soils have lost and are losing their resistance to wind erosion.	Little knowledge or understanding about the essentially fragile nature of the soils.
Plant diversity and productivity is decreasing even well away from urban centers.	Mongolia's grasslands are rich and can withstand grazing pressure.
Removal of most livestock dung from some areas interrupts the cycle by which nutrients are returned to the soil and plants.	Although much dung is removed, much remains.

Source: Modified from Whitten 1999:12–13.

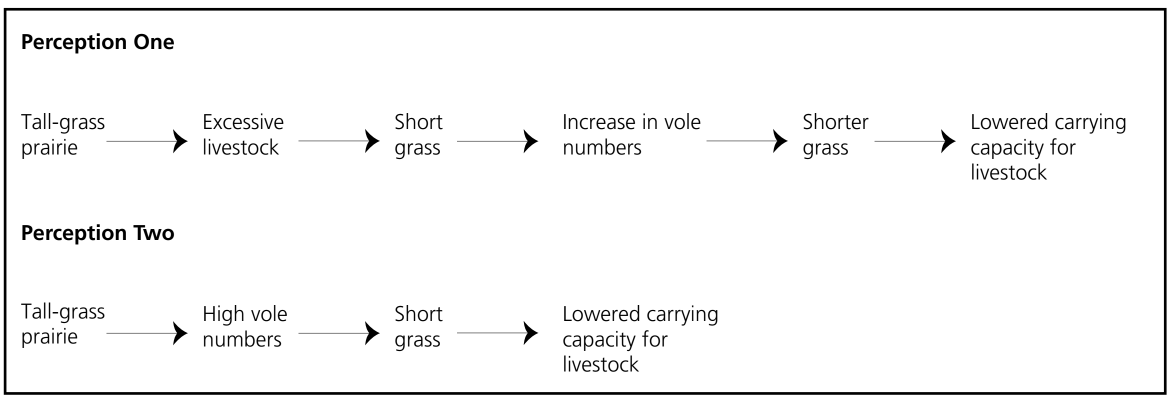
Notes:
[a] Similar views with slight modifications may be applicable to grasslands elsewhere; the two views here are presented as extremes and may be in reality represented by personal opinions that vary from issue to issue.

tion are primarily determined on the basis of expert opinion, without verification through field checks. The Net Primary Productivity models still are being perfected and require adjustments to account for variations in data reported by different satellites. The Rain-Use Efficiency index needs better precipitation data from consistent readings at an adequate number of meteorological stations. Researchers must be able to distinguish data on livestock densities as based on range-fed livestock or feed-lot livestock, and identify the management strategies used in the areas from which the data were collected. PAGE researchers adopted the assumption that highly intensive industrial production of livestock is primarily practiced in developed countries and that traditional, low-intensity livestock production methods predominate in developing countries. This assumption may not be accurate, however, because highly intensive industrial production methods are growing rapidly in developing countries (Delgado et al.1999: 48).

Recent improvements have been undertaken in some areas. The scale of ASSOD is 1:5 million, rather than 1:10 million—the scale of GLASOD. But, even with this improvement the scale of ASSOD is considered too broad to support national level planning. More recent NPP estimates are available over longer time periods, and models are continually being refined. The accuracy of estimates derived from the models, however, is difficult to verify on a global scale. Extensive field reconnaissance and analysis at the regional, national, and sub-national levels are required.

Figure 8

Two Perceptions of Grassland Degradation in Mongolia



Source: Modified from Whitten 1999.

BIODIVERSITY

The Diversity of Grasslands

Grassland biodiversity encompasses a wide range of goods useful to humans. Grasslands have been the seedbeds for the ancestors of major cereal crops, including wheat, rice, rye, barley, sorghum, and millet. They continue to provide the genetic material necessary to breed cultivated varieties that are resistant to crop diseases. Grasslands also provide habitat for plants and animals—soil microfauna and large mammals alike. Global and regional datasets identify biodiversity in the world's grasslands. The following PAGE analysis reviews these datasets, paying special attention to areas designated as especially important for preserving grassland biodiversity.

CENTERS OF PLANT DIVERSITY

The IUCN-World Conservation Union, and World Wildlife Fund–US (WWF–US) have identified 234 Centers of Plant Diversity (CPDs) worldwide (Davis et al. 1994 and 1995). To qualify as CPDs, mainland centers must contain at least 1,000 vascular plant species and at least 10 percent endemism; island centers must contain at least 50 endemics or at least 10 percent endemic flora (Davis et al. 1994: 6). CPDs house important gene pools of plants of value to humans, encompass a diverse range of habitat types, support a significant proportion of species adapted to special soil conditions, and are subject to the threats of large-scale devastation. The size of CPDs ranges from approximately 100 to more than 1 million km^2.

PAGE analysts have classified and mapped the CPDs on the basis of primary vegetation type (**Map 13**). At least 40 of the 234 CPDs are found in grassland areas, with an additional 70 containing some grassland habitat. Thus, nearly half of the CPDs include some area of grassland. These grassland CPDs represent areas where the diversity of grassland plants is high and where conservation practices could safeguard a great variety of species. For example, the Mahale-Karobwa Hills in Tanzania includes Zambezian woodland and grassland vegetation with approximately 2,000 vascular plant species, endemic or rare butterflies, and populations of chimpanzees and monkeys; the Upemba National Park in the Democratic Republic of Congo includes miombo woodland and grassland vegetation, with an estimated 2,400 or more vascular plant species. The World Atlas of Desertification identified 15 CPDs containing significant areas of tropical drylands (UNEP 1997: 136–7).

ENDEMIC BIRD AREAS

Grassland biodiversity has been identified in areas with a large number of endemic bird species. Birdlife International has identified 217 endemic bird areas (EBAs) worldwide. It defines an

EBA as

> An area which encompasses the overlapping breeding ranges of restricted-range bird species, such that the complete ranges of two or more restricted-range species are entirely included within the boundary of the EBA. This does not necessarily mean that the complete ranges of *all* of an EBA's restricted-range species are entirely included within the boundary of that single EBA, as some species may be shared between EBAs (Stattersfield et al. 1998: 24).

Birdlife International defines restricted-range species as

> All landbirds which have had a breeding range of less than 50,000 km^2 throughout historical times (i.e. post-1800, in the period since ornithological recording began). Some birds that have small ranges today were historically widespread, and are therefore not treated as restricted-range species. Extinct birds that qualify on range size are included (Stattersfield et al. 1998: 20–21).

Although the majority of restricted-range birds are forest species, and the key habitat in most EBAs is forest, grassland is the key habitat in 23 or approximately 11 percent of the 217 EBAs (**Map 13**). Each EBA is assigned a biological importance rank from 1 to 3 (most biologically important) on the basis of its size and the number and taxonomic uniqueness of its restricted-range species.

Of the 23 EBAs in which grassland/savanna/scrub is the major habitat type, 3 have the highest rank for biological importance: the Peruvian High Andes, Central Chile, and Southern Patagonia. The Peruvian High Andes EBA is 100,000 km^2 of arid and semi-humid montane scrub, grassland, and woodland with 29 restricted-range species, 11 of which are threatened. The Central Chile EBA is 160,000 km^2 of scrub and semi-arid grassland with 8 restricted-range species (0 threatened). The Southern Patagonia EBA is 170,000 km^2 of sparse steppe vegetation and tussock grasslands with 10 restricted-range species, 1 of which is threatened. Although not assigned the highest rank for biological importance, grassland biodiversity is great in many other EBAs.

GLOBAL 200 ECOREGIONS

The World Wildlife Fund–US has identified 232 ecoregions worldwide as "outstanding examples of the world's diverse ecosystems and priority targets for conservation actions" (Olson and Dinerstein 1997: 2). Of the 136 terrestrial ecoregions within this "Global 200," 35 are characterized as grassland ecoregions (**Map 14**).

The grassland ecoregions included in Global 200 were selected on the basis of species richness, species endemism, unique higher taxa, unusual ecological or evolutionary phenomena, and global rarity of major habitat types. For example, Ecoregion Number 93, the Patagonian Steppe and Grasslands in Argentina and Chile, was selected because it is the only area of cold temperate/subpolar steppe and grassland in South America and because it supports distinctive taxa at generic and family levels. Ecoregion Number 112, the Okavango Flooded Savannas in Botswana, Namibia, and Angola, is one of the world's largest flooded savannas with extraordinary concentrations of large vertebrates, including elephants (*Loxodonta africana*) and the African buffalo (*Syncerus caffer*) (Olson and Dinerstein 1997: 116). The 35 grassland ecoregions contain some of the most important grassland biodiversity in the world today.

