People, Ecosystems and Climate: Governance Risks from the Degradation of Ecosystem Services in the Face of Ongoing Climate Change[1]

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INTRODUCTION

During the 20th century, the human population quadrupled, growing from about 1.6 billion to over 6 billion, and population continues to increase by about 75 million people per year. All of these people have been ultimately dependent upon the world's ecosystems and the benefits that flow from them, and this dependence will continue. But as the human population has flourished, ecosystems have suffered in order to meet the accelerating demands for food, water, timber, and other natural resources. Planet earth has been transformed to provide substantial net gains to human well-being and economic welfare, but with these benefits have also come new risks derived from the degradation of ecosystems and the loss of ecosystem services. Concerns about these risks are now becoming more widespread among academics, governments, the private sector, and the general public (Nature, 2009). Emerging risks related to climate change have most dramatically illustrated this growing concern, though the impacts of climate change are felt by people primarily through changes in ecosystems.

So what, exactly, are ecosystem services? Simply, they are the benefits that ecosystems provide to people. The functions that ecosystems carry out -- a sort of natural infrastructure -- support, regulate, and provide the goods and services that people derive from biodiversity (the variability among living organisms at the levels of genes, species, and ecosystems) (CBD, 1992). The services from the wide range of scales of biodiversity do not arrive independently; rather, these services are delivered from ecosystems and elements of them functioning as a system. When the system is degraded, fewer services are delivered. This provides powerful justification for the importance society gives to conserving ecosystems, the services they provide, and the biodiversity that supports them. Further, recognizing biodiversity as the way that ecosystems store the information accumulated over the past two billion years of evolution dramatizes the point that the loss of biodiversity is tantamount to losing essential biological information that may enable humanity to develop new biology-based technologies that will enable our species to adapt to future conditions.

Many forms of development degrade ecosystems, but people can also restore them and can intervene meaningfully in their management to change the kinds of services ecosystems deliver. Whether they are managing forests, wetlands, farms, or backyard gardens, people realize that they are managing eco*systems*. Recognising the **complexity** of these ecosystems is very important for successful management - this complexity has evolved over more than two billion years to form ecosystems that have provided the functions of nutrient flow, the predator-prey interactions that helped drive evolution, and even the current atmosphere that supports life on Earth. Ecosystems are dynamic complexes of plant, animal, and micro-organism communities and their non-living environment interacting as a functional unit (CBD, 1992). They support the

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processes that cleanse air and water, pollinate crops, decompose waste, control noxious pests and diseases, and regulate extreme natural events. Water, food, fibres, organic fuels, and natural medicines are all produced by the intricate web of life that forms ecosystems. Arts, cultures and religions have been inspired by ecosystems, which also provide recreation and spiritual enrichment. Even those who focus on conserving a single species in the wild, such as giant pandas or blue whales, recognize that no species is an island, independent unto itself; rather, its survival depends on its relations with the other components of the ecosystem of which it is part (McNeely et al., 2009).

The Millennium Ecosystem Assessment (MA, 2003), carried out between 2001 and 2005 by nearly 1400 experts from 95 countries, classified ecosystem services into four groups: supporting services; regulating services; provisioning services; and cultural services (Figure 1).

