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SYNERGIES AMONG THE U.N. RIO CONVENTIONS:

ENVIRONMENTAL PREDICTION FOR BIODIVERSITY, DESERTIFICATION AND CLIMATE CHANGE

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ABSTRACT: Climate change has been described as one of the major challenges of the 21st century to conserving biodiversity, combating desertification and ensuring the sustainable use of natural resources, particularly since the rate of global climate change projected for this century is more rapid than any change that has occurred in the last 10,000 years. Various international Conventions have been developed to address worldwide concerns over the linked issues of biodiversity, climate change and desertification. Three Conventions, known as the Rio Conventions, along with the Forest Principles, were drafted in 1992 in recognition that these important environmental issues were intrinsically linked and that each affects and is affected by the other two. The Rio Conventions include the UN Convention on Biological Diversity (CBD) to reduce losses of species by 2010, the UN Framework Convention on Climate Change (UNFCCC) to stabilize concentrations of greenhouse gases to prevent dangerous interference and the UN Convention to Combat Desertification (UNCCD) to prepare action plans aimed at reducing desertification risks in arid regions. Enhanced cooperation between these and other international conventions, organizations and bodies will better ensure the environmental integrity of the conventions, promote synergies under the common objective of sustainable development, avoid duplication of efforts, strengthen joint implementation efforts and enable more efficient use of available resources. Responses to deal with the threats from the climate, biodiversity and desertification issues will require improved scientific understanding of their linkages along with better "environmental forecasting" capability to predict potential biodiversity and land use changes that may result. Environmental prediction tools that can forecast the effects or directions of climate-induced changes on ecosystems and their components are critical for the decisions that need to be taken to cope with the impacts of the changing climate and to meet all obligations under international Conventions. These tools will need to build from expert judgment, traditional ecological knowledge, analysis, new types of observations, and assessments, in addition to numerical simulation and prediction models.

Keywords: synergies, climate change, biodiversity, desertification, international agreements, environmental prediction

1. Introduction

Scientific studies now make it clear that the climate is changing at regional and global levels and that many ecosystems are already being impacted by these changes (CBD, 2006; World Wildlife Federation, 2003; Root *et al.*, 2003). As noted in the Millennium Ecosystem Assessment (2005a), climate change is one of the most important drivers of biodiversity loss and will continue to adversely affect biodiversity and its role as a source of goods and services.

Climate change has been described as one of the major challenges of the 21st century to conserving biodiversity, combating desertification and ensuring the sustainable use of natural resources, particularly since the rate of global climate change projected for this century is more rapid than any change that has occurred in the last 10,000 years (CBD, 2006; Orlando and Smeardon, 1999). Its threats to ecosystems and to desertification spread are further compounded by the fact that humans have altered the structure of many of the world's ecosystems through habitat fragmentation, land degradation, pollution, and other disturbances, making ecosystems less resilient to further changes. Responses to deal with these threats will require improved scientific understanding of the linkages between the climate, biodiversity and desertification issues, along with a better "environmental forecasting" capability to predict potential biodiversity and land use changes that may result.

Various international Conventions have been developed to address worldwide concerns over these linked issues. At the 1992 United Nations Conference on Environment and Development (UNCED), the so-called Earth Summit, in Rio de Janiero, Brazil, a series of conventions and measures were discussed, all aimed at linking economic development with the conservation of natural resources on the international, national and local levels. Three of these United Nations (UN) Conventions – the UN Convention on Biological Diversity (CBD), the UN Framework Convention on Climate Change (UNFCCC) and its Kyoto Accord and the UN Convention to Combat Desertification (UNCCD) – along with the Principles for a Global Consensus on the Management, Conservation and Sustainable Development of all Types of Forests (Forest Principles) [Note: [1] The Forest Principles recognize the central role of forests (all types of forests) to the conservation of biological diversity, sequestration of carbon and avoidance of desertification.] were a direct output of the provisions made for sustainable development in Rio de Janiero in 1992. Ten years later, at the 2002 World Summit on Sustainable Development in Johannesburg, the world's leaders reaffirmed the need to tackle these issues and endorsed the targets set by the three Conventions.

These U.N. Conventions and the Forest Principles were agreed to by 156 nations and the European Union for a common reason. They were drafted in recognition that the specific and important environmental issues of climate change, desertification and biodiversity loss are intrinsically linked and that each affects and is affected by the other two. The Rio Conventions address the sustainable management and use of natural resources for the benefit of future generations and call for sustainable development, sustainable use of natural resources, poverty eradication, capacity building at all levels and implementation using participatory approaches, international cooperation and integration of cross-cutting issues (UNDES, 1992).

The science assessments behind each Convention suggested that the manner in which humans were utilizing existing resources was both untenable and unsustainable. The various science assessments highlighted the fact that the impacts of climate change would vary from region to region and country to country and would depend on the country's capacity to respond and adapt to the changes (Alusa, 1997). Scientific evidence also indicated that actions to address loss of biodiversity would prove beneficial in combating desertification and its causes and often provide additional adaptation and mitigation capacity to deal with climate change. While biodiversity assets are at risk everywhere as a result of the changing climate system, desertification does not occur in all countries but only in those that have drylands (UNCCD, 1999).

While the geographical extent of drylands is large (41 percent of the Earth's land areas), a larger portion of global land is not dryland. Nonetheless, the effects of desertification can cross boundaries and affect countries that do not have arid regions (UNCCD, 1999). Of all ecosystems, drylands represent some of those most sensitive to climate change. Since drylands are home to more than 2 billion people or a third of the human population as of the year 2000, and some 10 to 20 percent of drylands are estimated to be already degraded, climate change will result in significant implications. It is expected that the changing climate will lead to significant increases in desertified areas, with wide-ranging implications for human well-being, poverty reduction and development (Millennium Ecosystem Assessment, 2005b). In regions where the environment becomes persistently drier and the soils further degraded through erosion and compaction, some of these desertified areas are likely to experience irreversible decline.

2. Convention Synergies

The Conventions share a common concern for many environmental and sustainable development issues since they contain numerous overlaps and opportunities for complementary actions. This is particularly true in requirements for research, reporting, training, public education and awareness and the need for capacity building. The significance of the inter-linkages and the trade-offs needed for each Convention to achieve its goals point to a strong potential for synergies in their implementation. Coordination between Conventions is desirable to achieve cost-effective "win-win" solutions on the part of governments and international institutions, and to assist in avoiding negative cross-sectoral impacts. For example, much could be gained by emphasizing implementation activities that are mutually reinforcing. This is particularly true with respect to activities that build national capacity. Other advantages can be realized in the elimination of redundancy and overlaps in reporting and related obligations, thereby capturing some efficiencies (UNEP, 2004). Overall, enhanced cooperation between Conventions will help to ensure the environmental integrity of the conventions, promote synergies under the common objective of sustainable development, avoid duplication of efforts, strengthen joint efforts and enable more efficient use of available resources (CBD, 2006).

There are many examples at regional, national and international scales where integrated joint work on the synergies (and dis-synergies) between the issues and their Conventions will be more effective than dealing with each separately. For example, since climate change poses one of the most significant threats to biodiversity and desertification, activities that promote adaptation to climate change can also contribute to the conservation and sustainable use of biodiversity and sustainable land and water management. Water conservation measures, for instance, that consider ecological needs for flow and storage often involve habitat enhancement along with water and land use management practices that balance long-term needs against available water supplies. In other cases, the development of adaptation activities that do not incorporate biodiversity consideration can pose an added stress on local ecosystems and biodiversity loss. As illustration, the adaptation action of building higher protective sea walls to protect coastal communities against sea level rise and storm surges can, without incorporating ecosystem considerations, result in the interruption of the life cycle and sustainability of species that spend part of their life on land and part in water.

There are two major international targets among the Conventions that make efforts to work towards synergies particularly relevant. The first is the challenging target of achieving, by 2010, a significant reduction of the current rate of biodiversity loss at the global, regional and national level, set by the Plan of the Convention on Biological Diversity and subsequently endorsed by the World Summit on Sustainable Development (UNEP, 2004). The other target has been developed under the Millennium Development Goal to achieve environmental sustainability through a target to 'Integrate the principles of sustainable development into country policies and programmers and to reverse the loss of environmental resources' (UNEP, 2004).

Although each of the three Rio Conventions has established objectives and targets, the Conventions are all at varying stages of, and requirements for, implementation. The descriptions that follow outline the objectives, targets and stages of implementation for each of the three Rio Conventions.

2.1 UN Framework Convention on Climate Change (UNFCCC)

The main objective of the UN Framework Convention on Climate Change (UNFCCC) is to stabilise greenhouse gas concentrations in the atmosphere at a level that will avoid dangerous human interference with the climate system (UNFCCC, 2005). This stabilization should occur within a time frame that will allow ecosystems to adapt naturally to climate change, ensure that food production is not threatened and enable economic development to proceed in a sustainable manner. In reality, current levels of greenhouse gas emissions will continue to increase, with the result that the climate system is likely to change at rates beyond those that ecosystems and many species can adapt to naturally (UNEP, 1994). While the UNFCCC does not specify the GHG stabilization levels, its follow-up Kyoto Protocol has initial targets requiring that developed countries reduce GHG emissions by 5.2 percent below 1990 levels over the period 2008-2012 (UNFCCC, 2005). While the GHG reductions set by the UNFCCC's Kyoto Accord will not stop climate change and its impacts, the targets are important to buy the necessary time required for human and natural systems to adapt to future changes. Because the climate of the future will eventually respond to all of the GHGs collected in the atmosphere over time, even efforts to cut GHG emissions to zero will not stop most changes. Hence, ecosystems and communities will need to adapt to climate change even if all anthropogenic emissions are reduced to near zero (UNFCCC, 2005).