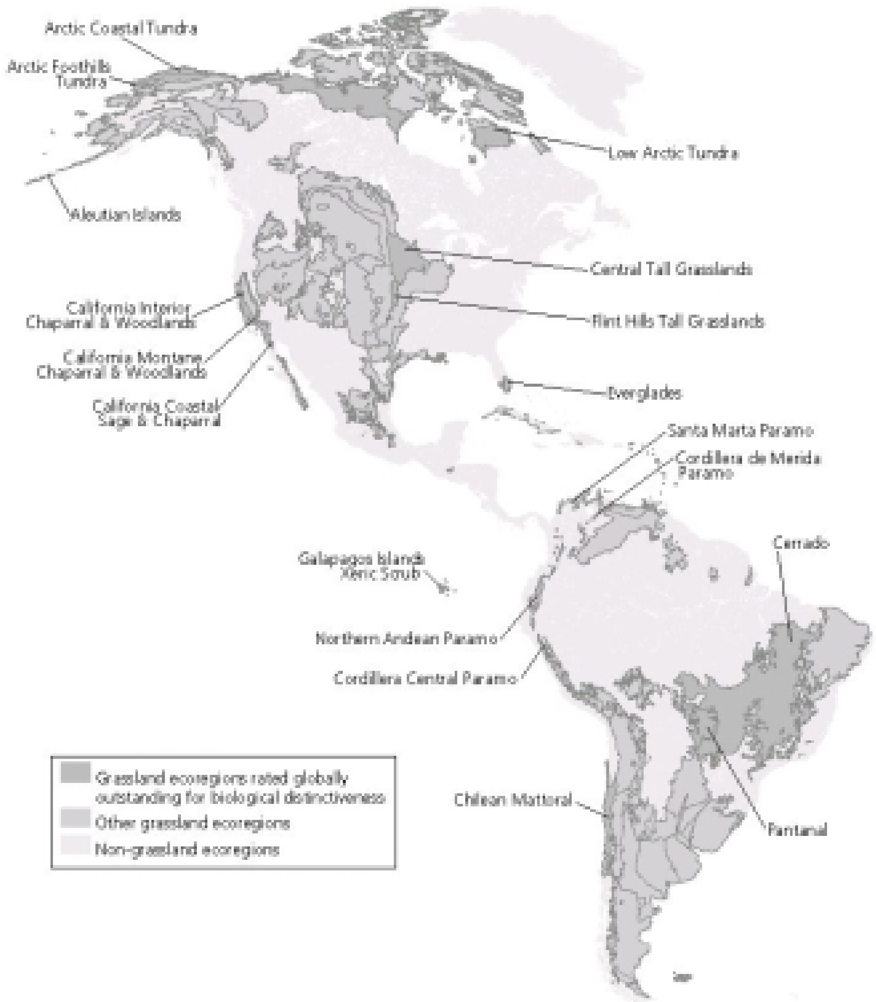
BIOLOGICAL DISTINCTIVENESS INDEX

The World Wildlife Fund –US has developed an index of biological distinctiveness for terrestrial ecoregions. This index is similar to Global 200 but is published now only for North America and Latin America. It includes measures for species richness, species endemism, rarity of habitat type (habitats that offer few opportunities for conservation), rare phenomena (distinctive ecological phenomena such as intact predator assemblages), and beta diversity (high turnover of species over distance or along gradients). The species data for North America are based on published and unpublished information on range and distribution. The remaining measures for North America, and all of the measures for Latin America are based on WWF–US analysis and expert workshops of regional working groups.

Ten of 32 North American ecoregions rated as globally outstanding for biological distinctiveness are grasslands (Ricketts et al. 1997) (**Figure 9**). These 10 ecoregions include:

- the Central Tall Grasslands (once the largest tallgrass prairie on earth, and still home to great plant diversity);
- the Flint Hills Tall Grasslands (containing the world's last large parcels of tallgrass prairie);
- the Everglades (supporting high species richness, particularly with respect to wading birds, alligators, crocodiles, snail kites, and mangrove species);
- the California Interior Chaparral and Woodlands, the California Montane Chaparral and Woodlands, and the California Coastal Sage and Chaparral (containing unique communities, a unique geologic history, high species richness and endemism);
- the Aleutian Islands Tundra (supporting large seabird colonies and many endemics);
- the Arctic Foothills Tundra (characterized by high-level predators, caribou migration, and a corridor for avian and moose populations);
- the Arctic Coastal Tundra (supporting caribou herds and arctic wildlife) (**Box 1**); and
- the Low Arctic Tundra (supporting large caribou herds, bird nesting colonies, and muskox).

Figure 9
Biologically Distinct Grassland Ecoregions



Source: Ricketts et al. 1997.

WWF–US has identified 33 additional grassland ecoregions in North America, rating 13 as regionally outstanding, 9 as bioregionally outstanding, and 11 as nationally important.

Nine of 34 Latin American ecoregions rated as globally outstanding for biological distinctiveness are grasslands (Dinerstein et al. 1995: 21). These 9 ecoregions include:

- the Cerrado of Brazil, Bolivia, and Paraguay (one of the largest savanna-forest complexes in the world);
- the Pantanal of Brazil, Bolivia, and Paraguay (one of the world's largest wetland complexes including flooded grasslands and savannas);
- the Santa Marta Paramo of Colombia, the Cordillera de Merida Paramo of Venezuela, the North Andean Paramo of Colombia and Ecuador, and the Cordillera Central Paramo of Ecuador and Peru (globally restricted habitats with high endemism);
- the California Coastal Sage-Chaparral in Mexico and the United States (rare habitat rich in species and endemism) (also listed for North America);
- the Chilean Matorral in Chile (rare habitat rich in species and endemism); and,
- the Galapagos Islands xeric scrub in Ecuador (high endemism).

WWF–US has identified 54 additional grassland ecoregions in Latin America (excluding deserts from the xeric shrublands) designating 9 as regionally outstanding, 28 as bioregionally outstanding, and 17 as locally important.

Thus, grassland biodiversity remains intact in at least 105 grassland ecoregions in North and Latin America. (Although the California Coastal Sage-Chaparral is in both Mexico and the United States, it is counted only once here). The condition of these grasslands has not been measured, but 18 have been assigned a rank of globally outstanding for biological distinctiveness.

PROTECTED AREAS

Protected areas around the globe have been identified by IUCN-The World Conservation Union and mapped by the World Conservation Monitoring Centre (WCMC). IUCN defines protected area as:

Box 1

Caribou Migrations and Calving Grounds: Globally Outstanding Ecological Phenomena

Large scale migrations of large terrestrial mammals are disappearing around the world. Grasslands and forested habitats that once supported extraordinary movements and seasonal concentrations of large herbivores are becoming increasingly threatened by development activities.

The annual return of barren-ground caribou (*Rangifer arcticus*) to their traditional calving grounds is an unforgettable spectacle that serves as one of the best examples of the migratory phenomena. Few places in the world can equal this scale of migration unfettered by fences, roads, agriculture, or people.

Throughout northern Canada and Alaska, free-roaming caribou are an important subsistence food for aboriginal peoples. In Russia, another important site for caribou, or reindeer, many populations are semi-domesticated and managed by local people.

There are 15 major caribou herds in Canada, each with different spring migration routes. The Eastern Canadian Shield Taiga ecoregion is home to the George River herd, the single largest caribou herd in the world. The Northwest Territories contain an additional 1.6 million caribou.

In Alaska, 25 caribou herds totaling approximately 1 million animals annually stream between wintering and calving grounds. Caribou range across virtually all of Alaska's ecoregions;introduced herds even occupy islands in the Bering Sea and Aleutian Islands.

Caribou cows, especially when they have newborn calves, are highly sensitive to human activities. Caribou, especially in large groups, may gallop away if startled by people or machinery. Calves may be knocked over and injured or may flounder in wet snow and become exhausted. When cows run, walk, or even stand in response to human activity, they are expending energy without feeding. Reduced food intake in turn reduces milk production that could potentially limit calf growth.

Not only do cows and calves need protection while on calving grounds, but the calving ground habitat itself needs protection. Loss of sedge meadows through the alteration of surface drainage could lead to reduced forage availability. Mining and mine exploration pose serious threats to the ecological integrity of caribou calving grounds and migration routes. There are already two active mines on the spring migration route and calving grounds of the Bathurst herd. Oil exploration and development activities also pose threats to the integrity of migration routes. Impacts of oil development along Alaska's North Slope are also a significant concern. Although caribou in the Central Arctic herd have become somewhat habituated over time to oilfield activities, increased development, including habitat loss, animal disturbance, and disruption of migrations remains a concern, particularly in calving grounds.

Recognizing these threats, the Governments of Canada and the Northwest Territories are working with the aboriginal people through wildlife co-management boards and other stakeholders to develop a protective strategy for the caribou calving grounds. Alaskan Native peoples are also increasingly playing a role in management decisions regarding caribou. The maintenance of the last great spectacles of nature depends on all stakeholders acting together.

> An area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means (IUCN-The World Conservation Union 1998: xiv).

IUCN assigns each protected area to one of six management categories. These categories vary in management purpose from scientific research to sustainable use, and include:

- strict nature reserves and wilderness areas (Category I);
- national parks (Category II);
- national monuments (Category III);
- habitat or species management areas (Category IV);
- protected landscapes (Category V); and
- areas managed mainly for the sustainable use of natural ecosystems (Category VI).

Using the PAGE land cover as a base map, we summarized data on the size of protected areas and the amount of grassland habitat in each area. For protected areas represented by points only, we generated circular buffers corresponding to the reported size of the protected area. We then identified large (at least 10 km^2) protected areas (in Categories I, II, or III) that are at least 50 percent grassland (**Map 15**). Our results show that 697 of these protected grasslands are found worldwide. This translates to less than 16 percent of 4,502 relatively large protected areas being composed of at least 50 percent grassland.

In a comparison of protected areas within other ecosystems, forests and agriculture ecosystems include 2.5 million km^2 and

1.6 million km^2 of protected area, respectively (**Table 16**). Grassland ecosystems include more protected area—nearly 4 million km^2. Because grassland extent is so large, however, only 7.6 percent of the PAGE grassland ecosystem area is protected while approximately 8.5 percent of the PAGE forest ecosystem area is protected. The protected grasslands that do exist cover the largest area in Sub-Saharan Africa—1.3 million km^2—and less than 1 million km^2 in the remaining regions ranging from 56,000 km^2 in Central America and the Caribbean to 791,000 km^2 in North America. One biome within grasslands has been described as the least protected biome in the world: only 0.69% of the world's temperate grasslands are protected under the global system of protected areas (Henwood 1998: 6; IUCN 1994: 257).

Trends in Grassland Biodiversity

GRASSLAND BIRD POPULATIONS

Every year since 1966, the Patuxent Wildlife Research Center has organized a roadside breeding bird survey for the continental United States and southern Canada. More recently, the survey has expanded to include Alaska and northern Mexico. The survey is based on observations of breeding birds along more than 3,500 survey routes, each approximately 40 kilometers in length. (See the Breeding Bird Survey [BBS] Home Page at http://www.mbr-pwrc.usgs.gov/bbs/.) Each spring, skilled volunteers travel the routes, stopping every 0.8 km to record all birds seen or heard within a 0.4 km radius during a three-minute period. By analyzing the number of individuals of each species detected per survey route, trends can be monitored over time for particular breeding ranges. BBS data also can be plotted spatially to show species richness and population trends.

The Patuxent Wildlife Research Center has grouped breeding bird species into five breeding habitat groups: grassland, wetland-open water, successional-scrub, woodland, and urban species (Sauer et al. 1999). The grassland habitat group discussed here includes 28 species, such as the upland sandpiper, long-billed curlew, greater prairie chicken, northern harrier, short-eared owl, vesper sparrow, savannah sparrow, and dickcissel. These species have similar behavioral and ecological traits and when data on their populations are combined, they can indicate changes in the condition of grassland habitat.

