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IMPACTS OF CLIMATE EXTREMES ON BIODIVERSITY IN THE AMERICAS

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IMPACTS OF CLIMATE EXTREMES ON BIODIVERSITY IN THE AMERICAS

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ABSTRACT: Since 1970, climate extremes have been impacting biodiversity in the Americas with greater frequency, duration and severity than ever previously recorded. There is widespread evidence of longer droughts, more frequent wildfires, higher temperatures and more intense storms, hurricanes and precipitation events. As well as greater variability of El Niño Southern Oscillation events, the total area impacted by flooding, glacier retreat and permafrost melt, desertification, landslides and avalanches has grown. Further, concurrent extreme events - such as flooding and high temperatures, droughts and high winds, and droughts and flooding - are becoming increasingly common. Extreme events are not only emerging as a critical factor in climate change; they also have a greater correlation to predicted changes in biodiversity than climate change alone. Although ecosystems show high resilience to hurricanes, ice storms and other extreme events, significant impacts on biodiversity may occur once certain thresholds in duration, intensity and severity are exceeded. The resulting losses in biodiversity can reduce ecological resilience and adaptive capacity to climate change. To manage for potential biodiversity loss and to provide adaptation options for ecosystems to become more resilient to climate hazards, researchers and policymakers require a baseline monitoring database. The current database, the forest biodiversity observing network, consists of more than 500 individual observing sites that allow for transect studies to interlink climate and biodiversity information. Canadian case studies are featured to illustrate the benefits of using transect studies to analyze the impacts of climate hazards and their associated risks for biodiversity. To strengthen the existing database of biodiversity observing sites in the Americas, future sites located in areas of critical biodiversity, across climate, chemical and ecological gradients, are discussed. Strategies for risk assessment and the analysis of impacts on biodiversity are shown for sites with hurricane, ice storm and heavy browsing damage.

Keywords: biodiversity, climate extremes, hazards, warming, hurricanes, ice storms, wildfire, drought, floods, diversity curves, synergies, ecosystems, conservation, resilience, adaptation, Smithsonian Institution, global monitoring network

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1. Introduction

The warming of the climate system is unequivocal, as is now evident from observations of increases in global air and ocean temperatures, widespread melting of snow and ice (glacial and permafrost), and rising global average sea level (IPCC, 2007). Within this new reality of climate change, the intensification of climate extremes has emerged as one of the most complex and critical factors, profoundly impacting species, ecosystems and the Earth's biodiversity as a whole (IPCC, 2001; Jentsch et al., 2007).

Small changes in climate can result in disproportionately great changes in frequency and magnitude of extreme events (Leemans and van Vliet, 2005). A shift in the distribution of temperature has a much greater effect at the extremes than near the mean. A shift of one standard deviation causes a one-in-40-years occurrence to become a one-in-six-years occurrence, reducing wait times between extreme events (Kharin et al., 2007). Thus, impacts will be more rapid, diverse and widespread than previously predicted (Leemans and van Vliet, 2005).

Ecosystems respond faster to extreme weather than to average climate. There is a more rapid appearance of ecological responses to extreme events and most observed changes in biodiversity are attributed to changes in extremes (Leemans and van Vliet, 2005). Seasonal extent and climate variability are more of a factor in explaining species gradients than annual climatic conditions, with the exception of annual potential evapotranspiration (Githaiga-Mwicigi et al., 2002). The rate of climate change and the impact and pattern of climate extremes will be critical, and these will vary at national, regional and even local levels.

Ecosystems display amazing recovery responses to most climate extremes. In some cases, biodiversity may actually increase because of a reduction in the dominant species that allows for a greater number of non-dominant species to occupy the site (Huston, 2007). There may also be an increase in biodiversity as more invasive species and warmth-demanding plant species occupy sites impacted by climate extremes. But while a warmer climate can, under certain scenarios, eventually support more biodiversity (new species), it also leads to losses of native species.

Biodiversity generally decreases in the immediate- to short-term when subjected to climate extremes, especially with reduced wait times between events. This is especially true of intense fires, hurricanes (Category 3 or higher), heat waves, extreme precipitation and storm surges, prolonged drought and desertification. The biodiversity of species adapted to cold and wet conditions, species in high latitude areas, species with low reproductive rates and/or limited mobility, endemic species, and specialist species with narrow habitat requirements and long lifetimes is expected to decrease with increased climate extremes (Archaux and Wolters 2006; Leemans and van Vliet, 2005, Appendix 1).