Climate change is likely to have significant impacts on most or all ecosystems since the distribution patterns of many species and communities are determined to a large part by climate. However, ecosystem and biodiversity responses to changes in regional climate are rarely simple. At the simplest level, changing patterns of climate will change the natural distribution limits for species or communities. In some cases and in the absence of barriers, it may be possible for species or communities to migrate in response to changing conditions. Rates of climate change will also be critical, and these will vary at regional and even local levels. The maximum rates of spread for some sedentary species, including large tree-species, may be slower than the predicted rates of change in climatic conditions (UNEP, 2004) The most vulnerable ecosystems to the changing climate will include those habitats where the first or initial impacts are likely to occur and those where the most serious adverse effects may arise or where the least adaptive capacity exists. These include Arctic, mountain and island ecosystems. Tools and guidance in the form of scientific predictions of ecological states are needed to highlight priority ecosystems for response and to guide climate change response options.

2.2 UN Convention on Biological Diversity (CBD)

The UN Convention on Biological Diversity (CBD) sets out commitments for maintaining the world’s ecological systems, goods and services as it goes about the business of economic development. The term “biological diversity” is commonly used to describe the number and variety of living organisms on the planet (OECD, 2002). It is defined in terms of genes, species, and ecosystems, which are the outcome of over 3,000 million years of evolution. Biodiversity also includes genetic differences within each species – e.g. differences between varieties of crops and breeds of livestock (CBD, 2003). The CBD has established 3 objectives: 1) the conservation of biological diversity; 2) the sustainable use of its components; and 3) the fair and equitable sharing of the benefits from the use of genetic resources. The overall target expressed by the CBD is to reduce the rate of loss of biological diversity by the year 2010 (UNEP, 1992).

The CBD is the first global, comprehensive agreement to address all aspects of biological diversity: genetic resources, species, and ecosystems (CBD, 2003) It recognises that the conservation of biological diversity is “a common concern of humankind”, that the Earth’s biological resources are vital to humanity's economic and social development and that biological diversity is a global asset of tremendous value to present and future generations. At the same time, species extinction caused by human activities continues at an alarming rate, with the result that the threat to species and ecosystems has never been as great as it is currently (CBD, 2003). While species extinction is a natural part of the evolutionary process, it is the rate at which losses are occurring that is supporting the conclusion that species and ecosystems are more threatened today than ever before in recorded history. The most recent estimates predict that, at current rates of deforestation, for example, some two to eight per cent of the Earth's species will disappear over the next 25 years (OECD, 2002). While extinctions are an environmental tragedy, they also have profound implications for economic and social development. At least 40 percent of the world's economy and 80 percent of the needs of the poor are derived from biological resources (OECD, 2002). In addition, the richer the diversity of life, the greater the opportunity for medical discoveries, economic development, and adaptive responses to such emerging challenges such as climate change.

In theory, and in practice as well, protecting biodiversity is in the self-interest of humans. Biological resources are the pillars upon which civilizations are built (Millennium Ecosystem Assessment, 2005c; OECD, 2002). Nature's products and services support such diverse industries as agriculture, cosmetics, pharmaceuticals, pulp and paper, horticulture, construction and waste treatment. The loss of biodiversity threatens essential ecosystem goods and services while also interfering with the earth's hydrological, weather and climate systems. The various "goods and services" provided by ecosystems include:

- provision of food, fuel and fibre;
- provision of shelter and building materials;
- purification of air and water;
- detoxification and decomposition of wastes;
- stabilization and moderation of the Earth's climate;
- moderation of floods, droughts, temperature extremes and the forces of wind;
- generation and renewal of soil fertility, including nutrient cycling;
- pollination of plants, including many crops;
- control of pests and diseases;
- maintenance of genetic resources as key inputs to crop varieties and livestock breeds, medicines, and other products;

- cultural and aesthetic benefits; and
- ability to adapt to change.
- (CBD, 2000; Millennium Ecosystem Assessment, 2005c).

The loss of biodiversity often destabilizes ecosystems and reduces their productivity and shrinks the goods and services available to reduce risks from natural hazards such as floods and droughts (CBD, 2000). Where biodiversity and ecological services have already been depleted (e.g. deforestation), human communities end up spending significant funds to counter storm damages.

2.3 UN Convention to Combat Desertification (UNCCD)

The UN Convention to Combat Desertification (UNCCD) promotes a fresh approach to managing dryland ecosystems and arid regions and recognizes that desertification is caused by climate variability and human land management activities. Desertification is defined by the UNCCD as "land degradation in arid, semiarid and dry sub humid areas resulting from various factors, including climatic variations and human activities" (Millennium Ecosystem Assessment, 2005b). Desertification involves the loss of biological and economic productivity, as well as complexity in croplands, pastures, and woodlands. The relationship between desertification and climate resembles the proverbial "chicken and egg" issue, where the array of impacts of climate on land and the implications of degraded land surface for the climate system are many.

The UNCCD recognizes that combating desertification is necessary in order to improve the lot of developing countries, particularly the least developed. As a result, the objective of the UNCCD is to combat desertification and mitigate the effects of drought in countries experiencing serious drought and/or desertification. Achieving this will involve long-term integrated strategies that focus simultaneously on improved productivity of land and the rehabilitation, conservation and sustainable management of land and water resources. The target of the Convention is the development of action programmes to manage dryland ecosystems and arid regions (UNEP, 1996).
The UNCCD is implemented through action programmes. At the national level, these programmes address the underlying causes of desertification and drought and identify measures to prevent and reverse it. Action programmes have been detailed for Africa, Asia, Latin America and the Caribbean, and the

Northern Mediterranean (UNEP, 1996). The Desertification Convention also recognizes that the implementation of the UNFCCC, the CBD and related environmental conventions as being significant to combating desertification.

Biodiversity, desertification and climate are closely related. Dryland degradation or desertification has an influence on local climates, on the global carbon cycle, and on the albedo, or reflectivity of the earth's surface, while the regional climate is a driver of desertification. Desertification is linked to biodiversity through its impact on vegetation. Since vegetation cover protects the topsoil from water erosion and from wind erosion, the loss of vegetation and its variety or biodiversity brings about desertification while the desertification process itself further prevents regeneration of the vegetation (UNEP, 1991). Because the fertility of dryland soils is relatively low and concentrated in thin topsoils, the result of topsoil erosion is an exposed underlying soil that is devoid of organic matter (contributing to water-holding capacity of the soil), nutrients (essential for plant growth) and seeds (for rehabilitating the vegetation). Once erosion starts, it is difficult to restore the natural vegetation because the topsoil has been lost, even in cases where the causes of erosion have been removed. This irreversibility represents the chronic nature of desertification. Once underway, the reduction of the vegetation cover further exacerbates desertification through: (a) increases in albedo, which can reduce local precipitation; (b) changes in surface roughness, which increase wind speeds and turbulence involved in evapotranspiration; and (c) increased warming due to reduced evapotranspiration (UNCCD, 1999).

Ecosystems impacted by desertification are those in which biodiversity is damaged to the extent that it can no longer sustain human livelihoods. In many cases, the transformation of dryland from rangeland use to cropland use often also leads to irreversible irrigation-induced salinization, damaging dryland biodiversity and the ecosystem services that come with it to the extent that it may be difficult to restore (UNCCD, 1999).

It is projected that an increase in global temperature of one to two Celsius degrees by 2030 to 2050 will result in significant climate change impacts in regions affected by desertification (Millennium Ecosystem Assessment, 2005b; Watson *et al.*, 1996). This warming is expected to exacerbate regional desertification by reducing below-ground and above-ground vegetation, the same vegetation that is so instrumental as a carbon sink and reservoir.

Desertification and climate change are linked through processes where live and dead plant material, above and especially below-ground, sequesters carbon ("sink") and functions as a stored carbon pool ("reservoir"). When desertification results in loss of vegetation, deforestation, loss of topsoil and the resulting loss of soil organic carbon, the contributions to climate change processes are exacerbated (UNCCD, 1999). Consequently, reduction in global carbon reservoirs and sinks is both a cause and an effect of regional and local desertification. Forests also are instrumental in preventing desertification damages, both directly through their effect on soil and water and indirectly through their role in mitigating climate change and supporting biodiversity.

Measures to combat desertification contribute to the objectives of the CBD, UNFCCC, Ramsar Convention for wetlands, and the Forest Principles and also provide tangible benefits to local populations in the form of agricultural productivity and poverty reduction. The UNCCD (1999) recommends that proposed strategies for combating desertification should not attempt to make drylands function as non-dryland ecosystems but should try to harness dryland attributes. Examples include measures that can turn the disadvantages of drylands, including intense solar radiation, high temperatures, low-quality water, and desolation and wilderness into the advantages of solar energy, winter cash-crops, aquaculture and ecotourism, respectively (UNCCD, 1999). The strategies ensure that drylands goods and services can be realized at relatively lower economic and environmental costs than they can in many non-dryland areas. At the same time, it is generally cheaper to increase the food production of already high-productivity ecosystems than it is to increase the production of ecosystems with inherent low productivity such as drylands. The income from alternate uses enables the inhabitants of the arid drylands to import food from ecosystems where the production of food is more profitable (UNCCD, 1999).

3. Taking Action on the Synergies: Environmental Prediction

One of the obligations under the CBD is to identify and address threats to biodiversity, such as climate change. A linked and ultimate objective of the UNFCCC is to stabilize greenhouse gas concentrations within a timeframe that is sufficient to allow ecosystems to adapt to climate change (UNFCCC, 2005). Meanwhile, the UNFCCC also calls for the conservation and enhancement of terrestrial, coastal and marine ecosystems as sinks for greenhouse gases, which also helps to promote the objectives of the CBD (UNCCD, 1999).

Many of the actions that will need to be taken to manage or adapt to climate change (and mitigate GHGs) and desertification will impact biodiversity. Under the United Nations Framework Convention on Climate Change and the Kyoto Protocol, countries are required to develop National Adaptation Plans and these plans need to include strategies for natural systems. Some of the adaptation actions outlined in National Adaptation Plans will synergistically assist efforts to conserve biodiversity while other actions will prove harmful to biodiversity conservation goals (CBD, 2006). In reality, very little work has been done thus far to ensure that crucial natural resources are included in national adaptation strategies.