Maps of the density and population trends of these 28 species, across the United States and southern Canada, show some consistent patterns (**Map 17**). The population distribution map reflects data from 1982 through 1996; the population trend map reflects data from 1966 through 1995. The largest number of grassland species is found in the Northern Great Plains, primarily in North Dakota, South Dakota, Montana, Saskatchewan, and Alberta. The fewest number of grassland species are found along the coasts, from southern British Colombia, south to southern California, and from Louisiana to South Carolina.

Populations of grassland species have experienced the most consistent declines of any group of birds monitored by the BBS (Sauer et al. 1997). (Areas of increasing trends tend to be small and localized.) Indeed, BBS records over nearly 30 years indicate a constant decline in grassland species. Habitat loss and increased mowing of grasslands for hay production on the breeding grounds, as well as problems along migratory routes or on the wintering grounds, may be responsible for many of the declines (**Box 2**).

LARGE GRASSLAND HERBIVORES

In some parts of the world, grasslands have developed largely because the browsing by wild herbivores has prevented the establishment and growth of trees. Main areas where grassland formation has been influenced by large herbivores are the savannas of Africa, steppes of Eurasia, and prairies of North America. The large wild herbivore community has been dominated by ungulates such as antelopes and zebras in Africa; gazelles, goats, camels, bison, and wild horses in Eurasia; and deer in North America (WCMC 1992: 280). Continent-wide data from systematic surveys of the distribution and abundance of grassland species other than birds are not generally available. PAGE analysts did not conduct an exhaustive search, but present some trend data for grassland wildlife populations for a smaller area.

Large herbivores are important to the development and ecology of the African grasslands; the greatest concentration of large mammals in the world is found on the savannas of northern Tanzania (WCMC 1992: 282). A long-term study of the Serengeti (Sinclair and Arcese 1995) resulted in data on the distribution and population trends of herbivores. Campbell and Borner (1995: 141) found little evidence of significant changes over the last 20 years (1971–1991) in resident wildlife densities within the Serengeti ecosystem. Three exceptions are noted: the rhino, which has been poached for its horn and is nearly absent; the roan antelope, now in a much restricted range; and the buffalo, numbers of which have declined in the northwest of the park but remained steady or slightly increased in other areas. The study detected a recent increase in the population density of topi, but population estimates of this herbivore are subject to high standard errors. Because the population of topi is made up of some very large herds of as many as 2,000 individuals, the failure to include one of the large herds in a census count could greatly affect the final estimate.

Areas with increased law enforcement activities experienced an increase in densities of several resident wildlife species (Campbell and Borner 1995: 142). In contrast, areas close to the protected area boundaries but less accessible to vehicle patrols experienced declines in wildlife densities that already were low. Expansion of human populations and concurrent increases in demand for wildlife meat, along with the inaccessi-

Table 16

Ecosystems and Protected Area

Ecosystem/Country	PAGE Area[a] (000 km^2)	Protected Area[b] (000 km^2)
GRASSLANDS	**52,544**	**3,989**
Asia (Excl. Middle East)	8,892	586
Europe	6,956	248
Middle East & N. Africa	2,871	216
Sub-Saharan Africa	14,464	1,329
North America	6,583	791
C. America & Caribbean	1,048	56
South America	4,867	307
Oceania	6,859	457
FORESTS	**28,974**	**2,453**
Asia (Excl. Middle East)	3,721	302
Europe	6,731	155
Middle East & N. Africa	90	1
Sub-Saharan Africa	2,659	155
North America	7,115	711
C. America & Caribbean	939	88
South America	6,861	957
Oceania	857	84
AGRICULTURE	**36,234**	**1,594**
Asia (Excl. Middle East)	10,370	268
Europe	7,448	338
Middle East & N. Africa	1,230	11
Sub-Saharan Africa	5,837	476
North America	4,406	97
C. America & Caribbean	611	43
South America	5,642	317
Oceania	690	45
OTHER[c]	**22,343**	**X**
ECOSYSTEM TOTALS[d]	**X**	**X**

Sources: PAGE calculations based on GLCCD 1998; NOAA-NGDC 1998; Olson 1994a and b; WCMC 1999.

Notes:

[a] Boundaries for each PAGE ecosystem category are defined independently resulting in an overlap of agriculture ecosystem area with grassland and forest ecosystem area. Area estimates for grasslands and forests exclude the stable lights extent. The PAGE estimates for agriculture ecosystem extent are based on the seasonal land cover regions (SLCRs) which roughly equals the IGBP agriculture extent plus the agricultural mosaic area for grasslands and forests but includes urban areas since an explicit urban class was not assigned in the SLCR map units.

[b] Protected area represents the total area of each PAGE ecosystem within an IUCN-designated protected area. A global map containing parks larger than 1,000 hectares and falling under IUCN management categories I-IV was produced for the analysis. Circular buffers corresponding to the size of the protected areas were generated for protected areas represented by points only. The global map of protected areas was intersected with the PAGE map and area estimates were summarized for each ecosystem category for all protected areas that had more than 50 percent in grassland, forest, and agriculture.

[c] The other category includes wetlands, barren land, and human settlements.

[d] Global totals cannot be calculated for PAGE categories because the agriculture ecosystem area overlaps with the grassland and forest ecosystem areas.

Box 2

Threatened Tall-Grassland Birds of Continental North America

One of the most rapidly declining groups of birds in North America and around the world are the birds that nest in temperate zone grasslands. Grassland habitats are ideal for conversion to row crops, hayfields, and pastures, and are therefore one of the first habitats to be permanently altered following human settlement.

Unlike many other species of wildlife, however, grassland birds adapted well to the human agricultural landscapes that dominated the continent through the 1950s, at least in the Midwest and the East. Grassland birds tolerate the introduced cool-season grasses that replaced the native warm-season grasses, and many species tolerate and even require disturbance in the form of grazing and fires to create suitable vegetation structure. Thus, following European settlement, grassland species probably became much more abundant in the Northeast.

Over the last three decades however, changing agricultural practices have led to some catastrophic declines in many of the species that were formerly abundant in agricultural landscapes. Some species, such as the Henslow's sparrow (*Ammodramus henslowii*) and the mountain plover (*Charadrius montanus*), are now candidates for the federal list of threatened and endangered species. Formerly abundant species such as the bobolink (*Polichonyx oryzivorus*) and lark bunting (*Calamospiza melanocorys*) are becoming increasingly patchy in their distributions.

Some of the problems faced by grassland birds include the following:

- loss of winter habitat in both North and South America, especially in the Western Gulf Coastal Grasslands and in the pampas of Argentina;
- earlier cutting of hayfields, which destroys many nests;
- a decrease in the area of hayfields and pastures available;
- fragmentation of grasslands, especially the many small patches in conservation reserves (CRP), which are often too small to contain populations of area-sensitive species;
- invasion of woody vegetation in grasslands, which provides cowbirds and nest predators with perches from which to search for nests;
- changing fire regimes and grazing pressures, which have altered the variety of vegetation structure; and
- increased exposure to pesticides and other agrochemicals.
- Possible management practices that would benefit grassland birds include:
- increasing the size of prairie restoration sites;
- maintaining a network of grassland reserves that can act as refugia;
- removing encroaching woody vegetation from large tracts (unless it is along a riparian corridor);
- maintaining some areas that are not grazed or burned for at least three years to provide habitat for species that require taller, denser vegetation;
- removing drainage tiles from selected watersheds to restore wet grasslands in which many species nest (including waterfowl);
- developing rotations that provide habitat for species that need both tall and short grass;
- minimizing early season mowing of hayfields;
- aggregating fields in the Conservation Reserve Program to create a few large rather than many small grasslands; and
- giving special conservation attention to the Western Gulf Coastal Grasslands.

Excerpted from *Terrestrial Ecoregions of North America: A Conservation Assessment* by Taylor H. Ricketts, Eric Dinerstein, David M. Olson, Colby J. Loucks et al. Modified from Essay 11: *The Most Threatened Birds of Continental North America* by Scott Robinson (pp. 69 – 70).

bility of some areas to enforcement patrols, are described as threats to the sustainability of wildlife populations.

Human Modification of Grassland Biodiversity

KEY AREAS FOR THREATENED BIRDS IN THE NEOTROPICS

Birdlife International has mapped the locations of threatened bird species in the Neotropics and compiled a map of 596 key areas for these species (Wege and Long 1995). The key areas were selected on the basis of specific guidelines: the area should support an existing population of the species, should be the location at which the species was most recently recorded, or should be the location at which experts have good reason to suspect that the species continues to exist. Preference was given to areas that are larger or more intact than other areas under consideration, that are already protected, that represent the entire range of a species, or that represent the species in more than one country (Wege and Long 1995: 11).

The three main types of habitat for the threatened birds in the PAGE study are wet forest, dry forest, and grassland areas. Of the 596 key areas, 42 are in grassland habitats, and nearly

12 percent of the threatened birds (38 species) are confined to grasslands (including paramo, campo limpo, campo sujo, savanna, and open cerrado) (**Figures 10** and **11**). Some of these key areas support greater numbers of threatened species and are under greater pressure than others. For example, the grasslands of southern Brazil and northern Argentina are especially important and threatened. These grasslands have undergone extensive change as a result of agricultural development. The wet "Mesopotamia" grasslands of the Entre Rios and Corrientes provinces in Argentina support 13 threatened species and have suffered from overgrazing and uncontrolled annual burning. If all 596 key areas (selected from an initial total of approximately 7,000 sites) were adequately protected, we would help ensure the conservation of 280 (97 percent) of the threatened species in the Neotropics (Wege and Long 1995: 19).

FRAGMENTATION AND ROAD DENSITIES

Globally, grasslands have been heavily modified by human activities; few large expanses of unaltered grasslands remain. In addition, small areas are frequently fragmented (Risser 1996: 265). Although forest fragmentation has been the source of recent and often heated discussions regarding the merits and drawbacks of road building, grasslands and their current fragmentation levels have received relatively little attention.