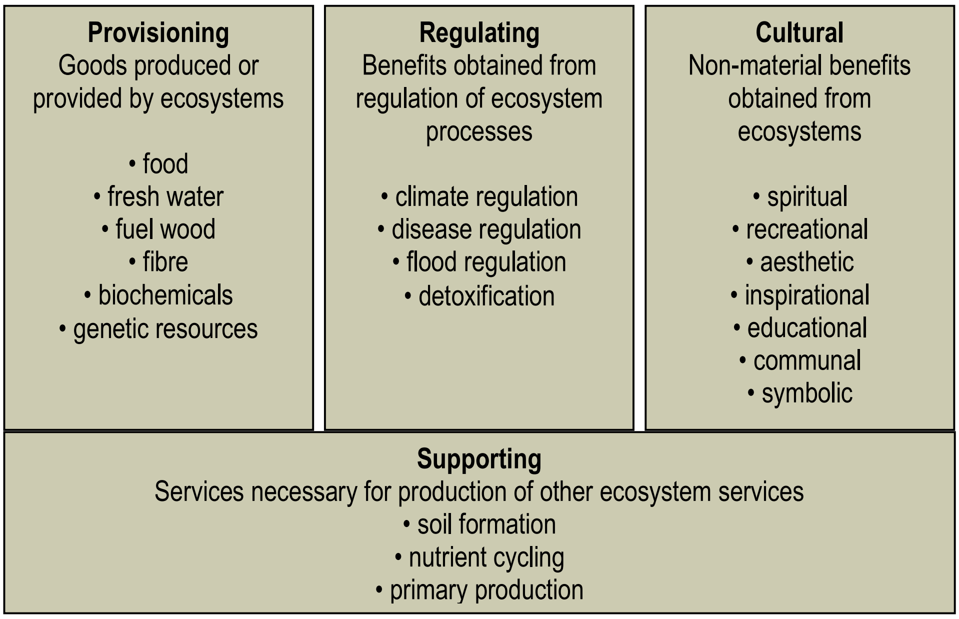

Figure 1 Framework for classifying Ecosystem Services
(Source: *Ecosystems and Human Well-Being: A Framework for Assessment*, by the Millennium Ecosystem Assessment. Copyright © 2003 World Resources Institute. Reproduced by permission of Island Press, Washington, D.C.)

The conclusions of this Assessment, however, were far from positive for the current state and future outlook of these ecosystem services – it found that 60% of the ecosystem services it assessed were being degraded or used unsustainably at global scales (MA, 2005). The Assessment reached four main findings:

- Over the past five decades, humans have changed ecosystems more rapidly and extensively than in any comparable period of time in human history, resulting in a substantial and largely irreversible loss in the diversity of life on earth;
- The changes to ecosystems have led to substantial net gains in human well-being and economic development, but these gains have been traded off against increasing degradation of many ecosystem services, and if this problem is not addressed, the benefits that future generations can obtain from ecosystems will substantially diminish;

- The degradation of ecosystem services could grow significantly worse during the first half of the 21st century, threatening the achievement of the Millennium Development Goals agreed by the world's governments (United Nations, 2000); and
- Reversing the degradation of ecosystems while meeting increasing demands for their services will require significant changes in policies, institutions, and practices (MA, 2005).

From these findings, two things stand out: the rapidity and degree of degradation to ecosystems in recent human history and the need for improved governance to halt, if not reverse, the trend towards faster, and more severe degradation in the near future. This paper starts by addressing the former issue, looking at the factors that contributed to ecosystem degradation and to the emergence of the significant risks that this degradation entails. It then moves on to look at the scientific basis for improving the governance of the risks society faces from continuing degradation of ecosystem services.

1. CONTRIBUTING FACTORS TO THE DEGRADATION OF ECOSYSTEMS

Technological advances and changing **social dynamics** are the most important factors that have contributed to ecosystem degradation and associated risks and they may be equated with the five major indirect drivers of ecosystem degradation identified by the Millennium Ecosystem Assessment, namely changes in population, economic activity (which increased nearly sevenfold between 1950 and 2000), socio-political factors, cultural factors, and technological changes. These factors do not directly degrade ecosystems, but operate more diffusely by amplifying and promoting the direct drivers of ecosystem degradation (these direct drivers are discussed below).

The impacts of social and technological changes have obviously been felt differently in different parts of the world, but generally speaking, consumption of ecosystem services is slowly being decoupled from economic growth, reflecting structural changes in economies that are becoming more service oriented. Second, global trade magnifies the effect of governance, regulations, and management practices on ecosystems and their services, enhancing good practices but increasing the damage caused by poor practices. And third, the MA found that urban demographic and economic growth has been increasing pressures on ecosystems globally, but affluent rural and suburban living often places even more pressure on ecosystems.

1.1 Social and technological change

As humans evolved, our ancestors -- like other species -- benefited from many of the basic functions of ecosystems. Several hundred thousand years ago, our ancestors used tools to open new opportunities to obtain food, shelter, and clothing, and learned to control fire, giving them unique power to influence ecosystems.

Eventually, our species, *Homo sapiens*, evolved and tools became more sophisticated as people developed a wide range of technologies to harness the resources provided by the ecosystems within which they lived, even domesticating some species that had the potential to be especially productive. The great diversity of ecosystems helped to nourish the thousands of human cultures that spread across the face of the Earth, from frigid polar regions to steaming rainforests and arid deserts.

Civilizations emerged in various parts of the world several thousand years ago, often based on irrigated agriculture that created highly productive food-generating systems largely under human control. The food surpluses supported more complex social organization, priesthoods, disciplined armies, monumental architecture, and the other trappings of civilization.