The task of incorporating biodiversity and desertification concerns into national adaptation plans so that synergies can be realized between the goals of the desertification and biodiversity conventions will require improved understanding of their regional linkages, along with predictions or projections of the outcomes of climate change adaptation and mitigation actions. At the same time, adaptation strategies will be needed for ecosystems and biodiversity to deal with the projected magnitude and rates of climate change. In many cases, the natural coping or adaptation processes for ecosystems will be insufficient and additional or planned adaptation activities will be urgently needed to slow the additional climate-induced rates of biodiversity loss, particularly in light of other stressors such as current levels of habitat conversion, fragmentation, and degradation present within most ecosystems. Planned management of ecosystems and natural resources will form an important aspect of the needed adaptive response to climate change.

Central to any adaptation responses are requirements for a better scientific understanding of the climatic processes that regulate ecosystems, along with the capability to predict ecosystem and biodiversity changes. It is only though improved prediction or forecasting capabilities that the potential consequences of various management strategies can be evaluated for their sustainability. Without this "environmental prediction" information, actions may be ineffective or adaptation actions taken that could hinder progress towards the goals of the other conventions. When describing the importance of environmental prediction, Arden Bement, the U.S. National Science Foundation Director, has stated that "forecasting environmental changes ranks as one of the grand challenges facing scientists, engineers, policymakers, and concerned citizens in our time. Fundamental research on predicting the state of the environment has great promise to contribute in myriad ways to our nation and our world" (National Council for Science and the Environment, 2005).

Environmental prediction products need to extend the prediction envelope well beyond the state of the physical atmosphere-ocean system to include predictions of environmental conditions such as risks for eutrophication, potential for algal blooms, daily beach water quality risks, offshore wind energy potential and specific wind turbine hazards, climatic design information for the safe and economical engineering of structures along coastlines and fisheries management predictions (e.g. ENSO related fisheries forecasts).

3.1 Ecological Predictions to Improve Response Decisions

Environmental predictions in the form of "ecological forecasts" predict the effects of biological, chemical, physical, and human-induced changes on ecosystems and their components (Committee on Environment and Natural Resources, 2003). These ecological forecasts, both qualitative and quantitative, offer scientifically sound state-of-the-art estimations of likely outcomes. Without this information, society cannot logically assess the costs and benefits of policy options to manage the impacts of climate variability or develop defensible adaptation strategies to deal with expected climate change.

Ecological forecasting models and guidance need to span spatial scales ranging from the site up to the global and often must consider information spanning time scales out to decades and centuries. While these forecasts do not guarantee the changes that may result, they do offer scientifically sound estimations of what is likely to occur. In essence, ecological forecasts answer the, "What will happen if ..." questions tied to these changes. Ecological forecasts, for example, help resource managers of national parks and crown lands to better understand their options and the likely effects of their decisions and help natural resource managers to anticipate the consequences of drivers such as climate variations and change. In the same way that a weather forecast can help society plan for future contingencies, an ecological forecast helps environmental managers make informed decisions on alternative management scenarios. Ecological forecasts also help to facilitate improved information exchanges at the science/policy interface and also help to identify the data, information, and predicted outcomes with the greatest economic, environmental, and policy implications (Committee on Environment and Natural Resources, 2003).

4. Environmental Prediction for Climate Change, Biodiversity and Desertification in the Americas

Like other regions of the world, the Americas are experiencing changing climate conditions and impacts on ecosystems and arid regions. The studies summarized below illustrate opportunities for synergies in responding to the issues addressed by the Rio Conventions. In many cases, the discussion highlights environmental prediction tools that can be used to evaluate response options. Many of the studies have been supported by programs under the Inter-American Institute for Global Change Research (IAI).

4.1 Inter-American Institute for Global Change Research

The Inter-American Institute for Global Change Research (IAI) is an intergovernmental organization supported by 19 countries in North, Central and South Americas and is dedicated to the open exchange of scientific information to increase understanding of global change phenomena and their socio-economic implications. The IAI operates on the principles of scientific excellence, sharing of environmental scientific research and international cooperation. The mission of the IAI is to develop the capacity to understand the integrated impact of present and future global change on regional and continental environments in the Americas and to promote collaborative research and informed action at all levels (http://www.iai.int/). The primary objective of the IAI is to encourage research beyond the scope of national programs by advancing comparative and focused studies based on scientific issues important to the region as a whole.

The IAI interprets the term global change as “the interactions of biological, chemical and physical processes that regulate changes in the functioning of the Earth system, including the particular ways in which these changes are influenced by human activities (IAI, 2003). The IAI research program has identified four broadly defined research foci (which are also related to the mandates of the Rio conventions):

1. Understanding Climate Change and Variability in the Americas
2. Comparative Studies of Ecosystem, Biodiversity, Land Use and Cover, and Water Resources in the Americas
3. Understanding Global Change Modulations of the Composition of the Atmosphere, Oceans and Fresh Waters
4. Understanding the Human Dimensions and Policy Implications of Global Change, Climate Variability and Land Use

A selection of results from several IAI Programs is described in the following sections.

4.2 Biodiversity and Central and South America's Changing Climate

The climate of South and Central America, including the Caribbean region, is changing and will continue changing into the future. For example, reefs in Belize experienced their first widespread climate-related coral bleaching event in 1995, with the bleaching process affecting over half of the corals and triggering the most devastating global loss of coral reefs on record (GEF, 2004). Changes in the Amazon Basin will prove very critical for the earth's climate and water systems, particularly since the Amazon River is the largest single source of freshwater runoff on Earth, representing some 15 to 20 per cent of global river flow (GEF, 2004). Because the Amazon's hydrological cycle is a key driver of global climate, the global climate will be very sensitive to changes in its hydrological cycle.

Since some 35 percent of the world's freshwater is found in Latin America, the combination of the changing climate and rising human demand from growing populations and economic activity will have significant implications from the community to the global level. Estimates of freshwater availability for Mexico and South America under changing climate conditions indicate that, by 2025, about 70 percent of the population of this large area will experience low water supply conditions (GEF, 2004).

Climate change is likely to substantially affect biodiversity and carbon storage in the globally critical Amazon Basin. The Basin contains a staggering portion of the world's biodiversity, with thousands of people in the Basin supporting themselves from its land and forests. The Amazon contains an unknown range of abundant biodiversity (e.g. at least 40,000 plant species; 3,000 fish; and over one million insect species) that provide global humanity with goods ranging from building supplies to medicines (GEF, 2004). A substantial amount of the world's carbon emissions stems from deforestation, with the Brazilian Amazon being a prime source. Amazon deforestation has ranged from 18,000 to 27,000 square kilometres per year in the last decade, implying a carbon release of between 200 and 300 million tonnes per year. Improved climate and ecosystem models are needed to capture the impacts of changing global carbon emissions from the Amazon to the climate system and to evaluate the merits of inventive programs to encourage "avoided deforestation" in this region.

Under climate change, sea-level rise is likely to hit coastal areas and lead to widespread loss of coastal land, infrastructure, and biodiversity, as well as the intrusion of soil-contaminating saltwater, particularly in the vulnerable parts of the Caribbean, Central America, Venezuela, and Uruguay. At the same time, likely increases in hurricanes and tropical storm intensities or frequencies will further increase risks to these coastal areas and island states. Some 60 of Latin America's 77 largest cities are located on vulnerable coastlines (GEF, 2004), highlighting the importance of environmental prediction and warning systems needed here to forecast future states of the coastal ocean, including storm surge levels and wave damage potential. The coastal ocean refers to continental shelf regions, bays and estuaries and their sea state. Although the damages cannot be avoided completely, better coordination of observations, monitoring of the atmospheric hazards and improved prediction systems can reduce the losses and help protect communities by preventing the hazards from becoming disasters.

It is also important in the longer run to also ensure that adaptation strategies for protection of coastal communities, such as construction of hard structures like sea walls and dikes, do not harm biodiversity conservation objectives. Examples of adaptation actions harmful for biodiversity include sea walls that are constructed without consideration of the needs of species dependent on land and marine habitats for their life cycle. Incorporation of biodiversity considerations into coastal protection structures can involve modification of designs so that critical species can cross barriers to seek land habitat as well as other soft protection options such as use of dunes and vegetation. Other synergistic adaptation actions that protect communities and also support biodiversity conservation and provision of ecosystem services include flood protection through conservation of wetlands and forests, protection of coral reefs, set back of coastal roads and developments, reductions in soil erosion potential through vegetative cover and water conservation measures.

4.3 Biodiversity and North America's Changing Climate

Various studies worldwide have indicated that climate is important in determining the spatial patterns of many species. This influence is significant in the case of butterfly diversity and the extent of northern edges of ranges. It has been speculated that as many as two-thirds of the butterflies globally have expanded their ranges northwards (as much as 250 km) and that climate heat (or energy) can explain 60 to 90 percent of the variability in butterfly species richness in cold and temperate climates (Kerr, 2001). There is early evidence in Canada that butterfly diversity is responding to climate changes observed over the past few decades (Kerr, 2001). At least two species – the Gorgone checkerspot and the Delaware skipper – have been observed to have recently established breeding populations near Ottawa, which is well north of the limits of the previous ranges (Kerr, 2001).

Elevated atmospheric carbon dioxide levels are also expected to alter butterfly patterns by changing the composition and types of the plant communities that supply their food (Bloch *et al.*, 2006). In particular, the ratios of carbon and nitrogen in plant tissues could lead to changes in patterns of herbivory through butterfly larvae. The net impact is not yet known, but it is likely that there will be a response in pollinator diversity.