A series of studies in the 1980s and early 1990s suggests that fragmentation of grasslands may lead to declines in songbird populations. Studies in Missouri (Samson and Knopf 1982), Illinois (Herkert 1994), and North Dakota (Kantrud 1981) indicate that less fragmented landscapes are associated with higher density and diversity in grassland bird species. Licht (1997: 58) states that "When one thoroughly examines the scientific literature, it becomes apparent that almost all grassland songbird species that are declining do better on large contiguous blocks of grassland habitat.".

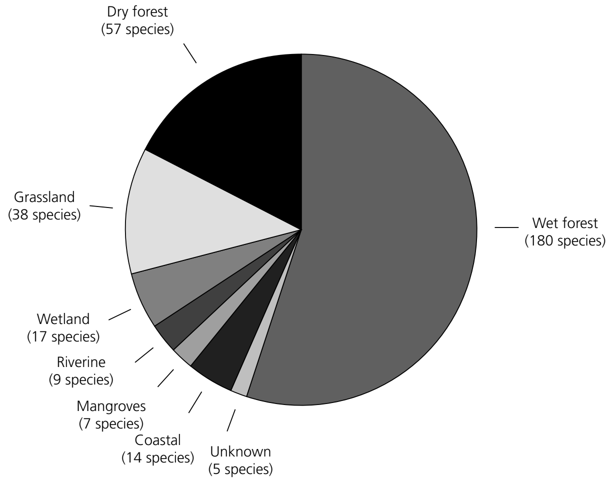
Additional studies show that fragmentation of grasslands can have negative effects on other species, including both plants and animals. It can lead to genetically isolated and reduced populations, which are more susceptible to inbreeding, genetic drifting, and extinction; fewer native species because of less variety in successional stages of grasslands; decreased probability of recolonization; and higher ratio of edge to area, leading to lower nest success and higher predation (Andren 1994; Johnson and Temple 1990; Franklin 1986).

To highlight areas where extensive grasslands remain, it would be instructive to superimpose a global database of roads onto a map of the world's grasslands. The large grassland areas could then be analyzed further for ecosystem condition and eventually lead to a map identifying remaining large, intact grass-

Figure 10
Key Threatened Bird Areas in the Neotropics

Source: Wege and Long 1995.

Figure 11
Habitats of Key Threatened Bird Areas



Source: Wege and Long 1995.

lands. PAGE analysts did not find consistent, up-to-date road data for the world. We did, however, select two areas to compare by superimposing mapped roads from the Digital Chart of the World (DCW) database over grassland areas on the PAGE grassland maps: Botswana, and the Great Plains of the United States.

For these two areas, we compared the size of habitat blocks with roads, with that of habitat blocks without roads. (Fragmentation occurring without roads may result from land use features such as croplands and built-up areas.) On the map of Botswana without roads, 98 percent of habitat blocks greater than 10,000 km^2 in area (**Map 18**). With the road map overlay, 58 percent of these blocks remain greater than 10,000 km^2 in area. On the map of the Great Plains of the United States without roads, 90 percent of habitat blocks are greater than 10,000 km^2. With the road map overlay, 70 percent of the blocks are between 100 and 1,000 km^2 in area and none of the blocks are greater than 10,000 km^2 in area (**Map 19**).

NON-NATIVE SPECIES

Although not always detrimental, the introduction of non-native plants and animals can change the composition of grasslands and affect their capacity to sustain biodiversity (**Box 3**). For example, ring-necked pheasants (*Phasianus colchicus*), introduced to the United States as an upland game bird, can have a negative impact on native prairie chickens though competition for food, harassment on courting grounds, and nest parasitization, and is thought responsible for the disappearance of prairie chickens in some areas (Licht 1997: 72–73). Exotic grass species, introduced as a way of improving rangeland in the Great Plains, also can lead to a decline in biodiversity. Studies show that indigenous bird species prefer nesting in native grasses—perhaps because native species maintain their structure better throughout the winter and provide better cover the following spring (Licht 1997: 74–75)

The World Wildlife Fund–US has mapped the distribution of non-native plant species in North America. It compiled data on native and non-native plant species in the United States and Canada and aggregated them to the ecoregion level (Ricketts et al. 1997: 81–84) (**Map 16**). The resulting map indicates the presence of at least 11 percent non-native species in all ecoregions within the Great Plains and more than 20 percent non-native species in two ecoregions: the California Central Valley Grasslands, and the Florida Everglades. In the absence of more detailed information it is difficult to determine whether these non-native species are invasive, and spread rapidly preventing growth of native species.

Several projects conducted under the auspices of the Global Invasive Species Programme (GISP) could facilitate analysis of invasive species in grasslands. The Early Warning Systems project, led by the Invasive Species Specialist Group (ISSG) of IUCN-The World Conservation Union, is developing a database of invasive species in regions around the world and emphasizing these species in the small islands in the Pacific and Indian oceans. ISSG also is developing a pilot database on 100 invasive species in all taxonomic groups that represent global threats to biodiversity. The database will be called "World's Worst 100." These databases will aid evaluation of the species' impact on ecosystem health.

Capacity of Grasslands to Sustain Biodiversity

While there are many programs that have identified current areas containing outstanding grassland biodiversity, the continued existence of these areas is not guaranteed. An emerging challenge is to conserve the flora and fauna in the Centers of Plant Diversity (CPDs), Endemic Bird Areas, Global 200 Ecoregions, biologically distinctive areas, and other protected areas. Some of these areas may be more vulnerable than others and require extra attention. For example, CPDs in Madagascar are subject to severe human pressures. PAGE analysts have determined that protected areas with sizeable grassland make up only 3 percent of the global land area, or 7.6 percent of the total grassland area. Protection, monitoring, and maintenance activities should be tailored to the needs of each area to ensure that each continues to support grassland biodiversity.

It already may be too late for some grasslands to provide goods or services related to biodiversity. In these areas, modifications from conversion to agriculture and urbanization, as well as fragmentation and the introduction of invasive species have considerably altered the biodiversity. The spectacular migra-

Box 3

Valuing a Fynbos Ecosystem

Fynbos: sclerophyllous scrub vegetation, or vegetation having tough, thick, evergreen leaves, found in areas with a Mediterranean climate, including South Africa.

The ability to estimate the value of South Africa's ecosystems with and without invasives has proved key to securing support for clearing programs. For example, a 1997 analysis valued a hypothetical 4-km^2 fynbos mountain ecosystem at R19 million (approximately US$3.2 million) with no management of alien plants and at R300 million (approximately US$50 million) with effective management of alien plants. The analysis was based on the value of just six major goods and services provided by the ecosystem: water production, wildflower harvest, hiker and ecotourist visitation, endemic species, and genetic storage (Higgins et al. 1997:165).

The authors also determined that the cost of clearing alien plants was just 0.6–5 percent of the value of mountain fynbos ecosystems. That may be a very conservative estimate, given the extraordinary species richness and endemism in South Africa's eight biomes and the fact that invading plants threaten to eliminate about 1,900 species (van Wilgen and van Wyk 1999, citing Hilton-Taylor 1996).

In fact, South Africa's biodiversity is perhaps the strongest long-term justification for limiting the extent of invasives, but the most difficult ecosystem service to value. It is possible, for example, to estimate a "market worth" for fynbos plants when developed as food and medicines or horticultural crops. However, it is more difficult to put a value on a species like the Cape Sugarbird, whose habitat is endangered by invasions in the Western Cape, or the oribi antelope, threatened by invaders that disrupt grasslands habitats.

Source: Modified from WRI 2000: 203.

tions of large vertebrates in the temperate grasslands and steppes of North America and Eurasia now occur only in isolated pockets, in the Daurian Steppe and Tibetan Plateau (Olson and Dinerstein 1997: 16). And the large-scale migration of herbivores, such as wildebeest and zebra, across the savannas of Africa now occur only over a much less extensive area, in East Africa and the central Zambezian region.

Grassland Biodiversity: Information Status and Needs

Some indicators available to evaluate grassland condition rely on subjective data rather than on quantitative measures. We now need a more universal adoption of quantitative indicators of condition and regularly collected, reliable data to evaluate the condition of grassland biodiversity on a global scale. Some regional data-gathering efforts are good models. The Breeding Bird Survey for North America provides high-quality information on species abundance and population trends. These survey data permit evaluation of long-term trends across several habitats. Other datasets on grassland wildlife populations are of good quality but have limited coverage. Datasets on invasive species must be expanded to cover the entire globe and must distinguish data on introduced species from data on harmful species.

Carbon Storage

Grassland Storage of Carbon

The carbon cycle refers to the fixation of atmospheric carbon dioxide (CO_2) through photosynthesis and the simultaneous or subsequent release of carbon dioxide through respiration. Through this process, carbon is cycled continuously through three main global reservoirs: the oceans, the atmosphere, and the terrestrial biosphere (including vegetation and soils). Over time, human activities have altered the amount of carbon that flows through and is stored in the various reservoirs.

Numerous studies report on rates of carbon accumulation in terrestrial ecosystems (Houghton 2000; Houghton et al. 1999). Houghton and Hackler (2000) estimate the global total net flux of carbon in the atmosphere from 1850 to 1995 that results from clearing or degradation of vegetation, cultivation of soils, decay of dead vegetation, and recovery of abandoned lands. They report a net flux from these land use changes as increasing from 397 TgC to 2103 TgC during this 140-year period (1 teragram equal 10^{12} grams).

To stop rising concentrations of CO_2 in the atmosphere, countries are actively seeking ways to increase carbon storage capacity on land. The large amount of land area covered by grasslands as well as the relatively unexplored potential for grassland soils to store carbon has increased interest in the carbon cycles of these ecosystems.