Civilization enabled people to benefit from a much broader spectrum of ecosystem services, but also gave them the power to threaten ecosystems. For example, Plato in 400 BC recognized that deforestation caused erosion and desiccated springs (Goldin, 1997). The Arabic medical treatises of the 9th century recorded sophisticated thinking concerning agricultural techniques including irrigation and crop rotation, as well as pollution control (Watson, 1983). The early civilizations of India, China, and Southeast Asia mobilized water and nitrogen-fixing algae to create irrigated rice-growing ecosystems that produced the world's richest cultures of those ancient times, though all eventually fell (McNeely and Wachtel, 1988). Civilizations that ignored the risks posed by degrading ecosystems crumbled and collapsed (Diamond, 2005; Toynbee, 1951), including all of the early civilizations.

More recently, our global civilization has married science and technology, with one offspring being energy from fossil fuels, rivers, and atoms. Applied to agriculture and manufacturing, human ingenuity and technology produced sufficient food and other products to generate global trade that supported a quadrupling of the world's human population during the 20th century, along with a 16-fold increase in the production of goods. As human population growth and wealth accelerated, however, possible limits to growth became a growing concern as the risks of over-exploiting ecosystems became increasingly likely (Ehrlich, 1968; Meadows *et al.*, 1972; Wackernagel and Rees, 1996).

1.2 Direct drivers of ecosystem degradation

The five main direct drivers each deserve more discussion, given their direct negative influences on ecosystem services. These direct drivers, impacted upon by the social and technological change discussed above, often interact to increase their impacts; climate change, for example, can lead to more invasive species and more rapid habitat changes, thereby complicating governance issues.

Habitat change

The conversion of natural ecosystems into anthropogenic ecosystems (such as farmlands, pastures, and plantations) is the most important direct driver of change in terrestrial ecosystems. This is driven indirectly by changing social dynamics – notably the drive for economic development. The MA divided the earth's land surface into 14 broad types of land cover (known as "biomes") and found that in 9 of them, between 20 and 50% of the area had been transformed, mostly to croplands or pastures. Only those biomes that are impervious to agricultural use, such as deserts, boreal forests, and tundra, have remained little affected by human action.

This significant expansion of agricultural land has been the critical factor that has enabled the human population to continue growing. While an estimated 1 billion people remain malnourished, the supply of food per capita has continued to increase steadily, a result largely of improved technology. Poor governance has prevented more equitable distribution of the benefits from food-producing ecosystem services.

Invasive species

Technological advances have quickly improved the size and speed of global communication and transportation networks. This has brought immense societal benefits. However, the resulting globalisation and growth in the volume of trade and tourism, coupled with the emphasis on free trade, provide more opportunities than ever before for invasive species to be spread accidentally or deliberately. Customs and quarantine practices, developed in an earlier time to guard against human diseases and economic pests, are inadequate safeguards against new threats to ecosystems posed by expanding global trade.

Invasive alien species are plants, animals, fungi, and micro-organisms that usually play a normal and healthy role in their native ecosystem. But when they arrive on foreign shores, where they intrude like a scruffy uninvited guest at a carefully arranged dinner party, they can cause havoc (Pejchar and Mooney, 2009). Thus the Convention on Biological Diversity, in its Article 8(h), calls for Parties to the Convention to "prevent the introduction of, control, or eradicate those alien species which threaten ecosystems, habitats or species". Such species are commonly called "invasive alien species", and include only a small fraction of the total number of non-native species that may enter a country.

The costs involved are substantial. Pimentel *et al.* (2000) claim that in the USA alone "losses in biodiversity, ecosystems services, and aesthetics from invasive species total about $137 billion per year" (Pimentel *et al.*, 2000). For example, Zebra mussels (*Dreissena polymorpha*) cost US industry about US$100 million per year, primarily by clogging pipes and reducing water flow to lakeside power plants. Zebra mussels, through their filtration and overgrowth activities, are predicted to cause the extinction of about 90 species of freshwater mussels in the Mississippi

Basin within the next 50 years. The golden apple snail (*Pomacea canaliculata*) was intentionally introduced into southeast Asia to serve as a potential food source, but instead, it had numerous negative impacts, including feeding on young rice seedlings, which cost rice farmers in the Philippines at least US$ 425 million per year.

While all parts of the world suffer from invasive species, isolated continents and islands with a long history of independent evolution are particularly vulnerable. Perhaps the most dramatic example is Australia, where an estimated 27,000 non-native species have been introduced since human settlement, of which about 10% have become established in the wild. These invasive alien species are threatening over 50 native species with extinction.

Over-exploitation

Many ecosystems are being affected by over-exploitation of certain elements. For marine systems, for example, fishing has been the most important direct driver of change in the past 50 years, and FAO has reported that over half of the commercially exploited wild marine fish stocks are over-exploited. Technological advances have played their part in this, as improved fishing equipment has made it easier both to locate fish stocks and to bring in much larger catches. Over-exploitation drove the most common North American bird, the passenger pigeon (*Ectopistes migratorius*) to extinction and the bison (*Bison bonasus*) nearly followed the same fate. Over-exploitation is nothing new; when humans first arrived in North America some 14,000 years ago, they drove some 34 genera of large mammals to extinction, including horses, camels, mastodons, giant ground sloths, and sabre-tooted tigers. Other parts of the world where humans arrived late, such as Madagascar, New Zealand, and Polynesia, also suffered massive extinctions from human over-exploitation (Martin and Klein, 1984).

Over-exploitation has also affected many forested ecosystems, through logging (both legal and illegal), hunting, and harvest of non-timber forest products. Many grasslands have been over-grazed, leading to increased soil erosion.

Pollution

One of the negative side-effects of changing social dynamics that favour industrialisation and urbanisation has been an increase in pollution of air, water, and soils, which has had a major impact on ecosystems. Air pollution has led to a significant threat to the ozone layer that protects the earth from ultra-violet radiation from the sun. When scientists recognized that the depletion of the ozone layer posed a serious threat to human health, an effective governance response was generated in the form of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer (UNEP, 2006).

But many other forms of pollution are more subtle and have not generated an appropriate governance response. Pollution in the form of nutrient loading, primarily of nitrogen and phosphorous, is primarily a result of agricultural chemicals being used to ensure high yields of crops. But this has also led to damaging eutrophication that has led to “dead zones” in many parts of the world, where the consumption of oxygen by algae prevents fish from being able to survive. For example, nitrogen flows from rivers to coastal oceans due to human activities have increased 15-fold in North Sea watersheds since the industrial and agricultural revolutions. Increases of 5.7-fold have been recorded in the Mississippi River basin, 10-fold in the Yellow River basin, 11-fold in the North-eastern United States, and 17-fold in the Republic of Korea (MA, 2005).

Climate Change

The rise in greenhouse gas emissions over the past 150 years or so is strongly correlated with changing social dynamics – industrialization and economic development leading to greater energy use and more carbon intensive economies. The climate change that is occurring due to increases in atmospheric greenhouse gas concentrations is anticipated to have numerous negative impacts on biodiversity worldwide. Ecosystems likely to be affected most directly and severely include coral reefs and polar regions, though the numbers of species facing extinction in all ecosystems are expected to increase as global temperatures continue to rise (Peters and Lovejoy, 1992; Schneider and Root, 2002). Perhaps more ominously, food prices are also likely to increase. The International Food Policy Research Institute projects that climate change will lead to an additional price increase of 32-37% for rice, 52-55% for maize, and 92-111% for wheat by 2050 (IFPRI, 2009). Average per capita food consumption in developing countries is expected to decline 15% by that time.

The Stern Review on the Economics of Climate Change (Stern, 2006) indicated some of the projected impacts of climate change on the world economy, outlined cost-effective responses to these impacts, and provided examples of implications for biodiversity. It indicated that with temperature increases and changes in rainfall patterns, crop yields in many areas would decline, thus affecting in particular many developing countries. The report also concluded that some mountain glaciers are likely to disappear, threatening water supplies in certain areas. With greater warming, areas such as the Mediterranean, the American Southwest, and Southern Africa are expected to encounter significant decreases in water availability, leading to negative impacts on biodiversity. The report also discussed how land use change can reverse emissions, for instance by curbing deforestation through appropriate policies. It pointed out that biodiversity enables ecosystems to sequester carbon, contributes to ecosystem resilience and provides the variability for adapting to changing conditions.

2. GOVERNANCE OF THE RISKS RELATED TO THE LOSS OF ECOSYSTEM SERVICES

The governance of ecosystem services is a bewildering complex of legislation and regulations at multiple levels, seldom coordinated and often contradictory as different parts of society make different claims on the benefits flowing from ecosystem services.

These governance issues can amplify or attenuate risks to human well-being. Given the prominence of climate change as a risk to societies, as judged by the level of governance responses and the funds being allocated to the issue, the remainder of this paper will emphasize the relationship between climate change and the other risks to ecosystem services. Rockström *et al.* (2009) sought to identify the ecosystem processes and associated thresholds which, if they are exceeded (contributing factor = loss of safety margins), could pose unacceptable risks from environmental change. The nine such processes they identified are presented in Figure 2.

PLANETARY BOUNDARIES

Earth-system process	Parameters	Proposed boundary	Current status	Pre-industrial value
Climate change	(i) Atmospheric carbon dioxide concentration (parts per million by volume)	350	387	280
	(ii) Change in radiative forcing (watts per metre squared)	1	1.5	0
Rate of biodiversity loss	Extinction rate (number of species per million species per year)	10	>100	0.1–1
Nitrogen cycle (part of a boundary with the phosphorus cycle)	Amount of N_2 removed from the atmosphere for human use (millions of tonnes per year)	35	121	0
Phosphorus cycle (part of a boundary with the nitrogen cycle)	Quantity of P flowing into the oceans (millions of tonnes per year)	11	8.5–9.5	~1
Stratospheric ozone depletion	Concentration of ozone (Dobson unit)	276	283	290
Ocean acidification	Global mean saturation state of aragonite in surface sea water	2.75	2.90	3.44
Global freshwater use	Consumption of freshwater by humans (km^3 per year)	4,000	2,600	415
Change in land use	Percentage of global land cover converted to cropland	15	11.7	Low
Atmospheric aerosol loading	Overall particulate concentration in the atmosphere, on a regional basis		To be determined	
Chemical pollution	For example, amount emitted to, or concentration of persistent organic pollutants, plastics, endocrine disrupters, heavy metals and nuclear waste in, the global environment, or the effects on ecosystem and functioning of Earth system thereof		To be determined	

Boundaries for processes in red have been crossed. Data sources: ref. 10 and supplementary information

Figure 2, Planetary Boundaries
Source: Rockström, Johan, et al., A safe operating space for humanity. **Nature** 461, 24 September 2009. Reprinted by permission from Nature Publishing Group, http://www.nature.com/

They concluded that three of what they called “Earth-system processes” have already transgressed their boundaries: climate change; rate of biodiversity loss; and interference with the nitrogen cycle. These problems were well rehearsed in the Millennium Ecosystem Assessment.

The conclusion from the scientific assessments from the Intergovernmental Panel on Climate Change, the Millennium Ecosystem Assessment, the Stern Report, the report of Rockström *et al.*, and numerous others indicate the seriousness of the risks posed by inadequate governance.

2.1 Risk governance at the international level

Governments have agreed numerous international conventions to address many of the governance risks of the degradation of ecosystem services. This section briefly discusses some of the major international conventions and their limitations as governance responses to the risks ecosystem degradation, especially those due to climate change.

The Framework Convention to Combat Climate Change (FCCC)

The objective of the Convention, stated in Article 2, is “to achieve…stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner”.

Despite its objective and principles designed to reduce human-induced causes of climate change, the convention does not consider the possible effects of climate change on existing environmental problems, nor does it identify specific ways to adapt to these problems. Rather, its primary focus has been on mitigating carbon emissions, especially through its Kyoto Protocol. Thus far, these measures have been insufficient.

The Convention on Biological Diversity (CBD)

The objectives of the Convention on Biological Diversity are to promote the conservation of biological diversity, the sustainable use of biological resources, and the fair and equitable sharing of benefits arising from the utilization of genetic resources (CBD, 1993).

In 2002, the CBD adopted a Strategic Plan including, as its mission, the target of achieving by 2010 a significant reduction of the current rate of biodiversity loss at the global, regional and national levels as a contribution to poverty alleviation and to the benefit of all life on Earth. This target was incorporated into the Millennium Development Goals (MDGs), but it is widely agreed that this target has not been met (Gilbert, 2009).

The United Nations Convention to Combat Desertification (UNCCD)

Desertification results from the reduction of productivity and nutrients, reduction of both above- and below-ground biomass for carbon sequestration, accelerated soil deterioration, and decreased plant and soil organic species diversity (Dregne, 1986) – it is both a problem caused by climate change and a contributing cause of climate change. The changes in ecological conditions expected as a result of climate change are likely to worsen desertification problems in many parts of the world.

The UNCCD seeks to combat desertification through international cooperation and calls on Parties to prepare national action plans to do so. However, to date relatively few national action plans have been prepared, and none have yet given adequate attention to the multiple relationships between climate change, ecosystem services, and desertification. Incorporating climate change and ecosystem management considerations into desertification action plans will give the plans a higher political profile, new opportunities for funding, and increased effectiveness in adapting to changing conditions. Improved governance can reduce the risks of desertification through enhancing the flow of ecosystem services.

The United Nations Convention on the Law of the Sea (LOS Convention)

The LOS Convention has yet to live up to its potential, but it does establish a comprehensive legal framework to promote peaceful uses of oceans and seas, equitable and efficient utilization of their resources, and conservation of their living resources (SCLOS, 1982). The many services provided by marine ecosystems, such as tourism and carbon storage by coral reefs, fisheries production by sea grass beds, and storm protection by mangroves, are worth billions of dollars per year.

The CBD in its Article 22.2 states, "Contracting Parties shall implement this Convention with respect to the marine environment consistently with the rights and obligations of States under the Law of the Sea" (Convention on Biological Diversity, 1993). Therefore, the Law of the Sea prevails in instances where the CBD's implementation conflicts with it, showing how two conventions can potentially collaborate for a greater cause (Glowka *et al*., 1994), including addressing the degradation of ecosystem services resulting from climate change. Effective governance of the risks to marine ecosystem services will therefore require unprecedented cooperation between conventions that appear to have rather different mandates, while in reality their interests are closely intertwined.

The Convention on Wetlands of International Importance

Also known as the Ramsar Convention, the Convention on Wetlands of International Importance promotes conservation and wise use of wetlands (Ramsar, 2008). Wetlands provide many ecosystem services, and in financial terms may be the most valuable ecosystems; for example they sequester about 37 percent of the terrestrial carbon pool (Bolin and Sukumar, 2000) and coastal wetlands in the US provide protection against hurricanes estimated to be worth US$ 23.2 billion per year (Costanza *et al*., 2008). While having mitigating effects on climate change, wetlands also emit methane (a potent greenhouse gas) into the atmosphere, with rice fields alone producing up to one-third of the total annual anthropogenic methane emissions (Neue, 1993).

The Parties to the Ramsar Convention have already recognized the importance of climate change to wetlands and, in Korea in October of 2008, they agreed a Resolution on climate change and wetlands (Climate-L.org, 2008) that aims to draw attention to the importance of wetlands on climate change and ecosystem services. It remains to be seen if this governance initiative leads to improved delivery of ecosystem services.

A governance gap: The missing convention on forests

Despite many years of efforts, the governments of the world have been unable to make much progress on developing an international convention on forests. Under the Kyoto Protocol, the Clean Development Mechanism provides funding for afforestation and reforestation, though only one such project concerning reforestation has been funded to date (UNFCCC, 2008). No funding is provided for maintaining old-growth forests, which store substantially larger quantities of carbon compared to younger forests and new plantations (Ciesla, 1995).

International interest has therefore been drawn towards a governance mechanism first proposed by a group of tropical forest countries and now widely supported: "Reduce Emissions from Deforestation and Forest Degradation" (REDD). The main idea of REDD is to provide funds from developed nations to developing nations in order to reduce emissions from deforestation and forest degradation through the implementation of appropriate policies and other measures. Most tropical forests are found within developing nations and are not properly maintained or conserved, even though, on average, tropical forests store 50 percent more carbon per unit area than their counterparts outside the tropics (Sanz, 2007; Moutinho and Schwartzman, 2005). When tropical forests are converted to farmlands or plantations, the naturally stored carbon within the living plants is immediately released into the atmosphere, thereby contributing to the greenhouse gas effect and fueling climate change (Moutinho and Schwartzman, 2005).

This is obviously a vital issue, so the UNFCCC has recently decided to adopt a framework for REDD, yet this alone will not be sufficient to make the necessary changes. An international convention on forests could take on the task of developing mechanisms for REDD as well as dealing with the combined problems concerning international forests that are partially covered by the various conventions and organizations mentioned above. Its purpose could be to address all of the issues that forests are now facing and thereby significantly contribute to enabling forests to provide their multiple ecosystem services, including the mitigation and adaptation of climate change, watershed protection services, protecting against the impacts of extreme climatic events, and cultural services to forest-dwelling peoples.

2.2 Risk governance at the national level

While the governance complexity at the international level seems daunting, governance at the national level is even more complex, as mandates of the various ministries are both overlapping and contradictory. Further, national legislative bodies meet regularly, seemingly with the major objective of enacting yet additional legislation that does not always fully consider pre-existing legislation, forcing regulators to negotiate among complex regulatory systems that may often be challenged in courts. Such legislative complexity may be one of the major risk factors in avoiding the continuing degradation of ecosystem services.

Nevertheless, policies to maintain the supply of ecosystem services have been adopted. A search of the ECOLEX database of national environmental legislation (a joint effort by IUCN, FAO and UNEP) yields no less than 602 mentions of “ecosystem services” within national laws. Provisioning services are the most common focus at the national level, perhaps because they are the most obvious, easiest to measure, and bring in the most tax revenue.

2.3 Economic factors in governing risks of degradations of ecosystem services

A major policy response to the recognition of the neglected values of ecosystem services has been the development of markets for them (TEEB, 2008). While markets already exist for many provisioning services, such as food or firewood, new markets are being developed for ecosystem services that previously were not considered in economic terms. For example, Costa Rica has long been a global leader in the ecotourism industry – in effect selling recreational ecosystem services (Rojas and Aylward, 2003). During the 1990s it pioneered systems by which downstream communities and companies paid upland dwellers for the maintenance and restoration of forests for water provisioning. More recently, Costa Rica has been active, alongside other tropical countries, in developing REDD as one approach to capture the economic benefits of carbon sequestration and storage in biomass, for climate regulation under the UNFCCC.

Given the emerging importance of ecosystem services in policies and markets, states, local governments, the private sector, and non-governmental organizations (NGOs) are seeking approaches to enhance the delivery of ecosystem services as a means of reducing the risk of their degradation. The key to effective planning is a clear statement of objectives. For example, the objective of a given agency might be to reduce by half the proportion of people with no access to clean water (part of the Millennium Development Goal 7), thereby reducing health risks. Data can then be collected, and models constructed, to inform options that could help to achieve this goal, such as installation of infrastructure (for purification or desalination), improvements in sanitation, and maintenance of forest habitat within watersheds that can perform the ecosystem service of providing clean water.

Different combinations and spatial configurations of these options will have different costs and benefits. Costs will include straightforward construction and maintenance, monitoring and evaluation, as well as opportunity costs (for example, maintaining forest habitats to store carbon and deliver water may require foregoing the income that could be earned from some timber harvests). Benefits will be both direct, in contributing towards the stated goal, and indirect, where ecosystem services can be “bundled” or “unbundled” to attract others to invest in the plan (for example, maintaining forest habitats will also deliver REDD (Grainger *et al.,* 2009)). With these data in hand, spatial cost-benefit analysis and/or reverse auction systems can then be used to derive a plan that will deliver the goal at minimum cost (or deliver as close to the goal as possible for a given budget).

Considerable effort is now being devoted to addressing economic factors of ecosystem services, especially through The Economics of Ecosystems and Biodiversity (TEEB), a major international study that is seeking better understanding of these economic dimensions (TEEB, 2008).

The concept of ecosystem services seeks to correct the present imbalances in market forces, which give greater weight to traded goods and services but tend to neglect ecosystem values and other non-market benefits that may deliver greater benefits to society and reduce risks from exposure to unexpected events. Through greater awareness of the full value of ecosystem services in reducing risks, policy-makers may be encouraged to take more enlightened action and markets could be reformed to better reflect the complex relationship among risk, human well-being and ecosystem health, and consequently support the conservation of nature. This often involves estimating the monetary value of well-defined ecosystem services, in order to make the economic case for change, followed by the introduction of mechanisms such as payments for ecosystem services, which can transform potential value into real cash-flow and behaviour change.

An important step is to develop ways to value ecosystem services, including for their role in reducing risk (or at least enhancing the capacity to adapt to risk). The TEEB study is poised to do just that. An interim report of the study (EC and BMU, 2008) states that human well-being is totally dependent on ecosystem services.

However, because many of these services are predominantly public goods, with no clear property rights, markets or prices, they are neither recognized nor adequately integrated into economic policy and decisions. As one result, insufficient appreciation of the full costs and benefits of maintaining healthy ecosystems leads to continuing biodiversity loss. TEEB, through the development and dissemination of economic tools to support the valuation of ecosystem services, hopes to rectify this situation, and more precisely identify the risks of allowing the continued degradation of ecosystem services.

At the same time, many people reject a perceived purely utilitarian view of nature, instead emphasizing the ethical or intrinsic values of biodiversity. While such values are notoriously difficult to measure, well-established approaches are available to reflect them in policy and governance (e.g. through legislation relating to the protection of endangered species). The intrinsic value of nature may be considered in the same light as other moral or cultural values, for example of great works of art, the survival of indigenous peoples, or human rights.

The roots of appreciation of the intrinsic value of biodiversity run very deep in many cultural and religious worldviews. All of the world’s religions have embraced notions of stewardship or caring for the natural world (Gardner, 2002), as have leading political philosophers, although such values are not equally distributed among components of the natural world (e.g. charismatic animal species are afforded considerably more intrinsic value than plants or micro-organisms in most cultures). Among contemporary thinkers, E.O. Wilson (1984) has most powerfully communicated intrinsic value, including detailed exploration of its evolutionary basis.

3. FILLING THE GOVERNANCE GAP BETWEEN SCIENCE AND POLICY

Sound science is an essential foundation to good policy making. But evidence has indicated that science is not nearly enough. For example, one of the most effective science bodies for influencing policy has been the Intergovernmental Panel on Climate Change, established by governments specifically to advise them on climate issues. Yet even the best IPCC advice is out of date by the time it arrives, and in any case, translating the science into policy leaves much to be desired. It is widely recognized that the recommended reductions in carbon emissions under the Kyoto Protocol would have little or no impact on the climate; the emissions reductions where based instead on political calculations. Similarly, the scientific advice offered on fisheries management goes largely ignored, leading to the significant overfishing of major fisheries stocks, such as tuna, that are being experienced today.

In the field of ecosystem services, Rockström *et al.* (2009) have recognized that the planetary boundaries that they have suggested are based on informed guesses, and they called for additional research to quantify the safe limits outside of which the earth system cannot continue to function in the way that led to our current level of civilization. They call for three specific kinds of research:

- Assessing the scale of human action in relation to the capacity of the earth to sustain it. The TEEB study is likely to provide considerable insights here, though it undoubtedly will also identify additional areas requiring further research;
- Improving the understanding of the biophysical constraints for the growth of the economy, based on understanding essential earth processes and the science of sustainability; and
- Research into resilience and its links to complex dynamics and self-regulation of living systems, in an effort to emphasize thresholds and shifts between ecosystem states.

They well recognize that many of the boundaries that they have identified may be inter-related, and that the relationships between these boundaries remain poorly understood. And even if the science linking climate change with ecosystem services were to be highly reliable, this is no guarantee that policy-makers will automatically understand how best to convert this science into policy. The current controversy over climate change is a dramatic example of how the political pressures, including by the private sector with interests in the status quo, can influence international policy at the international level.

On a more positive note, some municipalities have already taken significant steps toward energy independence that will reduce greenhouse gas emissions essentially to zero. And a few countries, such as Sweden, have set carbon neutrality as a national goal. But most of the discussions about climate change are focused primarily on emissions reduction, with little attention being given to the impacts of climate change on ecosystems,, nor the more important point that healthy ecosystem services can make substantial contributions to adapting to the climate changes that seem inevitable.

More broadly, governments and the scientific community are now working together to seek new forms of collaboration, such as the Intergovernmental Panel on Biodiversity and Ecosystem Services (IPBES) (Mooney and Mace, 2009).

CONCLUSIONS

The main risks to ecosystem services are increasing due to a complex system of emerging challenges, many of which derive from, or are influenced by, technological advances or changing social dynamics.

Despite the many international conventions that contribute to maintaining ecosystem services, the risks posed by the loss of ecosystem services continue to grow. While the UNFCCC remains the most important instrument for addressing the key issues of climate change, these issues will not be fully addressed unless the many other relevant international agreements are also applied to climate change. Biodiversity, for example, is critical for both sequestering carbon and adapting to climate change, while the conventions on wetlands and desertification deal with habitats whose effective management will contribute towards adapting to climate change in the coming decades (Houghton *et al.*, 2001). The Convention on the Law of the Sea deals specifically with marine ecosystems, and recent research is indicating how important marine environments are in addressing issues involving climate change (Bice, 2006; Laffoley and Grimsditch, 2009

Numerous other conventions and national laws and regulations can also be mobilized in support of improved governance for ecosystem services, though governments tend to prefer to compartmentalize their deliberations rather than seek ways to enable them to be mutually reinforcing. A new convention on conserving ecosystem services, or a protocol under either the CBD or the UNFCCC, might offer an opportunity to provide a coordinating mechanism that would help to demonstrate how collaboration can potentially increase effectiveness in addressing risks of continued degradation of ecosystems.

Improved governance of the risks of degradation of ecosystem services at the international level depends on more effective coordination of international environmental laws that address ecosystem services as part of a complex of issues as well as providing strong enforcement and implementation measures.

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