The Karner Blue butterfly is federally endangered in the northeastern United States (Indiana, Michigan, Minnesota, New Hampshire, New York, Ohio and Wisconsin) and is considered extirpated or locally extinct from Ontario, the only region where it once occurred in Canada (Packer, 1994). In Ontario, the butterfly was known to exist at six sites around the turn of the last century, but only two of these locations persisted into the 1980's. The Karner Blue uses lupine, *Lupinus perennis* (Leguminosae), as its obligate hostplant. The decline of the Karner Blue began with several habitat change processes that declined lupines in southern Ontario. While habitat fragmentation and degradation were contributing factors that resulted in the slow decline of Karner Blue population numbers along with extinctions of local satellite populations, the factor that was most responsible for their extirpation from Ontario was the occurrence of an extended drought in 1987 to 1989

(Schappert, 2000; Kerr, 2001). The drought caused the early senescence of the lupine so that the second brood caterpillars were unable to complete their development. Another species, the frosted elfin butterfly, *Incisalia irus* (Lycaenidae), is also dependent on lupine host plants and has not been seen in Ontario since 1989, likely also extirpated for the same reasons as the Karner blue (Schappert, 2000); Kerr, 2001). Several jurisdictions have developed and implemented Karner Blue Butterfly Recovery Plans to recover the habitats needed to support this species.

The development of Recovery plans for these and other species need to incorporate species and habitat monitoring actions, as well as environmental forecasts or projections of extinction and population risks. Often, it is the thresholds or discontinuities of environmental conditions that are most important in determining whether a species can be recovered but it can be very difficult to incorporate these types of events in ecological predictions. For example, extreme events can encompass disturbance events like droughts or fires but can also include preceding unusually wet and/or cool years or decades that prove beneficial for certain species and harmful to others. Such thresholds or extreme events can accelerate or retard processes of ecosystem changes, species invasions, species migrations and extinctions. In many cases, the effects of one kind of threshold event may be contingent on a previous extreme – for instance, species invasions may be contingent on an extended wet period following close on the heels of an extreme drought.

The sugar maple forest industry is unique worldwide to North America and is extremely weather sensitive. These “trademark” maple forests are currently dominant in northeastern North America and are expected to be replaced in future by species such as oak, which are more tolerant of hot summer weather. Many climatic factors influence sap production during the three to four weeks when it flows each spring, with daily temperature ranges being the most significant (MacIver *et al.*, 2006). Reports from the eastern United States and Ontario indicate that maple sugar sap flow has started up to one month earlier during the past decade compared to historical records – and that the duration of the season is decreasing. This shift in the optimum temperature range is already causing declines in sugar maple production in the United States and forcing sugar maple production to move northward. Over the past 50 years, the United States has gone from being the world’s largest producer of maple products to a distant second behind Canada. Global climate models project that additional winter and spring warming over this century will cause sugar maple forests to shift a further 2 degrees of latitude north. The warming – along with the industry adopting a number of adaptation actions, such as good forest management practices, efficient technologies for sap collection, fertilization and liming – will allow Canada's province of Quebec to increase sugar maple production and remain sustainable over the short-term (at least the next 20 years). Over the longer term, the warming climate is expected to cause a gradual decline in the sugar maple industry in Canada (MacIver *et al.*, 2006). The sustainability of the climate sensitive maple sugar industry depends on its adaptive capacity and, in particular, on the ability to manage and increase resilience of sugar maple forests to the changing climate. Adaptive actions for this industry include good forest management practices, efficient technologies for sap collection, and remedial actions such as fertilization and liming to reduce the cumulative stresses on established and aging sugar maple stands. Above all, it is very important that environmental prediction models be developed to help producers understand and cope with the variability of the changing climate (MacIver *et al.*, 2006).

4.4 Land Use Change, Habitat and Climate in the Region of southern Ontario, Canada

Integrated studies from the south-central part of Canada show that the atmosphere has a powerful influence on the biological and human systems of the region. These atmospheric influences are both direct and indirect and affect everything from the biodiversity of the plants and animals that can live in the region to the economic activities undertaken there.

The results from an Integrated Mapping and Assessment Project (IMAP) (Auld *et al.*, 2002) have shown support for several landscape-biodiversity-climate hypotheses applicable to southern Ontario, including:

1. available heat strongly impacts biodiversity;
2. the availability of atmospheric heat influences land use change and subsequently, habitat and biodiversity losses;
3. initial or subtle warming of a degree or two Celsius under climate change could significantly change the land use, landscapes and the biodiversity of southern Ontario.

(Auld and MacIver, 2000; MacIver and Auld, 2000)

Environmental forecasts based on these hypotheses have the potential to advise ecosystem managers of imminent threats to habitat and to guide strategies that can reduce risks.

Changes in the availability of heat in southern Ontario have been linked historically to the disappearance of wetlands and woodlots and the appearance of invasive species (Auld and MacIver, 2000). Results from this IMAP study indicate that historical patterns in the disappearance of remnant Carolinian woodlots and inland wetlands in the region can be linked to local summer heat amounts, as depicted in Figure 1. Summer heat can be represented by climatological quantities such as Corn Heat Units (CHUs) or growing degree days (GDDs). CHUs, like GDDs, indicate the warmth available for crop maturation during the growing season. Applying the empirical environmental prediction relationship found between land use change and heat units (shown in Figure 1) to global climate change model projections, the results suggest that an initial warming of 1 to 2 Celsius degrees in agricultural areas having fair to good soil quality could result in economic pressures for the elimination of many woodlot and wetland habitats. A warming and longer

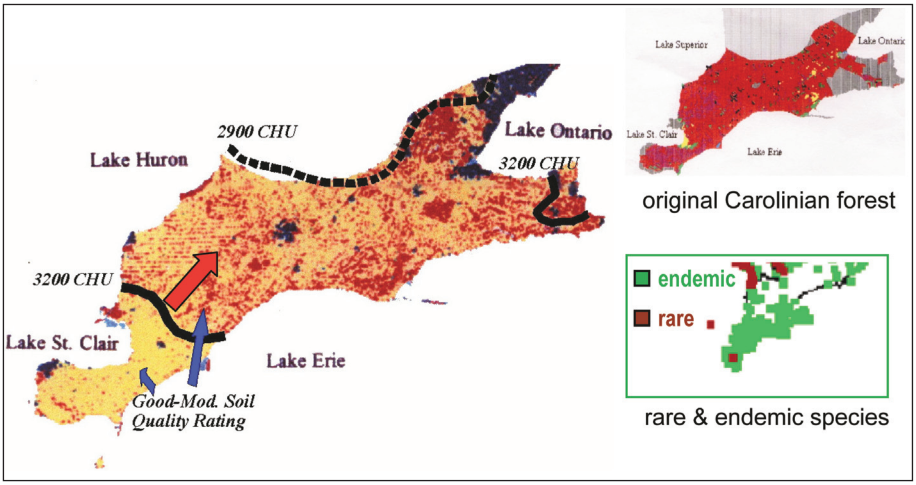


FIGURE 1

Projected changes in agricultural intensification expected with initial growing season warming under climate change. Warming and its associated agricultural intensification will likely increase pressures for woodlot and wetland reductions without aggressive conservation measures.

growing season can be linked to increased economic pressures on these habitats through shifts to more intensive and profitable agriculture. Figure 1 indicates that areas with heat units warmer than the 3200 CHUs and with agricultural soils rated as fair to good recently have seen the greatest losses of remnant woodlots. With climate warming, the 3200 CHU cotour may push northward and add new economic pressures for the clearing of woodlots in the newly warmed regions. Similar results were shown for the historical loss of inland wetlands, with the 2800 CHU contour generally delineating areas with greatest loss of wetlands.

The potential changes in habitat implied by this environmental prediction relation have important conservation policy considerations for southern Ontario. As depicted in Figure 1, enhanced conservation measures are needed to protect woodlots and wetlands in areas where imminent warming will increase CHU values above critical heat thresholds, resulting in pressures and risks to woodlots (e.g. northeast of the 3200 CHU contour). With the already fragmented woodlot and wetland landscape of the region coming under additional pressures due to a changing climate, these regions that will cross critical heat thresholds are in need of enhanced woodlot and wetland conservation and increased habitat purchase and acquisition efforts. The results also indicate the need for vigilant monitoring programs to not only detect the physical changes in the climate, but to also monitor the changes in ecosystems and in invasive species that are likely to follow (MacIver *et al.*, 2002; Auld *et al.*, 2002).

4.5 Ecological Forecasts of Biodiversity Changes for Southern Ontario

The following study developed the scientific foundations for an ecological forecasting system to link and predict general biodiversity trends and changes as a result of climate changes in southern Ontario (in south-central Canada). The relationship was based on work by Rochefort and Woodward (1992), who conceptualized that forest family biodiversity increased with available heat from the poles to the equator. This relationship was tested and confirmed empirically in Canada and in detail in southern Ontario using forest biodiversity measurements and climatological heat units calculated as Growing Degree Days (GDDs). The biodiversity measurements were taken following protocols developed by the Smithsonian Institution's Monitoring and Assessing Biodiversity (SI/MAB) Program; procedures for forest inventory plots tested at UNESCO-designated World Biosphere Reserves. Forest plots

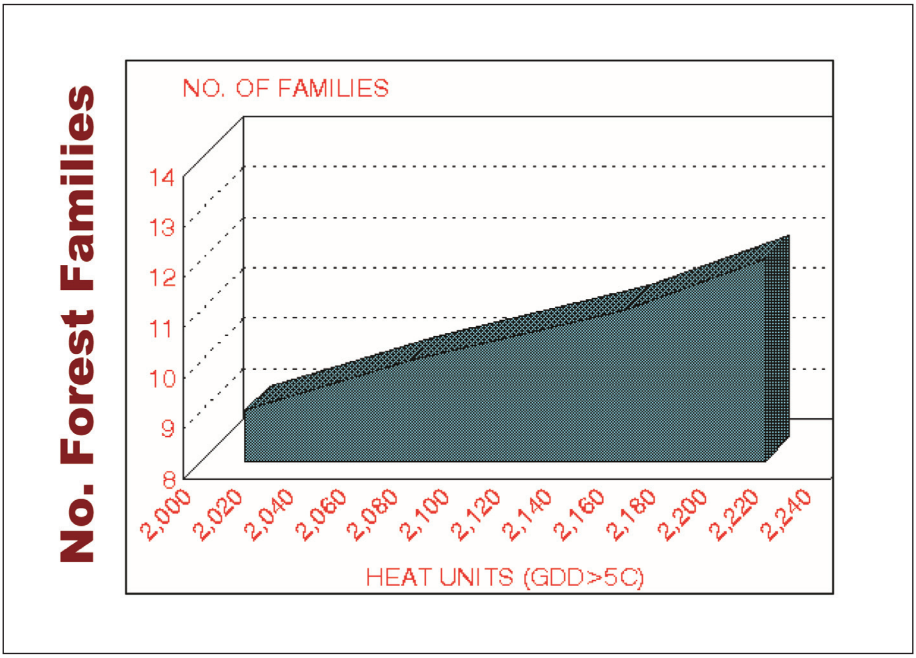
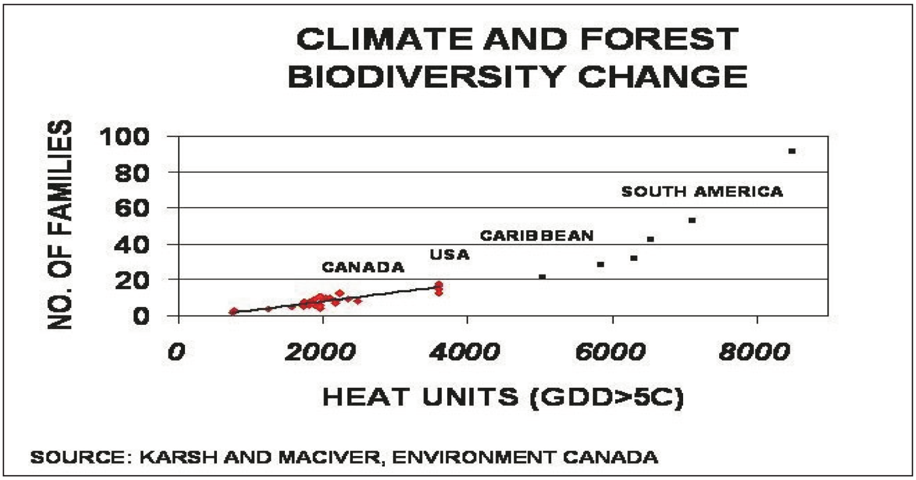


FIGURE 2

Relationship between number of forest families (biodiversity) and heat units (climate) along two transects through south-central Ontario.

monitored using the SI/MAB protocols can be compared with measurements taken at other sites around the world and provide information on tree species abundance and diversity, long term trends in forest growth, mortality and regeneration and impacts of forest disturbance. Figure 2 depicts the empirical forest family biodiversity-climate relationship as a function of GDDs for two north-south biodiversity transects: one in the Niagara Escarpment – a UNESCO-designated World Biosphere Reserve – and the other in the adjacent impacted landscape. The relationship provides a predictive climate-biodiversity baseline for southern Ontario that can be used to project the long-term implications of small increases in heat units (Karsh *et al.*, 2006; MacIver and Auld, 2000).

At the regional scale, the results confirmed the global relationship published by Rochefort and Woodward (1992), showing that family forest biodiversity increased with atmospheric heat or growing degree days (MacIver and Auld,



SOURCE: KARSH AND MACIVER, ENVIRONMENT CANADA

FIGURE 3

Number of families as related to heat units in Canada (16 sites along fitted line) and compared to reference sites in the U.S.A, Caribbean and South America.

2000; Karsh *et al.*, 2006). The study also suggested that an initial warming of 1 to 2 Celsius degrees could have potentially significant influences on biodiversity changes. This family tree and heat unit functional relationship for mixed wood stands was applied to climate change models using the Canadian General Circulation Model (CGCM2) climate change scenarios. The results showed that family forest biodiversity in southern Ontario had the potential to increase some 60 percent by 2050 in the Toronto region of Canada, similar to that experienced currently in the Washington D.C. area (Karsh *et al.*, 2006). However, because biodiversity conditions will not be in equilibrium, the concern is that much of this increase will result initially from invasive species that may expand at the expense of native species, placing greater emphasis on the need for early-detection networks and aggressive native biodiversity conservation programs.

Ecological forecasts cannot be produced without reliable information about the current and historical condition of ecosystems. In this study, it was the information from a network of forest biodiversity monitoring sites that proved crucial to increasing the understanding on the links between climate and forest biodiversity and to developing biodiversity-climate prediction relations. The environmental prediction relates integrated weather and climate data with biosphere and ecological data to project future changes in potential biodiversity. The prediction equations were further tested against other independent biodiversity observing sites and found to perform accurately in Canada, as shown in Figure 3.

Evidence suggests that the biodiversity is not always in equilibrium with the present climate. Examples of this include managed forest stands that have been exposed to human and natural impacts. For example, the prescribed burn or management techniques at some biodiversity monitoring sites were found to reduce the family tree biodiversity to 4 or 5 families, a reduction of close to 70 percent against the potential biodiversity baseline. The biodiversity-climate prediction line or baseline can be used as an effective diagnostic tool to identify areas where the biodiversity is not in equilibrium with the present climate (MacIver, 1998) and as a predictive tool under climate change (Karsh *et al.*, 2006).

4.6 The Role of Climate and Biodiversity in Ecosystem Functioning for the Americas

An IAI supported study (IAI CRN012) by Osvaldo Sala on "The Role of Biodiversity and Climate in the Functioning of Ecosystems: A Comparative Study of Grasslands, Savannas and Forests" (Sala *et al.*, 2000) aimed to better understand the individual and the interacting influences of biodiversity and climate on the functioning of ecosystems. Rather than using artificially constructed simulations of ecosystems, the study conducted experiments in intact ecosystems where the long-term consequences of species interactions were well-developed and where the many effects of positive species interactions could be observed. The results indicated that the relationship between climate and ecosystem functioning is more pronounced in intact ecosystems than it is in artificially constructed ecosystems, and that losses in biological diversity in natural systems result in more dramatic changes in primary production. For example, vascular plant removal experiments in the Patagonian steppe of South America showed that relationships between biodiversity and net primary production were positively correlated and affected rates of carbon and nitrogen turnover. In essence, the loss of genetic variability within a population of a given area can reduce its flexibility to adjust to environmental change and narrow the options for adjustments to climate change, for example, as well as for rehabilitating specific habitats. Arid region ecosystems were found to be particularly vulnerable to disruptions since dryland ecosystems are dependent on fewer species and any biodiversity loss can result in cascading effects on the whole system. The study concluded that intact ecosystems need to be used in studies exploring fundamental ecological relationships and in environmental prediction studies assessing the importance of biodiversity loss for ecosystem functioning.

Other study results indicated that agroecosystems provide a particularly good example of human practices where the services provided by natural ecosystems have been substituted in part by managed agroecosystems of interest to humankind. The comparisons between natural ecosystems and managed agroecosystems indicate that the services lost from natural ecosystems, such as nutrient and water regulation, are often substituted or compensated at considerable energy cost in managed agroecosystem substitutions (Mooney *et al.,* 1996). Results suggest that, for a given function, such as productivity or organic matter accumulation, it does not take many species to provide full services. But, for a greater set of services, the study concluded that landscape diversity forms an essential component of sustainability in agroecosystems (Sala *et al.,* 2000). The simplification of ecosystems in order to increase yields of individual products often comes at the cost of lost ecosystem stability and free ecosystem services such as controlled nutrient delivery and pest control. The loss of these services then needs to be subsidized through the use of fertilizers and pesticides. In order to develop environmental prediction tools, there is a growing need to explore more fully the role of genetic, species and landscape diversity in ecosystem functioning in agroecosystems versus natural systems.

Another IAI study by Holm Tiessen (IAI CRN 001) on *"Biogeochemical Cycles under Land Use Change in the Semi-Arid Americas"* for Northeastern Brazil used on-farm trials to investigate water and nutrient cycling. The study demonstrated the positive impact on biodiversity from agroforestry and from the inclusion of succulents into cropping systems (Tiessen *et al.,* 2001). Results indicated that stabilized food and fodder production could be realized from improved water efficiency and long-term sustainability of soils (Tiessen, 2003). Studies from northeastern Brazil indicated evidence of a "threshold of irreversibility" in desertification, highlighting the conclusion that soil degradation beyond a threshold point in dryland areas results in very slow or nearly irreversible recovery in soil and agricultural productivity. These thresholds form a critical element in the development of environmental prediction tools for the management of desertification.

In other studies, results show that grassland ecosystems with greater biodiversity are more resilient to droughts. One study (Tilman and Downing, 1994) showed that in a grassland community, primary productivity in more diverse plant communities is more resistant to and recovers more fully from a drought. The curvilinear relationship observed suggests that each additional species lost from a grassland community has a progressively greater impact on drought resistance. They concluded that the preservation of diversity is essential for the maintenance of stable productivity in ecosystems.

In the Canadian context, observations from some river basins in the western Canadian Prairies have indicated that water diversions for consumptive purposes during drought conditions have historically contributed to massive fish kills on rivers in southern Alberta (Lawford, 1992; Trout Unlimited Canada, 2001). During droughts of the past, including the Prairie drought of 1988, waterfowl numbers decreased substantially due to reduced habitat or wetlands and increased waterfowl diseases (Ducks Unlimited Canada, 2007; Viljugrein *et al.*, 2005). Other research from the Canadian Prairie drylands suggests a need for 1,000 pounds of crop residue per acre to prevent water and wind erosion processes (Lethbridge Research Centre, 2002). Practices that leave crop residues also conserve moisture by capturing snow, cooling the soil, reducing evaporation and in many cases, also providing an emergency feed supply. The research results indicated that the key to providing a solid litter cover is the avoidance of overgrazing. Allowance for a grass carry-over from one year to the next provides more resilience to withstand a drought in the following year.

4.7 Biodiversity, Climate Extremes and Disaster Management Services

Biodiversity provides important ecosystem services for community disaster management. An IAI research study by A. Lavell (IAI CRN 031) on "*Disaster Risk Management in Latin America: proposal for the consolidation of a comparative-regional social study based research, information and training network*" compared changing risk patterns associated with ENSO events over the last 35 years in Latin America and highlighted the role of social variables in the explanation of losses and damages. The results showed that losses vary temporally and spatially with different ENSO events, indicating difficulty in developing environmental prediction relationships on likely impacts based only on the physical characteristics of these events (e.g. weak events can result in high impacts). The study pointed to the importance of social factors and planning systems in reducing impacts from atmospheric hazards and highlighted the need for integrated risk and ecosystem management processes to reduce risks from ENSO and other recurrent hazards (Lavell, 2003). This conclusion was illustrated in one powerful example from the Lempira Sur development project in the Honduras, where ecologically sustainable, best management agriculture played a critical role in reducing disaster risks. During Hurricane Mitch, this relatively poor area suffered little damage compared to neighbouring regions and countries as a result of the types of land use and slope stabilization methods that were used in the region (Lavell, 2002; Lavell, 2000). In fact, the region suffered relatively reduced impacts and was able to provide food assistance to other areas severely damaged by the hurricane.

4.8 Biodiversity, Climate Change and Vector-borne Diseases

Anthropogenic land use changes can lead to the emergence, transmission means and spread of a range of infectious disease outbreaks. Human-mediated alteration and destruction of ecosystems, along with changing climate conditions, can damage the fragile interactions and balances between disease vectors and their natural means of control. Since many studies project that 25 percent or more of all current species may become extinct in the next 50 years given current extinction rates, there is growing concern over the implications for human health (Baillie *et al.*, 1997). At the same time, changing climate conditions will also enhance the emergence and potential spread of some infectious diseases.

An IAI supported study (IAI CRN 048) by U. Confalonieri on the *"Diagnostics and Prediction of Climate Variability and Human Health Impacts in the Tropical Americas"* investigated the linkages between climate factors, land use/cover changes and the seasonal and interannual dynamics of infectious diseases, with a focus on malaria and dengue fever. The results were intended to provide guidance for the design of climate-health early warning systems.

Both temperature and surface water availability were found to have important influences on the insect vectors of vector-borne infectious diseases. Of particular importance were vector mosquito species, which spread malaria and viral diseases such as dengue and yellow fever in the Tropical Americas. Since mosquitoes need access to stagnant water in order to breed, and adults need humid conditions for viability, it is projected that warmer temperatures in the future may enhance the potential for vector breeding and reduce the pathogen's maturation period within the vector organism. There is also the possibility that combinations of very hot and dry conditions may also reduce mosquito survival (Confalonieri, 2000; Confalonieri *et al.,* 2003).

Dengue fever has been claimed to be the most important arboviral disease of humans, occurring in tropical and subtropical regions and hitting hard in urban settings (Amarakoon *et al.,* 2004a, 2004b). ENSO events can affect dengue occurrence by causing changes in household water storage practices and in surface water pooling. For example, it was noted that between 1970 and 1995, the annual number of dengue epidemics in the South Pacific was positively correlated with La Niña conditions (i.e., warmer and wetter).

Other results showed that many diarrhoeal diseases vary seasonally with climate (Confalonieri 2003; Confalonieri *et al.,* 2003). In the tropics, diarrhoeal diseases typically peak during the rainy season, although both floods and droughts increase their risks. Major causes of diarrhoea were found to be linked to heavy rainfall or cumulative rainfall events that contaminated water supplies and included outbreaks of cholera, cryptosporidium, E.coli infection, giardia, shigella, typhoid, and viruses such as hepatitis A.

Similarly, results of studies from the United States and from Canada indicated that waterborne disease outbreaks can be linked to excess precipitation and runoff conditions, adding to the speculation that climate change may increase risks (all other factors remaining equal). Responses to reduce the risks for waterborne and other infectious diseases require improved understanding of the links between excess precipitation and other atmospheric and land use conditions. The outcome of this improved understanding is the potential for environmental predictions of "challenging conditions" that increase risks for waterborne disease outbreaks. Improved understanding of the links between excess precipitation, saturated ground conditions and waterborne disease outbreaks can lend itself to prediction and response systems for water quality managers. Given an environmental prediction of the contributing meteorological and climatological causes to outbreaks, the water manager can take adaptive or proactive measures to reduce risks, including more frequent water testing, increased water treatment, or the removal of vulnerable wells from service during critical or "challenging" times (Auld and MacIver, 2000).

4.9 Evidence of Links between Biodiversity, Climate and Sustainability in the Arctic

Canada's Arctic comprises about one-third of its landmass, although it is the least populated region in the country. In recent decades, the Arctic regions of North America have seen some of the greatest changes in climate worldwide. Studies show that the Mackenzie Basin of Canada's western Arctic is heating up faster than almost any other place on Earth, at rates as much as three times the global rate (ACIA, 2005). Valuable lessons for the future can be learned from watching the response of Arctic ecosystems and biodiversity to the changes unfolding, since similar amounts of changes and ecosystem impacts may result further south in the near future.

The circumpolar Arctic plays a critical role in regulating the earth's climate system through many direct and indirect feedback processes, including: air and ocean interactions in Arctic regions that influence ocean circulation patterns; reflectivity or albedo of polar snow and ice that limits the amount of sunlight and heat absorbed by the Earth; and layers of peat and permafrost that store vast amounts of carbon with the potential to greatly influence the global climate system (McGuire *et al.*, 2006; ACIA, 2005; ACIA, 2004).

In many parts of the Arctic, indigenous communities, whose knowledge of the land, sea, and ice dates back thousands of years, have recently reported significant climatic changes in the form of thinning of sea ice, changes in open water areas within the ice, and the presence of animals not previously found in their region. For the indigenous Inuit, who have long occupied the Canadian Arctic, the environment is inextricably linked to their communities through their subsistence on wildlife and natural resources (ACIA, 2005). Many of the changes noted by indigenous communities are backed by scientific observations and studies. Many of these impacts are documented in the 2005 Arctic Climate Impact Assessment (ACIA, 2005). The ACIA represented one of the most comprehensive studies ever of the impact of climate change on a particular region and was sponsored by the eight countries bordering the Arctic region and carried out by an international team of three hundred scientists. The documented impacts include melting permafrost in far northern latitudes triggering mudslides and damaging local fish populations, declines in sea ice extent and thinning ice thickness, increasing coastal erosion processes as a result of more intense storm surges, later ice freeze-ups on land and earlier spring melts and melting glaciers that have created torrents in place of streams. New species from the south are appearing in the high Arctic, including robins, barn swallows, pin-tailed ducks, salmon and new species of beetle. On the land, an influx of flies and mosquitoes are changing life for humans and animals (ACIA, 2005; ACIA, 2004).

Since biodiversity tends to decline with increasing latitudes (e.g. Arctic regions), the relative abundance, dominance and importance of the reduced biodiversity that exists tend to increase with latitude (ACIA, 2005). As a result, Arctic ecosystems and the indigenous peoples that depend on them often cannot afford to lose even one species, particularly when the loss can represent an important food source that can have a disproportionate impact on the economy, livelihoods and ecosystem function of the region. Observations and studies indicate that several animal species have become depleted or endangered due to the changing climate of the region. For example, in the Bering Sea region, steller sea lions have declined 50 to 80 percent and are now listed as “endangered” while northern fur seals are listed as “depleted” under the Marine Mammal Protection Act (National Marine Fisheries Service, 2006). Bering Sea populations of common murres, thick-billed murres, and red and black-legged kittiwakes have declined up to 90 percent (ACIA, 2005; ACIA, 2004). In addition, the conditions for support of adult polar bears have been declining in the northern Hudson Bay area over the past two decades along with the number of live births and the proportion of first year cubs in the population (ACIA, 2005; ACIA, 2004). With decreases in spring ice conditions and declines in their spring food source of seals, survival of polar bears has become compromised.

The Peary caribou have also been dramatically declining over the last four decades, with the die-off of this endangered species in the western Queen Elizabeth Islands now being linked to climate warming, heavier snowpacks and resulting starvation (Miller and Gunn, 2003). Examination of the carcasses indicated that death, not migration, was responsible for their population decreases, and that young (1+ year old) and bull (4+ years old) males died at a higher rate than females. Since bull caribou have greater energy demands during early winter rutting activities, which greatly reduce their body reserves, breeding males have often suffered greater proportional losses. It has been proposed that exceptionally severe snow and ice conditions from 1994-5 to 1996-7 caused a prolonged reduction in foliage availability that led to widespread starvation and a nearly cataclysmic die-off of Peary caribou. Future climate warming may increase the frequency of years with these unfavourable snow and ice conditions, either preventing or impeding the recovery of the Peary caribou population (Miller and Gunn, 2003).

While noting that the changing climate may give rise to new opportunities in the North, such as increased access to oil and gas minerals, the international Arctic Climate Impacts Assessment study (ACIA, 2005) found that the economic and social impacts on indigenous communities in the circumpolar Arctic are expected to be significant. Studies linking scientific approaches and indigenous traditional ecological knowledge or TEK in Canada's Arctic have concluded that it is extreme events that are most disruptive to communities, particularly events of greater magnitude than those historically observed and which exceed a system's absorptive capacity. The ACIA found that the shifting ranges and availability of species, together with shifting ice and weather conditions, pose major challenges to human health and food security for many communities. In some cases, communities have been able to adapt to the changes with positive outcomes. For instance, the appearance of Pacific salmon in the Beaufort Sea, and of mainland ducks in Sachs Harbour, has provided a supplement to the traditional diet (Berkes and Jolly, 2001).

In the decades to come, the Arctic will be a region of rapid change, making it an appropriate place to study environmental changes since boundaries here are magnified by the extremes of natural cycles. For example, observable boundaries in the Arctic such as the edge of the polar ice pack, the discontinuous to permafrost zone and the tree line are particularly sensitive to climate changes. The movements of these boundaries are not only sensitive indicators of climate and environmental change but also have major effects on the lives of Arctic residents, particularly on indigenous people relying on a subsistence lifestyle in the face of major changes and stresses. The Arctic region, among others, also offers opportunities to explore the benefits of merging scientific and traditional ecological knowledge (TEK) information holdings on environmental changes. There are numerous knowledge gaps in the ecological information about northern regions that science alone cannot fill. Indigenous knowledge, which integrates the biophysical, economic, social, cultural, and spiritual aspects of the environment, is often better suited to answer scientists' many questions on impacts (Freeman 1992). TEK emphasizes the inter-relationships between components of the environment without requiring scientific "rigour" to reduce complexity in order to achieve observational and experimental control, an approach that is often counter-intuitive to understanding on ecosystems. Instead, traditional ecological knowledge views humans as part of the natural environment, not simply as observers or controllers. Thus, any study aimed at understanding and predicting the natural environment is able to benefit by including the role of humans as "participants" within the natural environment. This is especially true for the Environmental Impacts Assessment process, where an effective process for the evaluation and monitoring of potential impacts must be incorporated into the planning stages of all proposed projects (Sallenave, 1994).

5. Conclusions

Climate variability and change can be an important driver of biodiversity loss and desertification. The evidence is abundant proving that ecosystem functions and patterns of land use can impact the earth's carbon, energy and water cycles and hence, affect local and regional climate. It is unfortunate that many ecosystem services are largely unrecognized for the vital role that they play in meeting societal needs and the role that they must play in both mitigation and adaptation to climate change. For example, nearly 60 percent of the carbon that is now emitted to the atmosphere from human activities is absorbed and stored by terrestrial and ocean ecosystems, thereby slowing the rate of global climate change (CBD, 2006). An estimated 40 percent of the global economy is directly based on biological products and processes, and the goods and services provided by biodiversity represent an important part of many communities and national economies.

The evidence clearly indicates that even if greenhouse emissions were stopped today, climate change and its impacts would still be felt for decades to come. Unfortunately, the projected magnitude and rates of climate change are expected to exceed the natural coping ability or autonomous adaptation capacity of ecosystems and biodiversity and hence, will be insufficient to slow the additional rate of loss of biodiversity. As a result, additional or planned adaptation activities are urgently needed now and will be needed into the future to slow the rates of biodiversity loss (CBD, 2006). In general, adaptation actions that support resilient ecosystems also help to maintain biodiversity so that it can continue to deliver ecosystem goods and services under changing climate conditions.

According to the CBD Technical Expert Group tasked to investigate the links between biodiversity, climate change adaptation and desertification (2006), the adverse consequences to biodiversity can be minimized, and positive benefits enhanced if biodiversity considerations are incorporated formally and routinely into adaptation planning. As an adaptation strategy, maintaining biodiversity allows ecosystems to provide goods and services while societies learn to cope with the challenges of climate change. However, adaptation strategies have limits, thus requiring that mitigation action also be taken to limit the rate and extent of climate change. Because biodiversity responses to climate change are non-linear, research indicates that limits to adaptation may occur as global temperatures increase to some 1 to 3 Celsius degrees above current levels (CBD, 2006; IPCC, 2001). These thresholds will vary between ecosystems and species. For example, a 1 degree Celsius increase above the historic mean annual temperature maxima is likely to lead to extensive coral bleaching and significant impacts relating to loss of ice habitat in the Arctic (CBD, 2006). Environmental prediction modelling suggests that under linear conditions, an increase in temperature of this magnitude could occur as early as 2015. After a threshold is passed, most ecosystem adaptation strategies are unlikely to be successful and remaining ones prohibitively costly.

As outlined in the CBD's Technical Expert Group report on synergies (CBD, 2006), activities to maintain and restore resilience in ecosystems can be thought of in terms of three components. The first component involves the maintenance of adequate and appropriate space, structure and environmental conditions for ecosystems, species and individuals to respond over varying temporal and spatial scales. This includes measures to enhance the capacity for species movement and replacement due to climate change (e.g. preventing habitat fragmentation and loss). The second component requires the limitation of the stresses that will amplify the impacts of climate change, and includes stresses such as species over-harvesting, invasive species, and pollution (contaminants and nutrients). Approaches to address these stresses are generally approachable on more local scales. The final component involves adaptive management measures, including multi-disciplinary monitoring to address significant knowledge gaps and to allow the testing of different approaches while adaptation implementation is underway. Adaptation actions need to be implemented soon, due to increasing costs from delayed actions and severe limitations on potential adaptation actions as climate change progresses.

Measures undertaken to implement commitments under one convention may have consequences for the implementation of other commitments in different conventions. In the end, enhanced cooperation between international conventions, organizations and bodies will better ensure the environmental integrity of the conventions, promote synergies under the common objective of sustainable development, avoid duplication of efforts, strengthen joint efforts and enable more efficient use of available resources (CBD, 2006). Maintaining biodiversity should be part of all national policies, programs and plans for adaptation to climate change. This is essential if the UNFCCC objective and Millennium Development Goals for poverty alleviation, food production and sustainable development are to be met (CBD, 2006). In particular, effective collaboration and networking between biodiversity and climate change communities at all levels are essential for the successful implementation of adaptation activities for biodiversity and the integration of biodiversity concerns into adaptation activities. For example, adaptation to climate change in different ecosystems (e.g., actions already planned under the implementation of UNFCCC and UNCCD commitments for drylands) should take into account relevant biodiversity considerations in the CBD programme of work on dry and sub-humid land biodiversity.

Environmental prediction tools that can forecast the effects or directions of climate-induced changes on ecosystems and their components are critical for the decisions that need to be taken to cope with the impacts of the changing climate and to meet all obligations under international Conventions. While these environmental predictions will not guarantee the changes to come, they will provide a sound basis to estimate what is likely to occur and to guide policies and decisions. These tools will need to build from expert judgment, traditional ecological knowledge, analysis, new types of observations, and assessments, in addition to numerical simulation and prediction models. Forecasts of such broad-based, long-term effects are particularly important because some of the most severe and long-lasting effects on ecosystems may result from chronic influences that are subtle over short time frames (Committee on Environment and Natural Resources, 2003). Environmental prediction tools will not result without information, data and spatially and temporally comparable observations about the current and historical condition of the climate system and ecosystems, all leading to improvements in the understanding of linkages and natural processes. The key to all of this happening will be increased collaboration, including stronger linkages and synergies between the UN Conventions, their objectives and their implementation measures.

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References

Alusa, A. 1997. *Scientific Linkages and Complementaries between the Conventions on Climate Change, Biological Diversity, Desertification and the Forest Principles.* Atmosphere Unit, United Nations Environment Programme, Geneva.

Amarakoon A., A. Chen, S. Rawlins and M. Taylor. 2004a. Dengue epidemics — its association with precipitation and temperature, and its seasonality in some Caribbean countries. *West Indian Medical Journal*, 53(2), 60.

Amarakoon A., A. Chen, S. Rawlins and M. Taylor. 2004b. *49th Annual Caribbean Health Research Council and Scientific Meetings*, Grenada, 21-24 April, 2004.

ACIA (Arctic Climate Impact Assessment). 2005, *Arctic Climate Impact Assessment*. Cambridge University Press, Cambridge, UK.

ACIA (Arctic Climate Impact Assessment). 2004. *Impacts of a Warming Arctic*. Cambridge, UK. Cambridge University Press. http://amap.no/acia/

Auld, H., D. MacIver, N. Urquizo and A. Fenech. 2002. Biometeorology and Adaptation Guidelines for Country Studies. In *Proceedings of AMS 15th Biometeorology and Aerobiology Conference*, Kansas City, Oct 27 – Nov 1, 2002.

Auld, H. and D. MacIver. 2000. Environmental Prediction: Early Detection of Atmosphere-Land Use Changes in Ontario, Canada. *Proceedings of the 14th Conference on Biometeorology and Aerobiology*, Davis, California, August, 2000.

Baillie, J. and T. Groombridge (ed.s). 1997. *1996 IUCN red list of threatened animals.* Gland, Switzerland, World Conservation Union.

Berkes, F. and D. Jolly. 2001. Adapting to climate change: social-ecological resilience in a Canadian western Arctic community. *Conservation Ecology*, 5(2): 18.

Bloch, D., N. Werdenberg and A. Erhardt. 2006. Pollination crisis in the butterfly-pollinated wild carnation *Dianthus carthusianorum*? *New Phytologist*, 169: 699–706.

CBD (Convention on Biological Diversity). 2006. Guidance for Promoting Synergy Among Activities Addressing Biological Diversity, Desertification, Land Degradation and Climate Change. Ad hoc Technical Expert Group on Biodiversity and Adaptation to Climate Change, *CBD Technical Series No. 25*, Secretariat to the Convention on Biological Diversity, Montreal, Canada.

CBD (Convention on Biological Diversity). 2003. Interlinkages between Biological Diversity and Climate Change: Advice on the Integration of Biodiversity Considerations into the Implementation of the United Nations Framework Convention on Climate Change and its Kyoto Protocol. Ad hoc Technical Expert Group on Biological Diversity and Climate Change, *CBD Technical Series No. 10*, Secretariat of the Convention on Biological Diversity, Montreal, Canada.

CBD (Convention on Biological Diversity). 2000. *Sustaining Life on Earth: How the Convention on Biological Diversity Promotes Nature and Human Well-Being*. Secretariat of the Convention on Biological Diversity, April 2000, Montreal, Canada.

Committee on Environment and Natural Resources, 2003. *Ecological Forecasting: Agenda for the Future.* Office of Science and Technology Policy, Committee on Environment and Natural Resources, Subcommittee on Ecological Systems, Washington, DC, 8 pp.

Confalonieri, U., 2003. Climate variability, vulnerability and health in Brazil._*Terra Livre*, 19-1(20): 193-204.

Confalonieri, U., J. Aron, *et al.*2003. Diagnostics and prediction of climate variability and human health impacts in the tropical Americas. In *3rd CRN / IAI - IGBP Meeting, "Building Global Change Networks in the Americas"*, January 27-28. Mendoza, Argentina.

Confalonieri, U. 2000. Diagnostics and prediction of climate variability and human health impacts in the tropical Americas. *IAI Newsletter*, 22: 24-25.

Ducks Unlimited Canada. 2007. *Our History – A Tradition of Wetland and Wildlife Conservation in Canada.* http://www.ducks.ca/aboutduc/history/index.html#top

Freeman, M. 1992. The Nature and Utility of Traditional Ecological Knowledge. *Northern Perspectives* 20: 1.

GEF (Global Environment Facility). 2004. It's Raining, It's Pouring, It's Time to Be Adapting. *Report of the Second AIACC Regional Workshop for Latin America and the Caribbean*. Global Environment Facility. Washington, DC, USA. http://www.aiaccproject.org/meetings/Buenos_Aires_04/Buenos_Aires.pdf

IAI (Inter-American Institute for Global Change Research). 2003. *Info Sheet: The IAI Science Agenda*. IAI/ID.24.E/2003.

IPCC. 2001. *Climate Change 2001: The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Edited by J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. van der Linden, X. Dai, K. Maskell, and C.A. Johnson. Cambridge and New York: Cambridge University Press.

Karsh, M., D. MacIver, A. Fenech and H. Auld. 2006. Climate-Based Predictions of Forest Biodiversity using Smithsonian's Global Earth Observing Network. In *Proceedings of the 17th Conference on Biometeorology and Aerobiology*, San Diego, May 22-25, 2006.

Kerr, J.T. 2001. Climate Change and Butterfly Species Richness Butterfly Species Richness Patterns in Canada: Energy, Heterogeneity, and the Potential Consequences of Climate Change. *Conservation Ecology* 5(1).

Lavell, A. 2003. Indicators for Disaster Risk Management. Some Results, Conclusions and Recommendations following the first Expert Meeting on Disaster Risk Conceptualization and Indicators Modeling. Inter-American Development Bank Information and Indicators Program for Disaster Risk Management. *Execution of Component II (Indicators for Disaster Risk Management) OPERATION ATN/JF-7907-RG PHASE 2*. August. Manizales: National University of Colombia.

Lavell, A. 2002. Local Level Risk Management: Concepts and Experience in Central America. *Abstract of a paper prepared for the Disaster Preparedness and Mitigation Summit*, 21-23 November, 2002, New Delhi, India.

Lavell, A., 2000._Desastres y desarrollo: hacia un entendimiento de las formas de construcción social de un desastre. El caso del huracán Mitch en Centroamérica. In N. Garita and J. Nowalski (ed.s). *Del desastre al desarrollo sostenible: huracán Mitch en Centroamérica*, BID-CIDHCS, 2000.

Lawford, R. 1992. Research implications of the 1988 Canadian Prairie provinces drought._*Natural Hazards*, 6:2, 109-129.

Lethbridge Research Centre, 2002. *Cover crops can prevent erosion of drought-stricken fields.* Lethbridge Research Centre Report, Lethbridge Alta., August 27.

MacIver D., M. Karsh, N. Comer, J. Klaassen, H. Auld, and A. Fenech, 2006. Atmospheric Influences on the Sugar Maple Industry in North America. *Occasional Paper 7*, Adaptation and Impacts Research Division, Environment Canada, Toronto, Canada.

MacIver D., N. Urquizo and H. Auld, 2002. Biometeorology and Adaptation in the Context of Climate Change and Biodiversity. *Proceedings of the 15th Conference in Biometeorology and Aerobiology/16th International Congress on Biometeorology,* Kansas City, Missouri.

MacIver, D. and H. Auld, 2000. The Changing Atmosphere, Forest Biodiversity and Productivity in Ontario, Canada. *Proceedings of the 14th Conference on Biometeorology and Aerobiology*, Davis, California, August, 2000.

MacIver, D., 1998. Atmospheric Change and Biodiversity. *Environmental Monitoring and Assessment*, 49, 177-189.

McGuire, D., Chapin F., Walsh J., and C. Wirth, 2006. Integrated Regional Changes in Arctic Climate Feedbacks: Implications for the Global Climate System. *Annual Review of Environment and Resources*, November 2006, Vol. 31, Pages 61-91.

Millennium Ecosystem Assessment, 2005a. *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, D.C.

Millennium Ecosystem Assessment, 2005b. *Ecosystems and Human Well-being: Desertification Synthesis*. World Resources Institute, Washington, DC.

Millennium Ecosystem Assessment, 2005c. *Ecosystems and Human Well-being: Biodiversity Synthesis*. World Resources Institute, Washington, DC.

Miller, F. and A. Gunn. 2003. Catastrophic Die-Off of Peary Caribou on the Western Queen Elizabeth Islands, Canadian High Arctic. *Arctic*. 56(4), 381-390.

Mooney, H.A., J. Cushman, E. Medina, E. Sala and E. Schulze. 1996. Functional Roles of Biodiversity: A Global Perspective, Chapter 17. *SCOPE 55*, John Wiley & Sons, Chichester.

National Council for Science and the Environment. 2005. Forecasting Environmental Changes: *A Report of the Fifth National Conference on Science, Policy and the Environment*. Craig M. Schiffries, Ed. National Council for Science and the Environment, Washington, D.C.

National Marine Fisheries Service, 2006. *Draft Revised Recovery Plan for the Steller Sea Lion* (*Eumetopias jubatus*). National Marine Fisheries Service, Silver Spring, MD. 285 pages.

OECD (Organisation for Economic Co-Operation and Development). 2002. *Integrating the Rio Conventions into Development Co-operation*. Organisation for Economic Co-Operation and Development, Paris, France.

Orlando B.M. and L. Smeardon. 1999. *Report of the Eleventh Global Biodiversity Forum: Exploring Synergy between the UN Framework Convention on Climate Change and the Convention on Biological Diversity*. Buenos Aires, Argentina. In collaboration with the Secretariat of the Convention Biological Diversity. IUCN – The World Conservation Union, Washington DC, USA.

Packer, L. 1994. Karner Blue Butterfly: a symbol of a vanishing landscape. In D. Andow, R.. Baker, and C. Lane, Eds., pp. 143-151, *Misc. Pub*. 84-1994, Minnesota Agricultural Experiment Station, University of Minnesota, St. Paul, MN.

Rochefort, L. and F.I. Woodward. 1992. Effects of climate change and a doubling of CO_2 on vegetation diversity. *Journal of Experimental Botany*, 43, 1169-1180.

Root, T.L., J.T. Price, K.R. Hall, S.H. Schneider, C. Rosenzweig and J.A. Pounds. 2003. Fingerprints of global warming on wild animals and plants. *Nature*, 421, 57-60.

Sala, O.E., R.B. Jackson and A.T. Austin. 2000. *The Role of Biodiversity and Climate in the Functioning of Ecosystems: A comparative study of grasslands, savannas and forests*. Inter-American Institute for Global Research, Sao Paula, Brazil.

Sallenave, J., 1994**.** Giving Traditional Ecological Knowledge Its Rightful Place in Environmental Impact Assessment. *Northern Perspectives,* 22, 1.

Schappert, P., 2000. *The Extirpation of the Karner Blue Butterfly from Ontario, Canada.* http://www.aworldforbutterflies.com/KBExcerpt.htm

Tiessen, H., R.. Menezes, I.H. Salcedo and B. Wick. 2003. Tree effects, soil fertility and organic matter turnover in a silvo-pastoral system in semiarid NE Brazil. *Plant and Soil*, 252, 195-205.

Tiessen, H., E. Sampaio and I. Salcedo. 2001. Organic matter turnover and management in low input agriculture of NE Brazil. *Nutrient Cycling in Agroecosystems,* 61, 99-103.

Tilman, D. and J. Downing. 1994. Biodiversity and stability in grasslands. *Nature,* 367, 363-365.

Trout Unlimited Canada. 2001. *Backgrounder: Heading into a Drought in 2001.* Trout Unlimited Canada, Calgary, Alberta, March 9.

UNCCD (United Nations Convention to Combat Desertification). 1999. Convention to Combat Desertification: Collaboration and synergies among Rio conventions for the implementation of the UNCCD. *Conference of the Parties CoP(3)/9*, Recife, 15-26 November 1999., Third session, 28 September 1999, document GE.99-66101.

UNDES (United Nations Department of Economic and Social Affairs). 1992. *Report of the United Nations Conference on Environment and Development*. Rio Declaration on Environment and Development. Rio de Janeiro, 3-14 June 1992.

UNEP (United Nations Environment Programme). 2004. *Synergies and Cooperation: A status report on activities promoting synergies and Cooperation between Multilateral Environmental Agreements, in particular biodiversity-related conventions, and related mechanisms*. UNEP World Conservation Monitoring Centre, Cambridge, UK.

UNEP (United Nations Environment Programme). 1996. *United Nations Convention to Combat Desertification.* United Nations Environment Programme, Nairobi, Kenya, pp 71.

UNEP (United Nations Environment Programme). 1994. *United Nations Framework Conventions on Climate Change.* United Nations Environment Programme, Information Unit on Conventions, Geneva, Switzerland, 29.

UNEP (United Nations Environment Programme). 1992. *Convention on Biological Diversity.* United Nations Environment Programme, Nairobi, Kenya, pp 55.

UNEP (United Nations Environment Programme). 1991. *Status of Desertification and implementation of the United Nations Plan of Action to Combat Desertification.* United Nations Environment Programme, Nairobi, Kenya, 88 pp.

UNFCCC (United Nations Framework Convention on Climate Change). 2005. *Caring for Climate: A guide to the Climate Change Convention and the Kyoto Protocol (revised 2005 edition).* Climate Change Secretariat (UNFCCC) Bonn, Germany.

Viljugrein H., N. Stenseth,G. Smith, H. Gunnhildur and H. Steinbakk. 2005. Density Dependence in North American Ducks. *Ecology*, 86:1, 245–254.

Watson, R., M. Zinyowera, and R. Moss. 1996. *Climate Change 1995*. IPCC, Cambridge University Press, Cambridge.

World Wildlife Federation. 2003. Buying Time: A User's Manual for Building Resistance and Resilience to Climate Change. In L. Hansen, J. Biringer and J. Hoffman (ed.s). *Natural Systems*. August, 2003, WWF Climate Change Program, WF Germany, Berlin.