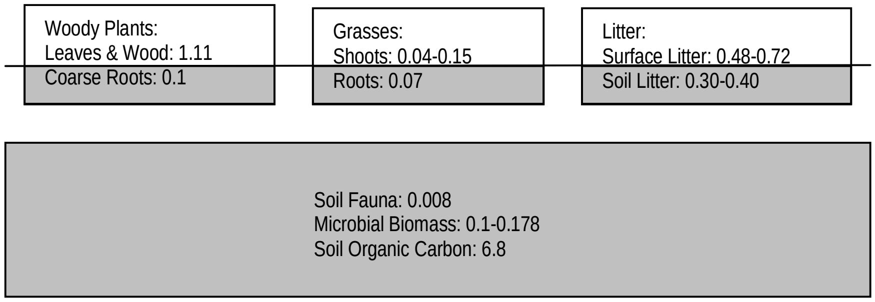
Key processes in the carbon cycle—herbivory, primary production, and decomposition—have been studied in the Nylsvley, South African savanna (Scholes and Walker 1993: 143-187). Principal pools in the carbon cycle for this savanna are woody plant and grass vegetation, the litter layer, soil fauna, and microbial biomass (**Figure 12**). By far the largest pool is the soil organic matter, which accounts for approximately two-thirds of the total carbon pool of about 9 $kgCm^{-2}$. This amount of soil organic carbon (SOC) may be average for a dry broad-leafed savanna but low relative to wet savannas (of Central and West Africa) (Scholes and Walker 1993: 84).

Carbon Stores in Grasslands and Other Terrestrial Ecosystems

To assist in this global analysis of ecosystem condition and the status of goods and services provided by the ecosystems, PAGE researchers have developed potential estimates of the spatial distribution of global carbon stores in terrestrial ecosystems. We present maps based on two global datasets, one for carbon stocks in vegetation, the other for carbon stocks in soil.

Our estimates of above- and below-ground live vegetation carbon storage are based on those developed by Olson et al.

Figure 12
Principal Pools in a Savanna Carbon Cycle



Notes:
Total Carbon Pool: 9 $kgCm^{-2}$
All units are in $kgCm^{-2}$. Carbon pools shown are average for a dry broad-leafed savanna; carbon pools for wet savannas would be higher.

Source: Modified from Scholes and Walker 1993:84.

(1983). These estimates have been described as "the most commonly used, spatially explicit estimates of biomass carbon densities at a global scale" (Gaston et al. 1998: 98). PAGE researchers applied Olson's estimates to the classification developed for IGBP and used as a base map in this pilot analysis (GLCCD 1998). The USGS EROS Data Center provided us with a match between Olson's low and high estimates of carbon storage for various ecosystems and the global ecosystems used in the IGBP classifications (USGS EDC 1999a). Although Olson et al.'s estimates of carbon storage for different vegetation types have been superseded by more recent national and regional studies, the PAGE researchers relied on these estimates as the only consistent set of estimates for vegetation types at the global level.

PAGE analysts mapped high and low estimates for carbon storage in above- and below-ground live vegetation (**Map 20**). The carbon values are expressed as a range, in metric tons of carbon per hectare with only the high values shown on the map. In terms of quantity of carbon stored, tropical forests are visibly outstanding, followed by boreal forests, temperate forests and tropical savannas. Non-woody grasslands store less carbon than the forested areas. Sparsely vegetated and bare desert areas have the least carbon storage potential.

PAGE researchers also prepared maps of soil carbon storage using estimates from Batjes (Batjes 1996). Batjes' estimates are based primarily on soil samples taken within 100 centimeters of the soil profile with special reference to the upper 50 centimeters, the depth most directly influenced by interactions with the atmosphere and with land use and environmental change (Batjes 1996:154). He analyzed over 4,000 soil profiles contained in the World Inventory of Soil Emission Potentials (WISE) database compiled by the International Soil Reference and Information Centre (ISRIC) (Batjes and Bridges 1994). Batjes then used these soil profile data to determine the average soil organic carbon (SOC) at several depths for each of the world soil types as defined by FAO. He summed the SOC content of the soil types found in each 30 x 30 minute grid of the digitized FAO-UNESCO Soil Map of the World (FAO 1991) and weighted the SOC values according to the portion of soil type area within each grid cell. Batjes' estimates of the global stock of organic carbon in the upper 100 cm of the soil are between 1,462 and 1,548 GtC (gigatons of carbon; 1 GtC = 1 billion tons). The high value corresponds to "stone-free" soil conditions.

PAGE researchers repeated Batjes' analysis using a more recent 5 x 5 minute grid of the Soil Map of the World (FAO 1995) and average SOC content values from Batjes (Batjes 1996; Batjes, personal communication, September 2000). We did not adjust for soil stone content, thus the PAGE estimate of global organic carbon of 1,553 Gt corresponds to Batjes' estimate of 1,548 Gt. The soil carbon map, as with the vegetation carbon map, shows forests with the highest carbon storage potential (**Map 21**). When the soil carbon data are compared to the vegetation carbon data, however, grassland soils have considerably larger potential carbon storage than grassland vegetation. This difference in carbon storage potential illustrates the fact that soils are the major storage pool for carbon in grassland ecosystems; unlike tropical forests, where carbon is stored primarily in above-ground vegetation, carbon in grasslands is stored predominantly in the soil (UNEP 1997: 141).

Our combined estimates for potential carbon storage globally in vegetation and soil ranges from 1,752 GtC (in the unvegetated regions) to 2,385 GtC (in forested areas), depicted in a map of the distribution and concentration of total carbon stores. These results are consistent with those presented in previous studies (IPCC 2000; Houghton 1996; Dixon et al. 1994). Here again, carbon storage potential appears highest in the tropical and boreal forests (with carbon storage values ranging from 300–400 metric tons per hectare), (**Map 22**). Although grasslands are more extensive than forests, their carbon storage potential per hectare is less, ranging from 100–300 metric tons. As indicated by the wide range between the low and high estimates for

Table 17

Estimated Range of Total Carbon Storage by Ecosystem

Ecosystem Type [a]	Total Land Area (10^6 km^2)	Global Carbon Stocks (GtC) Vegetation[b] (Low-High)	Soils [c] (Mean)	Total (Low-High)	Carbon Stored/Area (t C /ha) (Low-High)
Forests					
High-latitude	10.3	46-115	266	312-380	303-370
Mid-latitude[d]	5.9	37-77	84	122-161	206-273
Low-latitude	12.8	48-265	131	180-396	140-310
Sub-total	**29.0**	**132-457**	**481**	**613-938**	**211-324**
Grasslands[e]					
High-latitude	10.9	14-48	281	295-329	271-303
Mid-latitude[d]	20.1	17-56	140	158-197	79-98
Low-latitude	21.7	40-126	158	197-284	91-131
Sub-total	**52.6**	**71-231**	**579**	**650-810**	**123-154**
Agroecosystems[f]					
High-latitude	3.4	8-18	45	52-62	156-187
Mid-latitude[d]	12.7	21-52	134	155-186	122-147
Low-latitude	9.5	20-72	85	105-157	110-164
Sub-total	**25.6**	**49-142**	**264**	**313-405**	**122-159**
Other[g]					
High-latitude	18.6	3-31	65	69-96	37-52
Mid-latitude[d]	11.1	9-25	61	70-86	64-78
Low-latitude	8.8	4-16	34	38-50	43-56
Sub-total	**38.5**	**16-72**	**160**	**177-232**	**46-60**
Grand Total	**145.7** [h]	**268-901**	**1,484**[i]	**1,752-2,385**	**120-164**

Sources: PAGE calculations based on Batjes 1996; FAO 1995 and 1991; GLCCD 1998; and Olson 1994a and b.

Notes:

[a] Land area for each ecosystem is based on the Global Land Cover Characteristics Database. Urban areas, calculated from the Nighttime Lights of the World database (NOAA-NGDC), have been subtracted from the forest, grassland and agriculture ecosystem area totals.

[b] Carbon storage values for above– and below–ground vegetation include carbon stores in Greenland and Antarctica.

[c] Soil carbon data for Greenland and Antarctica were largely missing and were excluded.

[d] Temperate West European countries that extend north of 50 degrees north latitude are included in the mid-latitude range (Ireland, United Kingdom, France, Belgium, the Netherlands, Germany, Denmark, Poland, Belarus, Lithuania, Latvia, Estonia, and Ukraine).

[e] Grassland ecosystem extent is based on the IGBP/PAGE classification and includes savanna, shrubland, grassland, and tundra (from Olson 1994 a and b).

[f] Extent of agriculture ecosystems reported here differs from the PAGE agroecosystem area (Wood et al., 2000). That area includes cropland/forest and cropland/grassland mosaic and therefore is greater in extent and has larger carbon storage values.

[g] The category "other" includes wetlands, human settlements, and barren land.

[h] Total land area includes Greenland and Antarctica.

[i] Total world soil carbon stores, as reported by Batjes (1996) are 1,548 GtC. Our estimate of 1,484 is lower because ecosystem areas were summarized within latitudinal bands from a different resolution map than that used in the FAO soil map of the world (FAO 1991). As a result, some carbon stores in coastal areas were excluded.

potential carbon storage for each ecosystem, major uncertainties regarding these estimates remain.

PAGE researchers further analyzed these carbon data to determine the amount of carbon stored in each terrestrial ecosystem at high, mid, and low latitudes (**Table 17**). Latitudinal designations roughly correspond with tropical and subtropical ecosystems (25°S to 25°N), temperate ecosystems (25 to 50°N and 25 to 50°S), and boreal forests and tundra (50 to 90°N and 50 to 90° S). (Temperate West European countries that extend north of 50°N are included in the mid-latitude range (see notes for Table 17). We found that PAGE grasslands, including tundra and most of the IGBP non-forest types (open and closed shrublands, woodlands, savanna, and non-woody grassland), store approximately 34 percent of the total terrestrial carbon while forest ecosystems appear to store nearly 39 percent and agroecosystems about 17 percent (using the high estimates for all three ecosystems).

Grasslands store considerably more carbon in soils than vegetation (231 GtC for grassland vegetation [using the high estimate] versus 579 GtC for grassland soil). More carbon is stored in high- and low-latitude grasslands than in mid-latitude grasslands. In high latitudes, grassland soils high in organic matter make up this difference; in low latitudes, grassland vegetation is more extensive than in mid-latitudes. The largest quantities of carbon are stored in the boreal forests, the least in agricultural ecosystems at high and low latitudes. And, as noted previously, although grasslands generally store less carbon than forests on a carbon/unit area basis, the total amount of carbon that grasslands store is significant because the area of these ecosystems is extensive.

Human Modification of Grassland Carbon Stores

Modifications of grasslands that affect carbon storage include conversion to agriculture, urbanization, desertification, fire, livestock grazing, fragmentation, and introduction of non-native species. When grasslands are converted to croplands, removal of vegetation and cultivation, especially clean plowing, reduces surface cover and destabilizes soil, leading to the loss of organic carbon (Sala and Paruelo 1997: 238; Samson et al. 1998: 32). Similarly, paving of grasslands for urban development reduces carbon storage potential. Desertification, or degradation of land in dry areas as a result of climate variations and human activities, initiates loss of vegetative cover and soil erosion and eventually causes loss of carbon.

Fire in grasslands can release a tremendous amount of carbon. Biomass burning, especially from savannas, contributes up to 42 percent of gross carbon dioxide to global emissions (Levine et al. 1999:3; Andreae 1991: 6) (**Table 18**). Grazing of large numbers of livestock can lead to reductions in plant biomass and cover as well as trampling and compacting of the soil surface, decreases in water infiltration, and increases in runoff and soil erosion, along with losses of soil carbon (Sala and Paruelo 1997: 247). Fragmentation of grasslands with the construction of wide, paved roads in dense networks can lead to large losses of carbon storage in both vegetation and soils.

A recent study suggests that introduction of non-native species also can play a role in carbon loss from grasslands. This research suggests that even the introduction of some less aggressive species to grasslands may influence storage area for atmospheric carbon (Christian and Wilson 1999). Two scientists from the University of Regina in Saskatchewan, Canada, conducted an experiment using crested wheatgrass (*Agropyron cristatum*), a perennial tussock grass introduced from north Asia. They found that the soil beneath the crested wheatgrass contained significantly fewer nutrients and less organic matter than soil under native prairie (Christian and Wilson 1999: 2399). Different growth strategies may explain the discrepancy. The wheatgrass produces more aboveground shoots and a shallow root system; the native grasses are shorter above ground but have an extensive below-ground root network. The root network acts as an important storage area for carbon. One implication of this study is that replacement of native prairie grasses with wheatgrass may have eliminated an important storage area for carbon. The effects of crested wheatgrass, and perhaps of other introduced species that have not been investigated, may extend beyond displacement of native species and reduction of diversity to include alteration of carbon pools and the flow of energy and nutrients in grassland systems (Christian and Wilson 1999: 2397).

Capacity of Grasslands to Maintain or Increase Terrestrial Carbon Stores

Recent time-series measurements show that between mid-1991 and mid-1997, the combustion of fossil fuels added approximately 6.2 GtC per year to the atmosphere as CO_2. This increased the atmospheric concentration of CO_2 by 2.8 GtC per year (Battle et al. 2000: 2467). Of the remainder of the 6.2 gigatons, 1.4 GtC per year was sequestered by the terrestrial biosphere and 2.0 GtC per year by the oceans.

As part of the terrestrial biosphere, grasslands are potentially a sink for carbon. Depending on vegetation and soil con-

Table 18

Global Estimates of Annual Amounts of Biomass Burning

Source of burning	Biomass burned (Tg dry matter/year)[a]	Carbon released (TgC/year)[b]
Savannas	3690	1660
Agricultural waste	2020	910
Tropical forests	1260	570
Fuel wood	1430	640
Temperate and boreal forests	280	130
Charcoal	20	30
World Total	8700	3940

Source: Andreae 1991.

Notes:

[a] Teragrams; 1 teragram equals 10^{12} grams or 10^6 metric tons.

[b] Teragrams of carbon per year.

dition, however, this potential may be minimal. Grasslands, especially if overused in terms of plant production, can become a net source of CO_2 (UNEP 1997: 143). Thus, conversion to agriculture and degradation of dry grassland areas can reduce carbon storage potential in many regions of the world, especially the arid zones.

Global-scale revegetation programs, aimed at curbing land degradation and rehabilitating degraded lands, have been described as ways to increase carbon storage in grasslands (Trexler and Meganck 1993). Future carbon storage potential of the world's grasslands and drylands could vary considerably depending on land use practices (**Box 4**). Ojima et al. (1993: 102) estimated that "regressive" land management (increased grazing levels from 30 percent to 50 percent removal of vegetation) resulted in a loss of soil carbon in all regions after 50 years, with the largest losses in warm grasslands. In contrast, sustainable management (i.e., light grazing) resulted in a net increase in soil organic carbon.

Grassland Carbon Storage: Information Status and Needs

Carbon sequestration has become an important option for reducing the amount of CO_2 in the atmosphere and for reducing the effects of excessive carbon emissions. Although grasslands offer extensive area for carbon storage, more information is needed on how variations in their composition (non-woody vegetation, shrubs, trees, and soil types) affect the quantities of carbon that they can store. Estimates of carbon stores in grasslands made by PAGE researchers, and similar estimates by others, undoubtedly will be revised and updated because today's estimates of annual carbon release and uptake rates in grasslands, as well as in all other ecosystems, are considerably uncertain. The dynamics of soil carbon stocks have proven especially difficult to assess because of the large number of samples required for accurate estimates. Additional data collection and comparative analysis will improve our knowledge of potential vegetation and soil carbon storage capacity.

Box 4

Miombo Woodlands and Carbon Sequestration

The miombo woodlands have a great potential to either add to or help reduce the growing carbon dioxide content of the atmosphere. If substantial areas of miombo are cleared for agriculture, 6–10 Pg of C could be released. Conversely, if the woodlands are managed to maximize carbon storage, a similar amount could be sequestered. In both situations, approximately half of the change in carbon stocks occurs in the soil; the rest occurs in the biomass.

Net primary production or NPP in miombo woodlands ranges from 900 to 1600$gm^{-2}yr^{-1}$. The woody-plant biomass increases by no more than 3–4 percent annually in mature stands. As the upper limit of the sink strength, these rates could increase slightly under an atmosphere high in carbon dioxide, but given the pervasive nutrient limitations, an increase in net primary production of greater than 15 percent is unlikely.

Land use change does not inevitably lead to reduced carbon density. Well-managed tropical pastures in comparable environments in South America can have high carbon density, especially if the roots are deep (Fisher et al. 1994). Agricultural techniques which conserve biomass and build soil organic matter, such as agroforestry, could result in a landscape that is both agriculturally productive and rich in carbon.

The main technique for increasing carbon uptake in savanna woodlands is to reduce fire frequency. Experiments in many parts of Africa, including some in miombo woodlands, have shown an increase in woody biomass and soil carbon if fires are excluded (Trapnell et al. 1976). Permanent fire exclusion is virtually impossible in the strongly seasonal miombo climate, but a reduction in frequency from the current annual-to-triennial norm to once a decade may be achievable at reasonable cost. This would simultaneously increase the uptake of carbon dioxide, and decrease the emission of methane and ozone precursors. The carbon uptake would last from 20–50 years, as the woodlands reach a new equilibrium carbon density.

The carbon-storage benefits of miombo management could be extended beyond this initial 20–50 year period by harvesting the timber using sustainable methods, and either converting it to long-lived products such as furniture, or by using it in place of fossil fuels.

Excerpted from Frost, P. 1996. The ecology of miombo woodlands. In *The Miombo in Transition: Woodlands and Welfare in Africa*, ed. B. Campbell, 11–57. Bogor, Indonesia: Center for International Forestry Research (CIFOR). 266pp. Reprinted by permission of CIFOR. Modified from text box 2.3*: Miombo woodlands and carbon sequestration* (p. 28) by Bob Scholes.

Tourism and Recreation

If you've ever yearned to see the wilds of Africa roaming freely—lions, zebras, antelope, elephants—or experience the sublime beauty of the Serengeti plain with its violent sunsets and golden dawns, then please accept this special invitation to join us…

Overseas Adventure Travel (Honey 1999: 221)

Grasslands as Tourist and Recreational Attractions

Grasslands are particularly captivating for viewing game animals and for safari hunting. People are drawn to the large mammalian herbivores, as well as grassland birds, diverse plant life, and generally open-air landscapes. Some recreationists count on grasslands for hiking and fishing. Others regard specific grassland sites as culturally and spiritually important. For example, religious, ceremonial, and historical sites have been preserved throughout the prairies of the United States (Williams and Diebel 1996: 27).

Identifying and developing indicators to represent the status and condition of tourism and recreational goods and services provided by grasslands can be more subjective than quantitative. The level of enjoyment, or recreational satisfaction, obtained from grasslands does not lend itself to repeatable, objective evaluation. Although PAGE analysts did not resolve this difficulty, we identified some proxy measures that may lead to the development of more quantifiable indicators. In this section, we examine the number of tourists and amount of revenues from international tourism and safari hunting, and modification of grasslands to support tourism and recreation.

Trends in Grassland Tourism and Recreation

TOURIST NUMBERS AND INTERNATIONAL TOURISM REVENUES

The World Tourism Organization (WTO) and the World Bank provide data on the number of international tourists and the amount of international tourism receipts for various countries around the world (World Bank 1999: 368-369). The data are obtained primarily from questionnaires sent to government offices that are supplemented with published data from other official sources. The World Bank notes that "although the World Tourism Organization reports that progress has been made in harmonizing definitions and measurement units, differences in national practices still prevent full international comparability"(World Bank 2000:359).

The number of international inbound tourists is the number of visitors traveling to a foreign country for purposes other than business. The World Bank further clarifies these data by stating that they refer to the number of visitors arriving rather than the number of persons traveling. Therefore, a visitor who makes several trips to a country during the given period is counted each time as a new arrival. International visitors include tourists (overnight visitors), same-day visitors, cruise passengers, and crew members (World Bank 2000:359).

In developing countries with extensive grassland (countries in which grasslands cover at least 100,000 km^2 and make up at least 60 percent of the land area), the average annual number of tourists (between 1995 and 1997) ranged from 4,000 in Afghanistan to 4.9 million in South Africa (**Table 19**). In Australia, one of three developed countries with extensive grassland, an annual average number of 4 million tourists arrived between 1995 and 1997. In most countries with extensive grassland and for which tourism data are available, the number of international tourists increased over this 1985–87 to 1995–97 period by as much as 621 percent in South Africa and 387 percent in Zimbabwe. Exceptions include Mongolia, Afghanistan, and Somalia with declines of 57 percent, 56 percent, and 74 percent, respectively.

International tourism receipts include all payments for goods and services by international inbound visitors. In developing countries with extensive grassland, international tourism receipts, averaged for the three-year period 1995–1997, ranged from US$1 million in Afghanistan to US$1.9 billion in South Africa (**Table 20**). In Australia, the average annual total of international tourism receipts received in this same three-year period was US$8.5 billion, an increase of approximately 471 percent over 10 years. In all of the countries with extensive grassland and for which tourism data are available, international inbound tourism receipts increased over the 1985–87 to 1995–97 period by as much as 1,441 percent in Tanzania and over 800 percent in Ghana and Madagascar. Exceptions include Afghanistan, where receipts remained the same, and three countries that experienced 6–12 percent decreases: Benin, Central African Republic, and Nigeria.

Is the increase in the number of tourists and in receipts from tourism in many countries with extensive grassland related to the recreational and tourism services provided by grasslands? More detailed information on where tourists spend most of their time in these countries is needed to answer this question. However, in some countries we may be more certain that the number of tourists and level of receipts are indeed related to grasslands. In her review of ecotourism in Kenya, Honey (1999: 329) states that despite growth in beach tourism, "more than 90% of tourists visiting Kenya go 'on safari' or [visit] a game park, even if only for a day, and nearly 80% of those interviewed cited nature and wildlife as their major reasons for coming to Kenya."

Safari Hunting and Animal Trophies

PAGE analysts have examined trends in safari hunting in several African countries. On the assumption that large trophy animals rely on grasslands for daily or seasonal activities, we present these trends as proxies for measuring condition of tourism in grasslands according to revenues earned and numbers of participants.

In a review of the performance of the tourist hunting industry in Tanzania, the Department of Wildlife in Dar es Salaam found that the number of hunting safaris made by international visitors increased from just over 200 in 1988 to approximately 500 in 1993 (IUCN 1996: 72). The most popular safaris were 21 days in length, accounting for 71 percent of the safaris from 1988 to 1992-93. Shorter safaris were less popular and accounted for the remaining safaris. The total dollar value of the safari hunting industry increased from US$4.6 million in 1988 to US$13.9 million in 1992–3 (IUCN 1996: 78).

In Zimbabwe, the number of hunter days and hunting operators and the returns from the hunting industry all grew between 1984 and 1990 (Waterhouse 1996b: 85). The number of hunting days increased from 4,000 in 1984 to more than 10,000 in 1990. The number of registered hunting operators grew from 13 before 1980 to more than 150 in 1996. Total earnings per year in Zimbabwe's hunting industry similarly increased from approximately US$3 million in 1984 to close to US$9 million in 1990 (Waterhouse 1996b: 85).

Consistent and reliable data on trends in the size of trophy animals might be useful for evaluating the recreational value of grasslands (**Figure 13**). Such data, however, are not widely available and are not reported in a consistent format. Several African countries collect data on returns from tourist hunting, published by IUCN–The World Conservation Union (IUCN 1996:73–4). Among the species attracting tourist hunters according to numbers shot in 1992–93 are buffaloes, zebras, lions, and leopards. Between 1988 and 1993, both the number of animals killed and the number of tourists increased. Elephants were the only species that experienced a decrease in safari kills due to low overall numbers from illegal hunting for ivory. The demand for most species, excluding elephants, also increased (IUCN 1996: 74). But success in meeting that demand ranged only from 48 percent to 78 percent. The reliability of these data, and thus whether present harvest levels are sustainable, depends on their accuracy for a specified area—animals migrate and are attracted out of national parks—and on data on trends in the size and quality of trophy animals (IUCN 1996: 74).

Table 19

International Inbound Tourists in Countries with Extensive Grassland[a]

Region/Country	International Inbound Tourists: Average Annual Number (000) 1995-1997	Percent Change Since 1985-1987[b]
DEVELOPING COUNTRIES		
ASIA (Excl. Middle East)		
Mongolia	87	(57)
MIDDLE EAST & NORTH AFRICA		
Afghanistan	4	(56)
SUB-SAHARAN AFRICA		
Angola	8	X
Benin	145	150
Botswana	693	160
Burkina Faso	131	181
Central African Rep.	23	331
Cote d' Ivoire	233	25
Ethiopia[c]	109	69
Ghana	305	227
Guinea	96	X
Kenya	703	17
Madagascar	81	210
Mozambique	X	X
Namibia	405	X
Nigeria	699	202
Senegal	287	21
Somalia	10	(74)
South Africa	4,987	621
Tanzania, United Rep.	315	199
Zambia	235	85
Zimbabwe	1,722	387
DEVELOPED COUNTRIES		
Australia	4,059	180
Kazakhstan	X	X
Turkmenistan	196	X

Source: World Bank 1999.

Notes:

a. Countries with extensive grassland have at least 100,000 km^2 of grassland which covers at least 60 percent of the country's total area. An "X" signifies no data or data unavailable.

b. Negative numbers are shown in parentheses.

c. Includes Eritrea.

Grassland Modification to Support Tourism and Recreation

Tourism provides revenues but at the same time can be the source of natural resource degradation (**Box 5**). In 1992, the Tanzanian government closed a luxury campsite inside the Ngorongoro Crater because diesel engines, lights, latrines, and a garbage pit were causing environmental damage and disturbing wildlife (Honey 1999: 236). A Wildlife Division official from Tanzania claims that tourist hunters cause less damage than tourists with cameras. The hunters bring less garbage, cause less damage to roads, use mobile campsites instead of game lodges, and harass fewer wild animals. While trophy hunters may need to locate their target only once, tourists with cameras often are looking for quantity, and, in their quest for photos, may drive off roads and follow animals too closely (Honey 1999: 244–245).

Poaching is another major modification to grasslands, decreasing the quality of tourism and recreational services provided by grasslands. Despite government and privately sponsored efforts to control illegal killing of wildlife, poaching has continued to be a problem for several African countries (Honey 1999: 247). Tanzania's elephant population, taking a toll from illegal hunting, declined from 600,000 in the1960s to approximately 100,000 in the late 1990s. In 1997, as part of a policy to strengthen antipoaching activities, Kenya banned hunting and the commercial trade in wildlife trophies and products (Honey 1999: 298). Despite these restrictions, Kenya's elephant population dropped by 85 percent between 1975 and 1990 to approximately 20,000; the rhino population declined by 97 percent to less than 500.

Martha Honey, in her book on ecotourism (1999), helps to illuminate the condition of the recreational services provided

Table 20

International Tourism Receipts in Countries with Extensive Grassland [a]

Region/Country	International Tourism Receipts: Average Annual (million US$) 1995-1997	International Tourism Receipts: Percent Change Since 1985-1987[b]
DEVLOPING COUNTRIES		
ASIA (Excl. Middle East)		
Mongolia	21	X
MIDDLE EAST & NORTH AFRICA		
Afghanistan	1	0
SUB-SAHARAN AFRICA		
Angola	9	X
Benin	28	(7)
Botswana	174	361
Burkina Faso	32	459
Central African Rep.	5	(6)
Cote d' Ivoire	78	59
Ethiopia[c]	30	210
Ghana	249	801
Guinea	4	X
Kenya	440	46
Madagascar	64	814
Mozambique	X	X
Namibia	214	X
Nigeria	75	(12)
Senegal	147	33
Somalia	X	X
South Africa	1,962	312
Tanzania, United Rep.	313	1,441
Zambia	57	719
Zimbabwe	208	624
DEVELOPED COUNTRIES		
Australia	8,503	471
Kazakhstan	X	X
Turkmenistan	7[d]	X

Source: World Bank 1999.

Notes:
[a] Countries with extensive grassland have at least 100,000 km^2 of grassland which covers at least 60 percent of the country's total area. An "X" signifies no data or data unavailable.
[b] Negative numbers are shown in parentheses.
[c] Includes Eritrea
[d] Data are for 1996-1997.

by grasslands with her summation of the impacts of ecotourism in three African countries with extensive grassland. In Tanzania, most environmental damage has occurred in heavily visited areas. Although poaching has been a serious problem, the negative environmental effects of nature tourism have been relatively limited (Honey 1999: 256). In Kenya, the quality of national parks and reserves has declined since the 1970s as a result of poorly controlled and excessive tourism and the accompanying increase in lodges; water, wood, and electricity consumption; waste; off-road driving; and poaching (Honey 1999: 329). In South Africa, parks have long been considered among the best protected in the world. Numbers of visitors are well-regulated and poaching is minimal. A more careful analysis reveals that South Africa's parks were created by evicting rural Africans and making major alterations in the natural environment by importing animals, erecting electric fences, planting alien trees and shrubs, clearing brush, and building roads. More recently, ecotourism has strived to use low-impact practices through solar power, raised walkways, recycling of water and waste, use of local materials, and incorporation of indigenous designs (Honey 1999: 382–3).

Wildlife Exploitation Index

In their ecoregional assessment of North America, WWF–US presents a measure of wildlife exploitation (Ricketts 1997:137-138). They have assessed each ecoregion according to three exploitation categories: hunting and poaching; unsustainable extraction of wildlife as commercial products; and harassment and displacement of wildlife by commercial and recreational users. These categories are ranked according to three levels of exploitation: high (elimination of local populations of most tar-

Figure 13
An International Perspective on Trophy Hunting

Within the countries that allow trophy hunting, a broad range of species attract trophy hunters. Some hunting, such as in the open plains, is easy, while hunting in dense forests can be difficult. The approximate number of species that can be hunted varies by country and ranges from 34 species in Zimbabwe to 76 in the Sudan.

Profile of the Trophy Hunting Industry

Several characteristics of this industry generate a high profile; the trophy hunting industry:

- ♦ attracts attention, both welcome and unwelcome;
- ♦ provides an emotive activity, for hunters and anti-hunters;
- ♦ involves a large amount of money;
- ♦ is a lucrative industry, supporting a large number of companies;
- ♦ requires large capital investments;
- ♦ provides rural employment;
- ♦ supports economies in Africa and abroad (air charter, tanneries, curios);
- ♦ promotes wildlife use as a viable form of land use;
- ♦ promotes the country as a tourist destination; and
- ♦ stimulates other tourist-related activities (photography, hiking).

Source: Modified from Waterhouse 1996a: 12.

Box 5

Ecotourism and Conservation: Are They Compatible?

From African wildlife safaris, to diving tours in the Caribbean's emerald waters and coral reefs, to guided treks in Brazil's rainforests, nature-based tourism is booming. The value of international tourism exceeds US$444 billion (World Bank 1999:368); nature-based tourism may comprise 40–60 percent of these expenditures and is increasing at 10–30 percent annually (Ecotourism Society 1998).

This burgeoning interest in traveling to wild or untrammeled places may be good news, especially for developing countries. It offers a way to finance preservation of unique ecosystems with tourist and private-sector dollars and to provide economic opportunities for communities living near parks and protected areas.

But the reality of nature-based travel is that it can both sustain ecosystems and degrade them. Much nature-based tourism falls short of the social responsibility ideals of "ecotourism," defined by the Ecotourism Society as "travel to natural areas that conserves the environment and sustains the well-being of local people" (Ecotourism Society 1998). Destinations and trips marketed as ecotourism opportunities may focus more on environmentally friendly lodge design than local community development, conservation, or tourist education. Even some ecosystems that are managed carefully with ecotourism principles are showing signs of degradation.

Ecotourism's Costs and Benefits

At first glance, Ecuador's Galápagos Islands epitomize the promise of ecotourism. Each year the archipelago draws more than 62,000 people who pay to dive, tour, and cruise amidst the 120 volcanic islands and the ecosystem's rare tropical birds, iguanas, penguins, and tortoises. Tourism raises as much as $60 million annually, and provides income for an estimated 80 percent of the islands' residents. The tenfold increase in visitors since 1970 has expanded the resources for Ecuador's park service. Tour operators, naturalist guides, park officials, and scientists have worked together to create a model for low-impact, high-quality ecotourism (Honey 1999:101, 104, 107).

But closer examination reveals trade-offs: a flood of migrants seeking jobs in the islands' new tourist economy nearly tripled the area's permanent population over a 15-year period, turned the towns into sources of pollution, and added pressure to fishery resources (Honey 1999:115, 117). Only 15 percent of tourist income directly enters the Galápagos economy; most of the profits go to foreign-owned airlines and luxury tour boats or floating hotels—accommodations that may lessen tourists' environmental impacts, but provide little benefit to local residents (Honey 1999:108, citing Epler 1997). The hordes of tourists and immigrants have brought new animals and insect species that threaten the island's biodiversity (Honey 1999:54).

The Galápagos Islands well illustrate the complexities of ecotourism, including the potential to realize financial benefits nationally, even as problems become evident at the local or park scale. For example, to a government that is promoting ecotourism, more visitors means more income. But more visitors can translate into damage to fragile areas. Park officials often complain of habitat fragmentation, air pollution from vehicle traffic, stressed water supplies, litter, and other problems. In Kenya's Maasai Mara National reserve, illegal but virtually unregulated off-road driving by tour operators has scarred the landscape (Wells 1997:40).

These impacts can be minimized with investments in park management, protection, and planning. However, developing countries often lack the resources to monitor, evaluate, and prevent visitor impacts, and infrastructure and facilities may be rudimentary or nonexistent.

Low entrance fees are part of the problem; they often amount to just 0.01-1 percent of the total costs of a visitor's trip (Gossling 1999:309). Setting an appropriate park entry fee—one that covers the park's capital costs and operating costs, and ideally even the indirect costs of ecological damage—is one way that management agencies can capture a larger share of the economic value of tourism in parks and protected areas. Most parks have found that visitors are willing to pay more if they know their money will be used to enhance their experience or conserve the special area. To ensure broad affordable access to parks, Peru, Ecuador, Kenya, Jordan, Costa Rica, and several other countries have raised fees for foreigners while maintaining lower fees for residents.

Unfortunately, tourism revenues are not always reinvested in conservation. Of the US$3 million that Galápagos National Park generates each year, for example, only about 20 percent goes to the national park system. The rest goes to general government revenues (Sweeting et al. 1999:65). This is typical treatment of park income in many countries, but it undermines visitors' support for the fees and destroys the incentive for managers to develop parks as viable ecotourism destinations. Fortunately, some countries are using special fees and tourism-based trust funds to explicitly channel tourist dollars to conservation.

Some countries have introduced policies that help reimburse local residents for the direct and indirect costs of establishing a protected area. Kenya, for example, aims to share 25 percent of revenue from entrance fees with communities bordering protected areas (Lindberg and Huber 1993:106). Ecotourism planners also advocate sales of local handicrafts in gift stores, patronage of local lodges, use of locally grown food in restaurants and lodges, and training programs to enable residents to fill positions as tour guides, hotel managers, and park rangers. Both tour operators and visitors have a role to play by screening trips carefully and committing to ecotourist principles. Developers can choose sites based on environmental conditions and local support, and use sustainable design principles in building and resort construction.

Poorly planned, unregulated ecotourism can bring marginal financial benefits and major social and environmental costs. But with well-established guidelines, involvement of local communities, and a long-term vision for ecosystem protection rather than short-term profit by developers, ecotourism may yet live up to its promise.

Source: Modified from WRI 2000:34-35.

get species is imminent or complete; 20 points); moderate (populations of game and trade species persist but in reduced numbers; 10 points); and non-existent (0 points). Data are based on expert opinion from regional workshops.

The index of wildlife exploitation ranges from 0 to 10 (none to moderate) for the 43 grassland ecoregions in North America. Twelve grassland ecoregions have moderate wildlife exploitation: Palouse Grasslands; Canadian Aspen Forest and Parklands; Edwards Plateau Savannas; Western Gulf Coastal Grasslands; California Montane Chaparral and Woodlands; California Coastal Sage and Chaparral; Hawaiian High Shrublands; Tamaulipan Mezquital; Aleutian Islands Tundra; Interior Yukon/Alaska Alpine Tundra; Olgive/MacKenzie Alpine Tundra; and Torngat Mountain Tundra (Ricketts et al. 1997: Appendix D: 145–150) (**Map 7**). The wildlife populations in these regions are exploited by activities such as pesticide use, predator control, urban sprawl, introduction of invasive species, overgrazing, and high-impact recreational activities (for example, off-road vehicle use and hunting). A WWF wildlife exploitation index for other regions of the world has not yet been published.

Capacity of Grasslands to Sustain Tourism and Recreation

From the analysis above, PAGE researchers found that trends in number of tourists and revenues received from tourism have generally increased in most countries with extensive grassland. So too have the number of safari hunters and revenues from the hunting industry. Data on trends in the size of trophy animals killed are not readily accessible, although data for a five–year period from Tanzania show the number of safari animals killed increased for most species. The demand for most species, excluding elephants, also increased (IUCN 1996: 74).

On the other hand, environmental degradation and poaching may be having substantial negative effects on grassland tourism. And, according to expert opinion, wildlife populations in some grassland ecosystems persist, but in reduced numbers. Therefore, although people may be increasing their use of the tourism and recreational services provided by grasslands, the capacity of grassland ecosystems to continue to provide these services appears to be declining.

Grassland Tourism and Recreation: Information Status and Needs

At present, evaluation of the quality of recreational services provided by grasslands worldwide is largely subjective. Typically, we must use data that lack consistency and that are without comprehensive coverage. Data on recreational services, such as tourist numbers or hunting returns, are difficult to obtain, are of variable quality, and are not associated with ecosystem type. Assumptions generally made associating high tourism numbers and heavily used areas with degraded grasslands, and low tourism numbers and isolated reserves with grasslands in good condition, need to be verified with field data over long time periods. Accurate assessments of the quality of recreation and tourism in grasslands, and predictions about the continued capacity of grasslands to provide those services, require enhanced systems for data collection, monitoring, and reporting.

ABBREVIATIONS AND UNITS

ABBREVIATIONS

ASSOD	Assessment of the Status of Human-Induced Soil Degradation in South and Southeast Asia
AVHRR	Advanced Very-High-Resolution Radiometer
BBS	Breeding Bird Survey
CDIAC	Carbon Dioxide Information and Analysis Center
CIAT	Centro Internacional de Agricultura Tropical
CIESIN	Center for International Earth Science Information Network
CO_2	Carbon Dioxide
CPD	Center of Plant Diversity
DCW	Digital Chart of the World
EBA	Endemic Bird Area
EDC	EROS Data Center
EROS	Earth Resources Observation System
ESA	European Space Agency
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization of the United Nations
FEWS	Famine Early Warning System
GIS	Geographic Information Systems
GISP	Global Invasive Species Programme
GLASOD	Global Assessment of Human-Induced Soil Degradation
GLCCD	Global Land Cover Characteristics Database
GLO-PEM	Global Production Efficiency Model
IFPRI	International Food Policy Research Institute
IGBP	International Geosphere-Biosphere Programme
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
ISRIC	International Soil Reference and Information Centre
ISSG	Invasive Species Specialist Group
IUCN	World Conservation Union
MHT	Major Habitat Type
NASA	National Aeronautics and Space Administration
NBII	National Biological Information Infrastructure
NDVI	Normalized Difference Vegetation Index
NGDC	National Geophysical Data Center
NOAA	National Oceanic and Atmospheric Administration
NPP	Net Primary Productivity
NRC	National Research Council
ORNL	Oak Ridge National Laboratory
OTA	Office of Technology Assessment
PAGE	Pilot Analysis of Global Ecosystems
RUE	Rain-Use Efficiency
SLCR	Seasonal Land Cover Region
SOC	Soil Organic Carbon
SOTER	World Soils and Terrain Digital Database
SPOT	Systeme Pour l'Observation de la Terre
TM	Thematic Mapper (Landsat)
TNC	The Nature Conservancy
UMD	University of Maryland
UNCCD	United Nations Convention to Combat Desertification
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNSO	UNDP Office to Combat Desertification and Drought
USAID	United States Agency for International Development
USGS	United States Geological Survey
VCL	Vegetation Canopy Lidar
WCMC	World Conservation Monitoring Centre
WISE	World Inventory of Soil Emission Potentials
WRI	World Resources Institute
WTO	World Tourism Organization
WWF-U.S.	World Wildlife Fund–United States

UNITS

GtC	Gigaton of Carbon (1 x 10^9)
ha	Hectare
kg	Kilogram
km	Kilometer
mm	Millimeter
PgC	Petagram of Carbon (1 x 10^{15})
TgC	Teragram of Carbon (1 x 10^{12})

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