The threat of climate extremes to biodiversity is 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 them less resilient to change. The situation is

dire, with biodiversity decreasing 1,000 times faster now than at rates found in the fossil records (Balvanera, 2006). In the past, one mammal and two bird species were lost every 400 years; at present-day rates, 58 mammals and 115 birds are being lost in an equivalent time span (Groombridge, 1992). Species of mammals and birds reported to be extinct since 1970 include the Omiteme cottontail, Toolache wallaby, Dobson's fruit bat, Colombian grebe, Bush wren, and the Guam flycatcher (<http://www.unep-wcmc.org/latenews/extinct.html>).

Biodiversity and climate have a complex, symbiotic relationship. Not only does climate impact biodiversity but biodiversity, in turn, also mitigates climate extremes. Biodiversity is fundamental to climate regulation and is an important consideration in stabilizing ecosystems and supporting sustainable development (Stott, 2007). Ecosystems containing many different plant species serve as more efficient carbon sinks, are more productive and can better withstand and recover from climate extremes, pests and disease. As extreme events continue to escalate in intensity, the capacity of natural ecosystems to act as buffers to climate change, including climate extremes, is undermined. This has serious implications for ecosystems and societies (IPCC, 2001; Jentsch et al., 2007).

How ecosystems cope with escalating climate extremes is thus a central question in climate change and ecological conservation (Reusch et al., 2005). The International Panel on Climate Change reports a measurable increase in intense tropical cyclone activity and areas impacted by drought since 1970 (IPCC, 2007). The same trend is evident for wildfire and severe floods. Most current climate change studies indicate that the frequency, duration, severity and intensity of extreme events will continue to increase and that there will be more climatic variability (Conway, 2007; Markham, 1996; Jentsch et al. 2007, Appendix 1). With such intensive changes impacting ecosystems, it is imperative to understand these changes and to track responses to climate extremes across a range of ecosystems and bio-climatic zones in the Americas.

A comprehensive review of the scientific literature was compiled to identify current and anticipated impacts of six major categories of climate extremes on biodiversity in the Americas: extreme heating; hurricanes; drought; ice storms; wildfire; and precipitation and floods. Analysis of these findings, as well as data obtained from a standardized assessment of diversity in existing 1-ha biodiversity sites, reveals how dramatically climate extremes are reshaping ecosystems and reinforces the need for a global monitoring organization to track changes and make appropriate adaptation recommendations.

2. Measuring the Impact of Climate Extremes

Gauging the impact of climate extremes on biodiversity requires reliable quantitative forms of measurement. Diversity curves are a rapid assessment tool that allows scientists to consider all species and not focus solely on the rare ones. They can be used to illustrate climate-related impacts, with the y-axis representing proportional abundance on a logarithmic scale and the x-axis representing the number of species or families. The families are ranked from greatest to least abundance, with each family having a minimum of five individuals.

Diversity curves provide a relative measure of proportional abundance of trees between sites, identifying areas of high, moderate and low abundance. Latitudinal gradients of diversity exist from high in the tropics to low in the arctic. Peru averages 152 different plant species per hectare, with a diameter of 10 cm or more. In northern Europe, the average is 18 species per hectare; in the eastern United States, it is 29. In Canadian sites, the average number of tree species is 11 per hectare. The diversity curves can also show if and to what extent the number of families might be reduced through climate extremes, as well as other threats such as human impact and prescribed burns (Environment Canada, 2003).

Figure 1 shows diversity curves for tree families generated from biodiversity data for the hurricane-impacted site at Bisley, Puerto Rico vis-à-vis comparable diversity at Backus Woods, Long Point Biosphere Reserve, Canada, and Soberania National Park, Panama, highly diverse Urubamba, Peru, moderately diverse Jiangfengling National Park, China, and Dikola, Cameroon, and single-species forests in the Charlevoix Biosphere Reserve, Canada. Black spruce at Charlevoix is an important Canadian monoculture benchmark: however, this is only one tree family per hectare compared to nearly 50 in South America. Backus Woods, Canada, and Bisley in Central America have a similar number of families (<15), while Dikola, Cameroon, has around 30 families per hectare (Figure 1). The diversity curves suggest that the conservation of a single species in a northern ecosystem may be more critical to the way that an ecosystem functions than it would in a highly diverse tropical ecosystem, with its abundance of species and genetic variations.

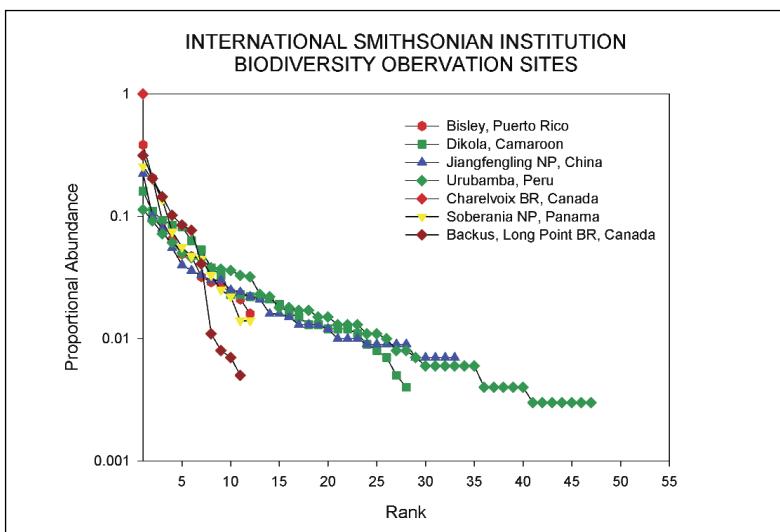


Figure 1 Diversity in Smithsonian International forest biodiversity observing sites for Asia, Africa, South America and Canada.

The diversity curves provide a benchmark for establishing existing biodiversity under current climate conditions. To see how climate extremes may affect this biodiversity, sites for which data are available have been evaluated to determine if they experienced a climate extreme during the monitoring period. The diversity curves were then compared before and after the event and also with similar sites that had not experienced a climate extreme. Since the existing network of 1-ha biodiversity monitoring plots were sites of opportunity – established in biodiversity reserves, parks or university lands and not necessarily in places where climate extremes were expected to occur – there is not enough data to generate diversity curves for the majority of the climate extremes examined here. The resulting gap in data underscores the importance of strategically locating sites in ecosystems vulnerable to climate extremes.

3. Literature Review and Analysis of Impacts of Climate Extremes

3a. Extreme Warming

Global air temperatures are expected to increase by 1.4 to 5.8°C by the end of the century, a rate of warming almost certainly without precedent in the last 10,000 years (IPCC, 2001). Increasing frequency and occurrence of higher day and night extreme temperatures is predicted. It is estimated that 3% of species will do well under the new conditions, 9% will experience no change, 15% will be able to adapt and 73% will not be able to adapt (Fischlin, 2007). Heat-stressed and degraded systems are expected to be replaced by better adapted ones, but degradation is fast and recovery is slow. The recovery process is impacted by habitat fragmentation, pollution and other land-use changes. All regions of the Americas will be impacted, particularly raised peat bogs, the arctic, alpine and mountainous areas, the boreal forest, and arid and semiarid ecosystems.

Warmth-demanding plant species have become more abundant in the last 30 years, coinciding with a precipitous rise in temperatures. More generalist species that are better able to compete and opportunistic species with wide ranges and rapid dispersal are likely to become more abundant, while endemic species and specialists with narrow habitat and long lifetimes are in danger of declining. There will likely be an increase in weedy plants or invasive species because of their ability to reproduce at a faster rate. High temperatures may also reduce cold resistance of plants and negatively influence species' responses to variability in temperature extremes. With extremely high temperatures, there is a risk of species extinctions and decline or death of tropical or temperate forests.

Canadian ecosystems and communities are already experiencing the challenge of adapting to a changing climate, with average temperatures in Canada's north warming at rates some two to three times greater than the rest of the world. Canada's northern ecosystems, indigenous cultures and population health are experiencing significant impacts from the changing climate and from other related atmospheric changes, including increasing persistent organic pollutants, ultraviolet radiation levels, an expected 50% melting of the permafrost and decreased snowfall (Gough and Leung, 2002). Ice is thinner, breaking up earlier and forming later. Animals, including polar bears and some bird species, may be extirpated in Ontario, Canada, as their range shifts north (Varrin et al., 2007).

In tropical Central and South America, there is a high risk of bird loss and significant species extinctions in the near future in areas with the most significant concentration of biodiversity. A 1°C increase in global air temperature puts 50% of large primates and 9% of tree species at risk of extinction and modifies the functioning and composition of forests (IPCC, 2001; MEA, 2005). It also reduces boreal forests by 25% and causes major dieback in these and other forests (Markham, 1996). With forest dieback in the Amazon, there is less recycling of rainfall and increased CO₂ in the atmosphere (Betts, 2007), as well as a massive concomitant increase in the abundance of lianas. This increase in lianas results in a less efficient carbon sink since it provides smaller forest carbon stores than the larger, longer-lived trees (Betts, 2007).

Several biomes in Costa Rica with the highest numbers of endemic species are especially vulnerable to extremes in temperatures and may experience the largest reductions in area or will disappear completely (reviewed by Malcolm et al., 2006). El Niño Southern Oscillation has been identified as the cause of decreasing precipitation and increasing temperature in Costa Rica. When these climate extremes are combined with deforestation, a rising of the cloud cap will probably occur. In the cloud forests, ferns and orchids will die with the lifting of the cloud cap, and toad and frog populations could go extinct (Markham, 1996; Killeen, 2007). Loss of trees in cloud forests is irreversible. If trees are cut, no vegetation is able to gather moisture from clouds and conditions are too dry for the forest to re-establish (Wilson and Agnew, 1992; Folke et al. 2004). Preserving sufficient forest cover in the Amazon Basin to maintain rainfall patterns requires conservation efforts and monitoring across the entire eco-region (Olson et al., 2001).

Extremes in temperature will exacerbate many of the impacts on biodiversity already observed. Ranges of flying insects, birds and raccoons have moved north, arctic and alpine plants have contracted northwards, and genetic changes have been noted in insects, birds and mammals. Breeding dates have shifted for frogs, spring peepers and birds. Other impacts that will be compounded by temperature extremes include increased local diebacks and extinction rates of trees, earlier budding and leafing, and a polewards or upward shift of the treeline border between trees and tundra (IPCC, 2001). 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.

Studies have shown that the urban climate of Toronto, Ontario, Canada, has already warmed equivalent to the expected 2050 climate. To illustrate the impact of extreme temperature on biodiversity, a 1-ha climate change experimental site was established in 2002 at the Humber Arboretum in Toronto. Along with native tree and shrub species, trees native to Washington D.C. – a region two growing zones to the south, the distance that trees might potentially have to migrate with a change in temperature extremes – were also planted at the site. On this site, tree survival and growth was undermined by extreme browsing damage caused by deer and mice populations, which have increased with milder winters. Despite protection from tree guards and other measures, more than 70% of the newly planted trees were browsed, with approximately 30% mortality in five years (Karsh et al., 2008). One of the lessons of this study is that temperature extremes in the urban forest need to be offset with the planting of much larger stock to reduce browsing impact from the corresponding increase in animal populations.

3b. Hurricanes

The number of hurricanes, storms and catastrophic wind events are all expected to increase and to become more intense. A greater number of Category 4 and 5 hurricanes are predicted, as these are linked to El Niño weather events and ocean warming. Since Category 3 or higher hurricanes can result in a restructuring of the forest, Caribbean islands, tropical montane forests, coral reefs and mangroves are all at risk (Krockenberger et al., 2003).

The most immediate and severe effects of hurricanes are complete defoliation and mortality. Most of the damage is a direct result of wind or falling debris, so wind protection in these forests is crucial. Hurricanes may prevent pioneer tree species from living long enough to reach the forest canopy and large individuals of early successional species have the highest damage rates (Dallmeier and Comiskey, 1998). This creates room for late successional hardwoods (Arevalo et al., 2000). Species with rapid growth following the hurricane are the best survivors.

The “storm” forests in the Caribbean are characteristic of the type of trees that grow in a hurricane’s wake: short, shrubby, multi-stemmed trees with spongy heartwood. There is an increase of ethylene production at the root collar resulting in more auxin being produced and more hormones, which results in a sprouting response (van Bloem et al., 2006). