

Ecosystem Management

Increasing pressures of human population, exploitation, pollution, and climate change have already pushed some ecosystems over critical thresholds. Other ecosystems are edging closer to thresholds beyond which a return to stable conditions could be difficult—if not impossible.



Many natural ecosystems have been converted to cropland and other uses. Agricultural workers in China.
Credit: Rob Broek

INTRODUCTION

Restoring a damaged ecosystem is a difficult and complex task, and one about which we still have much to learn (Jackson and Hobbs 2009, Scheffer and others 2009). Efforts to designate 'planetary boundaries', which are intended to define a 'safe operating space' for humanity with respect to Earth systems, have begun. These boundaries are associated with the planet's biophysical subsystems or processes (**Figure 1**). One boundary considered to have been crossed already is biodiversity loss. One hundred species per million are currently estimated to be lost per year (Rockström and others 2009a, Rockström and others 2009b).

The other boundaries considered to have been crossed are climate change and interference with the nitrogen cycle. Determining a planetary boundary for disruption of the nitrogen cycle is difficult, but scientists have proposed one based on the total amount of nitrogen removed from the atmosphere for human use. If an acceptable rate of human nitrogen fixation is 35 million tonnes per year, as they have provisionally proposed, the amount currently being converted, estimated at

about 120 million tonnes per year, is more than three times too high. Much of this nitrogen fixation is for fertilizer production. Some nitrogen is also fixed by leguminous crops, such as soybean.

Unintended releases of reactive nitrogen to the environment pollute waterways and coastal zones, accumulate in terrestrial systems, contribute several gases to the atmosphere, and ultimately undermine the resilience of critical Earth subsystems (see Harmful Substances and Hazardous Waste chapter). Scientists warn that we may also "soon be approaching the boundaries for global freshwater use, change in land use, ocean acidification, and interference with the global phosphorous cycle" (Rockström and others 2009a, Rockström and others 2009b).

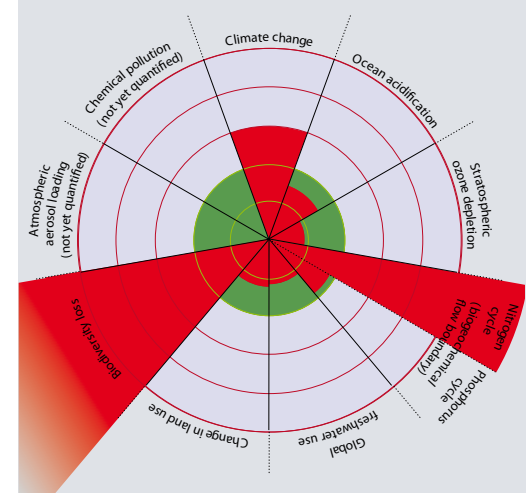
Rising temperatures, shrinking supplies of freshwater, deteriorating agricultural conditions, and sea-level rise increasingly threaten global food supplies (Battisti and Naylor 2009, FAO 2009a, FAO 2009b). By 2050, East Asia will require 70 per cent more water for irrigation than today to feed its growing population; South Asia will require 57 per cent more (FAO 2009a, Mukherji and others 2009).

Figure 1: Planetary boundaries

In 2009, a team of researchers suggested that a safe operating space or boundary for human activities should be considered in order to sustain the integrity of the planet's functioning natural systems. They proposed nine components of Earth systems that show signs of global environmental change driven by human activities. As shown below, these components are climate change, disruption of biogeochemical cycling, biodiversity loss, depletion of the stratospheric ozone layer, acidification of oceans, consumption of freshwater, land use changes, aerosol loading in the atmosphere, and chemical pollution. The inner green shading represents the proposed safe operating space for the nine planetary systems. The red wedges represent an estimate of the current position for each variable. The boundaries for climate change, biodiversity loss, and interference with the nitrogen cycle have been crossed.

The interdependencies between these components are extremely complex. For example, increased concentrations of CO₂ in the atmosphere can lead to ocean acidification and increased radiative forcing. This radiative forcing, in turn, contributes to shifts in climatic zones that can exacerbate land use changes and increase consumption of freshwater. Shifts in climate zones, ocean acidification, disruptions in the nitrogen and phosphorous cycles, and chemical pollution can contribute to biodiversity loss.

Source: Rockström and others (2009a)



By 2025, 3.4 billion people are expected to live in countries categorized as water-scarce (Calzolaio 2009).

The health of soils and their capacity to process carbon, nutrients, wastes, toxins, and water are important factors for Earth's ability to minimize adverse environmental effects. It will be impossible to meet the planet's nutritional demands without seriously reforming agricultural, land, and ecosystem management practices (FAO 2009b, Montgomery 2008, Montgomery 2007).

The economic and financial crisis of 2008-2009 has already caused an additional 90 million people to fall into extreme poverty (UN 2009). However, a pause in the acceleration of global economic activity could provide opportunities to halt destructive practices, rein in energy use, pursue new energy sources, begin creating 'green' jobs, and concentrate on developing sustainable pathways to growth and new approaches to ecosystem restoration (Levin 2009, UK 2009, Stern 2007).

Biodiversity loss

The International Union for Conservation of Nature's (IUCN) Red List Index of Threatened Species is the most comprehensive source of information on the conservation status of plant and animal species. It is based on an objective system for assessing the risks that species will become extinct if no conservation action is taken. Not only does the Red List identify species and their designated threat category (Critically Endangered, Endangered, or Vulnerable), but it is a rich source of information on the nature of threats, ecological requirements, species distribution, and conservation actions that could prevent extinction or reduce the risk of it taking place (Walpole and others 2009).

According to the latest Red List, 17 291 species out of 47 677 assessed are under threat: 21 per cent of all known mammals, 30 per cent of all known amphibians, 12 per cent of all known birds, 28 per cent of reptiles, 37 per cent of freshwater fishes, 70 per cent of plants, and 35 per cent of invertebrates (IUCN 2009).

Biodiversity is the basis of ecosystem health and of the provision of ecosystem services (Mooney and Mace 2009). It is also a critical factor in managing ecosystems for resilience, that is, their ability to absorb and recover from disturbances.

The Conference of the Parties (COP) to the Convention on Biological Diversity called for a significant reduction in the rate of biodiversity loss by the year 2010. This target will likely not be met (Diversitas 2009, Gilbert 2009). Targets adopted to protect 10 per cent of the world's forests will not be met either, despite widespread agreement on the essential role that forests play in biodiversity conservation and climate change mitigation and adaptation (Coad and others 2009). The global set of indicators used to track progress toward the 2010 biodiversity target is underdeveloped and underinvested. To improve data reliability, global monitoring must be balanced with capacity development at the national level. In 2010, the COP will review progress towards the 2010 target. It is expected to agree on a new set of targets and a revised indicator framework (Walpole and others 2009).

ECOSYSTEM DEGRADATION

The Millennium Ecosystem Assessment (MA) was carried out between 2001 and 2005 to assess the consequences of ecosystem change. It analysed the options available to enhance the conservation and sustainable use of ecosystems, and focused on the linkages between ecosystems and human wellbeing. In particular, it looked at 'ecosystem services'; the benefits we obtain from ecosystems. The MA considered direct and indirect drivers of change in regard to ecosystems and their services, the current condition of those services, and the effects of changes in ecosystem services on human wellbeing (MA 2009).

Changes in biodiversity due to human activities have been more rapid in the past 50 years than at any other time in human history. Many of the drivers of change that lead to biodiversity loss, and to changes in ecosystem services, are growing in intensity. The extent of dead zones in the oceans has doubled every ten years since the 1960s. About 400 coastal areas are now periodically or constantly oxygen-depleted due to fertilizer run-off, sewage discharge, and combustion of fossil fuels (Diaz and Rosenberg 2008).

The scale and importance of ecosystem transformations have evoked speculation that humankind has entered a new geological epoch succeeding the 10 000-year Holocene. It has been suggested that with the Industrial Revolution we

entered the 'Anthropocene', in which human activity is the main driver of environmental change. Some scientists would argue that the challenge we face today is finding a way to maintain the Holocene's more desirable environmental state (IGIP 2009, Rockström and others 2009a, Zalasiewicz and others 2008).

Threats to marine fisheries

Overexploitation, pollution, and rising temperatures threaten 63 per cent of the world's assessed fisheries stocks (Worm and others 2009) (**Box 1**).

In 2009, for the third year in a row, a major sockeye salmon run in British Columbia, Canada, was closed to fishing. Of an expected 10 million sockeye salmon, just over 1.3 million appeared, with impacts on the economy and the people and animals that rely on them for food. Some experts blamed warmer ocean and river temperatures, together with declining food supplies in the open oceans (CBC 2009, Orr 2009).

Damaged aquatic ecosystems can be successfully restored. In a two-year study on fish stocks, catch data were supplemented with information from other sources, including stock abundance and exploitation rates in ten ecosystems, ecosystem surveys from 20 regions, and ecosystem models from 30 regions, to provide a precise and accurate assessment of the state of certain fisheries. Stocks showed signs of recovery in five of the ten ecosystems studied. Regions showing the greatest improvement were in Iceland and off the coasts of



Shuswap Lake-Adams River salmon run, Canada
Credit: Hank Tweedy

Box 1: Marine Assessment of Assessments launched in 2009

The UN General Assembly requested UNEP and the Intergovernmental Oceanographic Commission (IOC) of UNESCO to co-lead a process to evaluate the potential for establishing a regular marine environmental assessment process. This process is intended to provide decision-makers with accurate and timely information about the state of the marine environment, including socio-economic elements. The start-up phase is an 'Assessment of Assessments' (AoA)—a thorough synthesis of what has been done nationally, regionally, and globally to assess the marine environment and related aspects of human societies and economies.

The AoA report, launched in 2009, sets out a framework and options for coordinated global reporting and assessment. The report recommends some potential products and activities that could be delivered during the first cycle. These include capacity building; improving knowledge and methods of analysis; enhancing networks among existing assessment processes and international monitoring and research programmes; and creating communications tools and strategies.

Source: UNEP IOC-UNESCO (2009)

California and New England in the United States (Worm and others 2009). There are also positive signs in some developing countries. In Kenya and Tanzania, for example, scientists, managers, and local communities are cooperating to restrict some types of fishing equipment and close certain areas to fishing (Nyandwi 2009).

Combining traditional control measures like catch quotas and community management with closures, equipment restrictions, ocean zoning, and economic incentives is a promising approach. The study concluded that when fishery industries, scientists, and conservation biologists work together, sharing the best available data and bridging disciplinary divisions, ecosystem management can be effective (Worm and others 2009).

Half of all fish consumed globally are produced by aquaculture. This does not necessarily relieve pressures on wild species since much of the feed for farmed fish is made from these species. Up to five kilograms of wild fish is required to produce one kilogram of aquaculture salmon (Dewailly and Rouja 2009, Naylor and others 2009). Expansion of fish farming in coastal areas has contributed to the loss of over 50 per cent of the world's mangrove forests compared with the early 20th century. Shrimp farming accounts for almost three-quarters of this loss (Bosire and others 2008).

Coastal areas

Almost half of the world's largest cities lie within 50 kilometres of a coast. Rich coastal areas provide food, recreation, and transportation, and serve as huge biogeochemical processors (Vörösmarty and others 2009). These areas are experiencing increasing pressures from the land side, as

populations grow and coastal wetlands are lost to agriculture and urban expansion. At the same time, creeping inundation is eroding coastlines on the ocean side (Vörösmarty and others 2009).

Many of the world's largest deltas are densely populated and heavily farmed. Nevertheless, they are increasingly vulnerable to flooding and conversion of land to sea. A recent study found that 24 of the 33 largest deltas are sinking and that all but five have experienced temporary flooding in the last decade. Tens of millions of people have been affected and a total of 250 000 square kilometres has been inundated (Syvitski and others 2009). Deltas are at risk from sea-level rise, and direct human activities have significantly increased the vulnerability of deltas. Dams and reservoirs, for example, interrupt the natural flow of rivers and keep sediments from reaching the deltas.

In the next 40 years, it is estimated that the total amount of land vulnerable to flooding will increase by as much as 50 per cent globally (Syvitski and others 2009). Thousands of lives have already been lost as a result of recurrent flooding in the deltas of the Irrawaddy River in Myanmar and the Ganges-Brahmaputra in India and Bangladesh.

Mangrove forests provide valuable ecosystem services, not only functioning as essential spawning grounds, but also stabilizing coastal areas (Alongi 2008). They shelter these areas from storms and help prevent flooding, and upstream and underground salinization. They also furnish fuel, food, and medicines to local communities, in some cases contributing to biodiversity conservation (Pritchard 2009, Walters and others 2008).

Mangrove forests, like coral reefs and tidal flats, attenuate wave energy and contribute to coastal



The Sundarbans in Bangladesh are part of the world's largest delta, formed by the Ganges, Brahmaputra, and Meghna rivers. The mangrove forest covers about 38 000 square kilometres.

Credit: www.sundarbans.org

defences far more cost-effectively than 'hard' defences. During the 2004 Asian tsunami, areas protected by intact mangrove forests and coral reefs were less affected than areas without such natural barriers (Pritchard 2009, Wetlands International 2008). The need to maintain and restore 'blue carbon sinks' in the oceans, seas, and marine ecosystems to combat climate change was a focus of international attention in 2009. Of all the biological carbon captured in the world, over half ('blue carbon') is captured by marine living organisms (Nellemann and others 2009, UNEP 2009).

ECOSYSTEM MANAGEMENT MODELS

Policy-makers need the capacity to create and implement policies for social-ecological systems, foresee consequences, and evaluate outcomes. Relevant research should bridge disciplines effectively and create the areas of knowledge required to build systems that are resilient.

Ecosystems that have high biodiversity are more resilient than those that do not. Management and policy formulation need to be based on an understanding of how biodiversity enhances ecosystem resilience. In a biosphere shaped by human actions, managing for resilience is critical in order to cope with uncertainty (Resilience Alliance 2007, Elmqvist 2003).

By quantifying social-ecological connections and the associated trade-offs of different actions over relevant time frames, managers can better anticipate the impacts of their actions (Carpenter and others 2009). Ecosystems respond to stressors and drivers in complex, non-linear, and sometimes even abrupt ways. Moreover, ecosystem services are affected by the interactions of multiple drivers, the varying spatial extents and time lags of processes, and conflicting connections between and among various services. Changes in one ecosystem service invariably impact another (Kellner and Hastings 2009, Mitchell and others 2009).

The recommendations of the Millennium Ecosystem Assessment some five years ago have proven difficult to apply. Balancing human needs with ecosystem health is particularly challenging. In view of the complex interactions between multiple

drivers and human feedback, policy decisions designed to manage and improve ecosystems can be exceedingly hard to make, and even more problematic to evaluate. These concerns are illustrated by an analysis of World Bank projects between 1998 and 2006 that had the dual goals of promoting biodiversity and alleviating poverty. Only 16 per cent of the projects were considered successful in both areas (Tallis and others 2008).

How to quantify the trade-offs that occur when ecosystem services interact with human needs remains poorly understood. Researchers have suggested that a conceptual framework needs to be developed for assessing changes in social-ecological systems through the use of a suite of broadly accepted metrics and indicators that can be collected consistently and compared across a range of cases (Carpenter and others 2009). Only

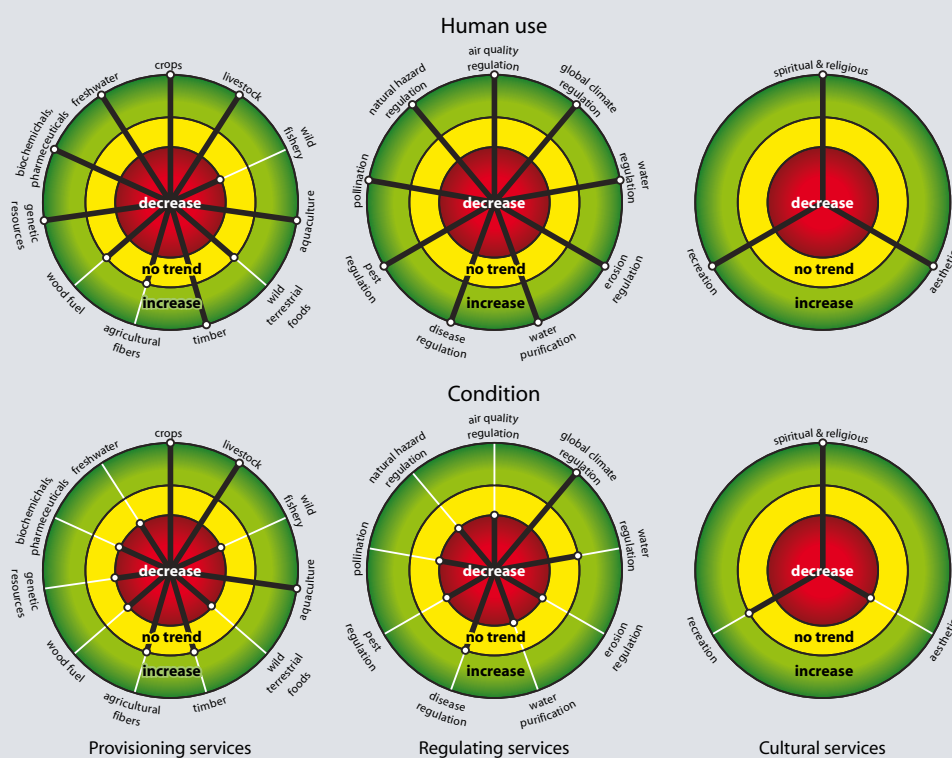
then can there be an accurate analysis of policies and management practices intended to increase ecosystem resilience and improve ecosystem services (Figure 2).

Some scientists believe that future research should focus on controls of ecosystem services themselves, addressing the effects of multiple drivers. Such research would directly address the need for information about how drivers and management interventions change ecosystem services. It would evaluate not only the direct effects of biodiversity, but also biodiversity's role in modifying the effects of drivers on ecosystem services. New, integrated models need to be developed to identify conceptual frameworks for ecosystem assessment, and to address scales and drivers for specific situations. Changes in ecosystem services could then evoke feedback through human responses (Carpenter and others 2009).

There are significant gaps in long-term observation and monitoring programmes, particularly in regard to data and interactions between drivers of change, ecosystems, and human wellbeing. Data collection needs to be consistent, rigorous, and available through searchable databases, on-line virtual libraries, and training programmes. Local and traditional knowledge also needs to be collected and considered. The development of tools that can help model or analyse the responses of biodiversity and ecosystem services to drivers of change and, in turn, help predict how those responses would affect human wellbeing are key. The different scientific disciplines need to work together to create a common, credible, replicable, and scalable framework (Connelley and others 2009, Daily 2009, Ostrom 2009, UNEP IPBES 2009a).

The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) is designed to serve as an international mechanism to deliver scientific expertise on biodiversity and to follow up on the MA's global strategy to address problems presented in its findings (UNEP IPBES 2009b). International cooperation aimed at halting biodiversity loss focus on the importance of these efforts to human wellbeing and poverty eradication. To emphasize the importance of biodiversity among scientists, governments, and the general public, the UN has declared 2010 the International Year of Biodiversity.

Figure 2: Expansion of ecosystem services for human use



Trends in human use (upper diagrams) vs. condition of ecosystem services (lower diagrams). Provisioning, regulating, or cultural ecosystem services are shown at left, centre, and right. The length of the black radial lines indicates the degree of change in human use or condition of the service.

Source: Carpenter and others (2009)

Agricultural ecosystems

The world food crisis has resulted from the combined effects of competition for cropland, weather conditions, crop disease, and export restrictions (Battisti and Naylor 2009). Food production relies entirely on ecosystems' ability to provide water, nutrient-rich soils, climate regulation, pollinators, and to help control infestations. These factors, along with the conversion of cropland to biofuel production, may reduce the amount of cropland available for growing food crops by 8-20 per cent by 2050 (Ericksen 2008). Environmental degradation will be a major constraint on future world production, affecting both food prices and food security. Soil erosion has already led to a 40 per cent global decline in agricultural productivity (Ericksen 2008).

Maintaining and building efficient food systems in the face of growing population pressures and climate change is one of the most serious challenges the world faces. In the tropics and subtropics, the temperatures of the growing season at the end of the 21st century are expected to surpass the highest temperatures recorded in the last 100 years (Battisti and Naylor 2009), with profound effects on crop and livestock production. In addition, to secure supplies of agricultural produce some countries are making investments in other developing countries to grow crops (**Box 2**). The food price spike in the first half of 2008 has increased concerns about the global food supply in the future. Although technically it seems possible to feed the 9 billion people expected to inhabit the planet by mid-century, diminishing

returns, rising input prices, and the difficulties of logistics, institutional arrangements, and security constraints in some areas mean that the world food economy is likely to reach a ceiling long before this technical potential is realized.

Based on an analysis of the literature, researchers argue that if the long-term decline in food prices in the 20th century changes, the short-time horizons of private and public actors are likely to pose special risks since they could prevent timely investments in increasing world capacity for food production. Governments can exercise a number of options to mitigate this risk, such as influencing supply and demand for farm products, investing in research and infrastructure, and reducing price instability in agricultural markets (Koning and Van Ittersum 2009).

Box 2: Foreign land acquisition

Countries that export capital, but lack sufficient land or water to grow their own crops, have triggered a powerful and contentious investment trend in the developing world, mainly in Africa. According to a recent FAO study, leasing of farmland by foreign companies, investment funds, and foreign governments has become a worldwide phenomenon. Abu Dhabi has leased 28 000 hectares in Sudan to produce maize, beans, and potatoes for the United Arab Emirates (UAE). China is producing palm oil for biofuel on 2.8 million hectares in the Democratic Republic of the Congo. India has invested US\$4 billion in Ethiopian cropland to grow sugarcane and flowers.

Outsourcing agricultural production to countries in need of capital is nothing new, but these land acquisitions are different in kind and scale. Major food importers including China, India, the Republic of Korea, Qatar, Saudi Arabia, and the UAE are leasing or purchasing vast tracts of farmland, as much as 15-20 million hectares, in developing countries. According to the International Food Policy Research Institute, the value of these transactions is estimated at US\$20 to US\$30 billion.

These large-scale land acquisitions followed, in particular, the food crisis of 2007-2008, when wheat, rice, and cereal prices skyrocketed. Food market turmoil and concerns about the cost of imports, coupled with the threat of climate change and ongoing water shortages, have provided an impetus for this surge in land transactions. Some countries are also looking for opportunities to make a profit on food and on products such as biofuels.

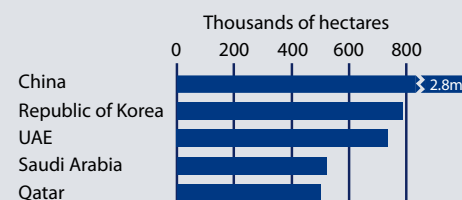
Advocates point out that these transactions provide income to struggling countries, and that local communities could benefit from access to new crop varieties and technologies. Critics warn that local populations could be pushed off their land. Moreover, countries in which millions of people are starving will be exporting food. This practice has been described as 'neo-colonial'.

In 2009, there were riots in Madagascar when the Korean company Daewoo Logistics attempted to lease 1.3 million hectares (nearly half the island's total arable land) to produce maize and palm oil.

Criticism of such transactions has continued to grow. In response, a number of organizations, including the FAO, the UN Conference on Trade and Development (UNCTAD), and the World Bank, are developing guidelines to regulate this practice.

The land rush appears to have slowed down. As Jean-Philippe Audinet, Acting Director of the Policy Division of the UN International Fund for Agricultural Development (IFAD), says, "some don't want to take this political risk, reputational risk and economic risk." However, there are concerns that once food prices start to climb, such acquisitions will again begin to increase.

Hectares obtained by key investors, 2006-2009



Source: International Food Policy Research Institute

Since 2006, 15 to 20 million hectares of farmland in developing countries—in size, about one-fifth of all that in the European Union—has been subject to transactions or talks involving foreigners, according to the International Food Policy Research Institute.

Sources: BBC (2009), Coluta and others (2009), Economist (2009), FAO (2009c), Viana and others (2009), Rice (2008)

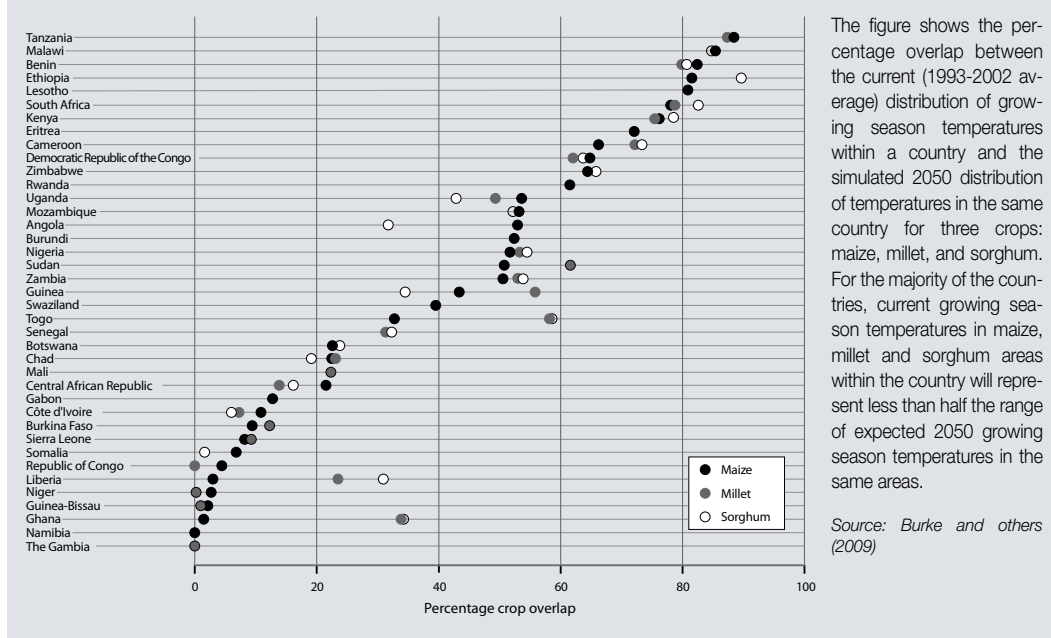
Expanding Africa's genetic resource base

Most of Africa's population experiences climate-related stress and shocks on a regular basis as a result of climate variability. The scale and nature of these impacts, however, will change dramatically as climate changes (Conway 2009).

Food security issues have become increasingly prominent since the food price crisis of 2007-2008. Vulnerability to fluctuations in food supplies has been of particular concern (Mittal 2009). Recent studies call for concerted adaptation efforts to build resilience in African agricultural systems in the face of climate change (Burke and others 2009, Conway 2009, Lobell and others 2008). In adapting to climate change, African farmers could benefit from wider experience available in other parts of the continent and from access to genetic resources available elsewhere (Burke and others 2009).

Knowledge about the potential speed and magnitude of shifts in climate conditions is also required (**Figure 3**). Donor and research institutions must understand how rapid and how extreme these changes will be so they can prioritize the collection, evaluation, and conservation of genetic resources. African crop diversity may not be sufficient to allow the adaptation of crop production to climate change. While great strides have been made in the collection of plant genetic resources for seed banks over the last half-century, collections in key areas of African crop diversity are largely unavailable for a variety of reasons (Burke and others 2009).

Figure 3: Percentage crop overlap in African countries 2002-2050



Investments in the collection and conservation of crop diversity in countries, including Cameroon, Nigeria, Sudan, and Tanzania, would be promising initial activities.

Many African countries could benefit from the genetic resources of other countries on the continent if these resources were effectively managed and shared. Interdependence among countries in regard to plant genetic resources has led to the development of collaborative mechanisms such as the Multilateral System for access and benefit sharing of the International Treaty on Plant Genetic Resources for Food and Agriculture, sometimes referred to as the 'Seed Treaty'. This interdependence will clearly increase with climate change, as will the need for international collaboration in the conservation and use of crop genetic diversity (Burke and others 2009).

ECOSYSTEM-CLIMATE INTERACTIONS

Ecosystems' capacity to deliver essential services to society is already under pressure. The additional stresses imposed by climate change in the coming years will require extraordinary adaptation. It will be necessary to track the changing status of ecosystems, deepen our understanding of the biological underpinnings of ecosystem service

delivery, and develop new tools and techniques to maintain and restore resilient biological and social systems, building on an ecosystem foundation that has been radically altered during the past half century. Most rivers have been totally restructured; water bodies are severely polluted and fish stocks are depleted; coral reefs are near a tipping point and may disappear as functional ecosystems due to warming, pollution, and acidification; and over half the planet's land surface is devoted to livestock and crop agriculture, with little consideration given to the ecosystem services that are being lost as a consequence (Fagre and others 2009, Smol and Douglas 2007).

Climate change, mainly caused by anthropogenic GHG emissions, will disrupt our ecosystem base in new ways. Already we see widespread signs of change. Species behaviour is being altered, disrupting longstanding mutualisms. We are seeing extinctions within vulnerable habitats, and conditions in which migrations are necessary for survival. This represents an extraordinary threat and calls for urgent attention by the scientific community (Mooney and others 2009).

Scientists and conservation managers are re-examining ecosystem management approaches in

relation to climate change, including looking at how ecosystems influence climate and how climate drives changes in ecosystems (Glick and others 2009, Chapin and others 2008, Hoegh-Guldberg and others 2008, Campbell and others 2008, MacLachlan and others 2007).

Considering multiple interactions and feedbacks between climate and ecosystem management could lead to innovative climate mitigation strategies to reduce at the same time, for example, GHG emissions and rates of land degradation and deforestation. Achieving each of these objectives would result in multiple ecological and societal benefits. Assessing such strategies' effectiveness requires a good understanding of interactions among feedback processes, their consequences at the local and global levels, and the ways that changes on various scales in different regions are linked (Chapin and others 2008).

Oceans' role in climate mitigation is being explored through the attention being given to 'blue carbon' sequestration. A recent UNEP publication, produced in collaboration with FAO and UNESCO, reports that an estimated 50 per cent of the carbon in the atmosphere that becomes sequestered in natural systems is cycled in seas and oceans (Nellemann and others 2009). Seventy per cent of the carbon stored permanently in marine areas is found in mangrove, seagrass, and salt marsh ecosystems. Yet these critical ecosystems are disappearing more rapidly than land ecosystems and urgently need to receive greater attention.

An essential tool for ecosystem-based responses to climate change is active adaptive management, in which systems are closely monitored and management strategies are altered to address expected and ongoing changes (Lawler and others 2009). A global mean warming of 2°C by 2100 could have catastrophic effects—although the precise nature of these effects is still being debated. The 2007 IPCC Fourth Assessment Report predicted that drought, higher temperatures, and severe weather would affect food productivity, threaten up to 30 per cent of species with extinction, and cause the bleaching of much of the world's coral reefs (IPCC 2007a, IPCC 2007b). Many scientists are now convinced that temperature rises and the impacts in the 21st century will exceed those projected in the 2007 IPCC report (Le Quéré

and others 2009, Rockström and others 2009a, Rockström and others 2009b, Smith and others 2009, UNEP 2009).

Managing ecosystems in a way that ignores the probable impacts of climate change would fail to meet the most basic management objectives. Therefore, the uncertainty of these impacts is one of the greatest challenges facing ecosystem managers. Successful management strategies need to take account of the uncertainty inherent in projections of impacts on climate, and how these uncertainties will affect the outcomes of management activities.

Progress on REDD

The active protection of tropical forests is now widely perceived as a crucial ecosystem management priority and a cost-effective way to reduce global carbon emissions. Formalizing the concept of 'reducing emissions from deforestation and forest degradation' (REDD) while building consensus, knowledge, and awareness concerning the importance of including a REDD mechanism in a post-2012 climate change treaty is the aim of the new collaborative UN-REDD Programme.

REDD is an ambitious, innovative payment scheme for ecosystem services. It recognizes forests as a major mitigating factor with respect to climate change; it also offers financial incentives to keep tropical forests standing and growing. Roughly 25 per cent of terrestrial carbon is stored in forests. Deforestation accounts for about 20 per cent of man-made greenhouse gas emissions, more than those produced by the entire transport sector. REDD assigns a monetary value to standing forests in developing countries and allows developed countries to offset their CO₂ emissions by reimbursing local landowners, including indigenous people, for protecting the forests instead of cutting them down. For example, Brazil's first REDD project is in the state of Amazonas at the Juma Sustainable Development Reserve, where each family receives US\$28 a month if the forest remains uncut (Viana 2009).

There are challenges related to ensuring that this programme operates effectively and has a maximum impact, for example monitoring. Today, satellite imagery is the main tool being used to track forest destruction and degradation (Box 3).

Box 3: Using satellite imagery to track forest destruction and degradation

Over one per cent of all tropical humid forests was lost between 2000 and 2005. NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) is able to capture images of large-scale deforestation. Clear-cut areas of 15-25 hectares can be identified. Brazil has a well-established satellite imaging programme, the Amazon Deforestation Monitoring Project (PRODES), which monitors the world's largest tropical rainforest. This is just one of the tools being used to try to halt the illegal logging and rainforest destruction that contribute 30 per cent of global carbon emissions. A joint pilot project with Japan (the Daichi satellite) has made it possible to see beneath cloud cover, a frequent challenge in imaging tropical forests.

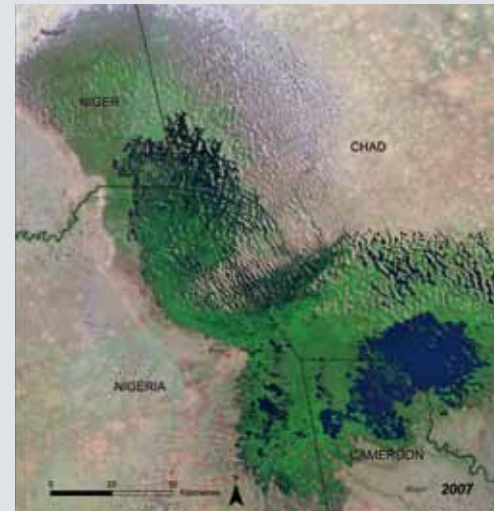
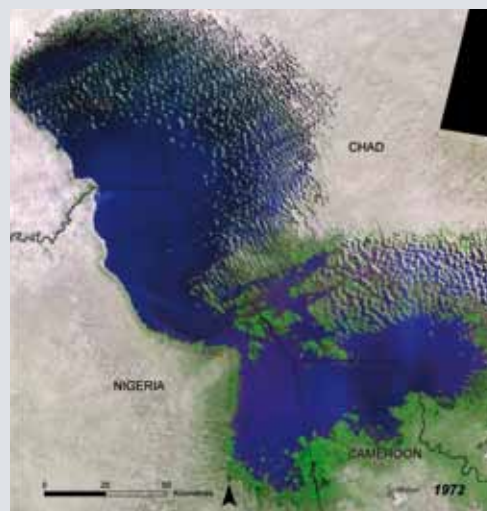
These satellites are part of the Global Earth Observation System of Systems (GEOSS). Launched in response to a call for action by the 2002 World Summit on Sustainable Development and by the G8, this initiative, involving 80 governments and the European Union, links all existing Earth observation systems and organizations for the purpose of obtaining a complete picture of the planet. Its GEO Portal is a single internet access point where imagery, data, and analytical software packages relevant to all areas of the globe can be found. This project is designed to help understand and predict climate change, improve water management, and make the management and protection of terrestrial, coastal, and marine resources more effective.

A new initiative focusing on biodiversity has been established within GEOSS, as the Group on Earth Observations Biodiversity Observation Network (GEO BON) has been added to the GEO family.

While satellites can track the destruction and degradation of forests, they are unable to evaluate carbon content, a parameter that would be required for an accurate REDD assessment. Determining carbon content and monitoring carbon emissions from forests is currently time-consuming and difficult. Calculating the biomass and ultimately the amount of carbon sequestered in a forest often requires manual measurement of trees' diameter and height. This is performed plot by plot, tree by tree. However, new software will allow users to map and monitor forest degradation and deforestation using a personal computer.

The Carnegie Landsat Analysis System - Lite (CLASLite) uses images from Earth observation satellites like Landsat, in combination with LiDAR (the Light Detection and Ranging system), to estimate how much carbon is contained in a forest. This will be an especially important monitoring tool for large and remote tropical forests. Data are based on remote sensing technologies that can map 10 000 square kilometres per hour, yet CLASLite is as accurate as more traditional data collection techniques.

Sources: Asner (2009), GEOSS (2009), Tollefson (2009)



The Lake Chad drainage basin, a 2 500 000 km² hydrologically closed catchment, extends to eight countries: Algeria, Cameroon, the Central African Republic, Chad, Libyan Arab Jamahiriya, Niger, Nigeria, and Sudan. It is home to over 20 million people, who derive direct or indirect livelihoods from the lake. Most of the region's rainfall occurs in the southern one-third of the drainage basin, contributing about 90 per cent of the basin's run-off. The northern two-thirds is dominated by arid conditions.

As these satellite images from 1972 and 2007 show, the surface area of the lake has been reduced dramatically over time despite a recent increase in its water levels. Less rainfall and increased water consumption by the area's inhabitants have changed the water balance within the drainage basin and are continuing to do so. The lake is especially susceptible to climatic variability since it is rather shallow, with an average depth of 4.11 metres. As a result of lower rainfall and greater water usage, the extent of Lake Chad has decreased by 95 per cent over roughly 35 years.

Credit: Atlas of Our Changing Environment (http://na.unep.net/digital_atlas2/google.php)

In order to have an effect on atmospheric CO₂ concentrations, trees must be protected against any kind of degradation, fire, or logging for at least 100 years (Shrope 2009).

A second, even more difficult challenge is how to determine the 'reference levels' against which future greenhouse gas abatement would be measured. The problem is how to find a way to ensure that REDD mechanisms do not perversely reward countries with high deforestation rates while discriminating against those with low ones. Furthermore, countries that receive funding should have effective accountable governance to ensure that payments received are redistributed to communities and individual landowners to compensate them for not cutting down trees. Land ownership needs to be clear, and special efforts should be made to involve and protect indigenous populations (Cotula and Meyers 2009, Viana 2009). Local communities that depend on these ecosystems for their livelihood will be impacted the most.

REDD initiatives are most likely to succeed where they build on the interests of indigenous people and forest communities. Attention must be paid to the balance of incentives, benefits, rights, and political participation across levels of decision-making, interest groups, and administration. Incentives can include payments or other benefits for good practices, development of alternative livelihoods, formalizing of land tenure and local resource rights, and intensification of productivity on non-forest lands. The pressure to reduce deforestation should be spread across many levels to alleviate the burden on forest communities.

A healthy standing forest provides many benefits beyond carbon sequestration and mitigation of climate change. Forests also protect biodiversity, halt soil erosion, and maintain water quality. Critics of REDD would like to see these other benefits be given greater recognition than they are at present.

It has been estimated that putting US\$22-29 billion into REDD would cut global deforestation by 25 per cent by 2015 (IWG-IFR 2009). Transaction costs are likely to be very high, although lower than those associated with almost any other mitigation vehicle with similar impacts. REDD provides a useful mechanism for offsetting developed countries' CO₂ emissions, as long as

these countries do not use it as a comparatively easy way out to avoid reducing their own emissions (Wollenberg and Springgate-Baginski 2009).

Assisted colonization

Climate change has already forced changes in distributions of many plants and animals at the local level, some of which have led to severe range contractions and even the potential extinction of some species. The geographic ranges of many species are moving to higher latitudes and altitudes, in response to shifts in the habitats to which they have adapted over long periods. Some species are unable to disperse or adapt rapidly enough to keep up with changes in climatic conditions. Not only do these species face increased risks of extinction, but entire ecosystems, such as cloud forests and coral reefs, may cease to function in their current form due to a lack of options to migrate or adapt in time (Hoegh-Guldberg and others 2008).

Discussions of conservation responses to climate change consider 'assisted colonization', the translocation and successful colonization of species that are threatened with extinction by climate change, to be one option (McLachlan and others 2007). Researchers have proposed the adoption of a risk assessment and management framework to help identify circumstances that require moderate action, such as enhancement of conventional conservation measures, and those calling for a more extreme response, such as assisted colonization.

There are many socio-economic as well as biophysical considerations. For example, moving threatened large carnivores into livestock grazing areas is controversial. In some cases, until more suitable habitats can be found or developed, the use of gene banks could be a practical option for the conservation of species. Existing gene banks for agriculturally significant seeds have been established with a view to conservation in a warming world. This approach could be a useful alternative for many more plants and animals that may not now be of economic significance, and could prove invaluable in an uncertain future (Swaminathan 2009, Hoegh-Guldberg and others 2008).

Assisted colonization entails some risks, particularly when translocated species become invasive, but these must be weighed against the possibility of extinction and ecosystem loss. Already some regions, including the Arctic, are experiencing higher temperatures. Others are likely to experience unprecedented warming within the next 100 years, as well as altered precipitation patterns and increasing ocean acidity. The future for some species and ecosystems is so uncertain that assisted colonization could be their best chance. The relevant management decisions will require careful thought, supported by solid scientific understanding (Running and Mills 2009, Hoegh-Guldberg and others 2008).

LOOKING AHEAD

Many questions about the health, functions, and resilience of ecosystems remain to be answered. It is clear, however, that ecosystem management has an important role to play in mitigating and adapting to the impacts of climate change. If managed properly, ecosystems can provide a cost-efficient and effective way to reduce these impacts. Managing ecosystems for resilience, and protecting biodiversity to support this resilience, is critical both to meet development objectives and to address the challenges of climate change.

There are interventions that can mitigate or facilitate adaptation to climate change. They consist of *technology-based* adaptation, such as a new seawall; *direct ecosystem management* concerned with specific ecosystems or ecosystem services, such as constructed wetlands; or longer-term *indirect ecosystem management* related to ecosystem resilience and functions, which will have a range of ecosystem co-benefits. These benefits directly enhance priority ecosystem services. Maintaining healthy, resilient ecosystems is therefore key to the mitigation of, and adaptation to, climate change (Figure 4).

Figure 4: Coastal ecosystem management adaptation options

Adaptation option	Climate stressors addressed	Other management goals addressed	Benefits	Constraints
Allow coastal wetlands to migrate inland, for example through setback, density restrictions, land purchases	Sea level rise	Preserve habitat for vulnerable species; preserve coastal land/development	Maintains species habitats; maintains protection for inland ecosystems	In highly developed areas, there is often no land available for wetlands to migrate, or it can be costly to landowners
Incorporate wetland protection into infrastructure planning, for example for sewer utilities	Sea level rise; changes in precipitation	Maintain water quality; preserve habitat for vulnerable species	Protects valuable and important infrastructure	
Preserve and restore the structural complexity and biodiversity of tidal marshes, seagrass meadows, and mangroves	Increases in water temperatures; changes in precipitation	Maintain water quality; maintain shorelines; invasive species management	Vegetation protects against erosion, protects mainland shorelines from tidal energy, storm surge, and wave forces, filters pollutants, and absorbs atmospheric CO ₂	
Identify and protect ecologically significant areas such as nursery grounds, spawning grounds, and areas of high diversity	Altered timing of seasonal changes; increases in air and water temperatures	Invasive species management; preserve habitat for vulnerable species	Protecting critical areas will promote biodiversity and ecosystem services (for example, producing and adding nutrients for coastal systems, serving as refuges and nurseries for species)	May require federal or state protection
Integrated Coastal Zone Management approaches to achieve sustainability	Changes in precipitation; sea level rise; increase in air and water temperatures; changes in storm intensity	Preserve habitat for vulnerable species; maintain/restore wetlands; maintain water availability; maintain water quality; maintain sediment transport; maintain shorelines	Considers all stakeholders in planning, balancing objectives; addresses all aspects of climate change	Stakeholders must be willing to compromise; requires much more effort in planning
Incorporate consideration of climate change impacts into planning for new infrastructure	Sea level rise; changes in precipitation; changes in storm intensity	Preserve habitat for vulnerable species; maintain/restore wetlands	Engineering could be modified to account for changes in precipitation or seasonal timing of flows; siting decisions could take sea level rise into account	Land owners will likely resist relocation away from prime coastal locations
Create marshland by planting the appropriate species—typically grasses, sedges, or rushes—in the existing substrate	Sea level rise	Maintain water quality; maintain/restore wetlands; preserve habitat for vulnerable species; invasive species management	Provides protective barrier; maintains and often increases habitat	Conditions must be right for marsh to survive, for example sunlight for grasses and calm water; can be affected by seasonal changes
Use natural oyster breakwaters or other natural breakwaters to dissipate wave action and protect shorelines	Increases in water temperatures; sea level rise; changes in precipitation; changes in storm intensity	Preserve coastal land/development; maintain water quality; invasive species management	Naturally protects shorelines and marshes and inhibits erosion inshore of the reef; will induce sediment deposition	May not be sustainable in the long term because breakwaters are unlikely to provide reliable protection against erosion in major storms
Replace shoreline armoring with living ones through beach nourishment and planting of vegetation	Sea level rise; changes in storm intensity	Maintain/restore wetlands; preserve habitat for vulnerable species; preserve coastal land/development	Reduces negative effects of armoring, such as downdrift erosion; maintains beach habitat	Can be costly; requires more planning and materials than armoring
Remove shoreline hardening structures like bulkheads and dikes to allow shoreline migration	Sea level rise	Maintain sediment transport	Allows shoreline migration	Costly for, and destructive to, shorelines property
Plant submerged aquatic vegetation (SAV) such as seagrasses to stabilize sediment and reduce erosion	Changes in precipitation; sea level rise	Maintain/restore wetlands; preserve habitat for vulnerable species; preserve coastal land/development	Stabilizes sediment; does not require costly construction procedures	Seasonality: grasses diminish in winter months, when wave activity is often more severe because of storms; light availability is essential

Source: Adapted from Hale and others (2009)

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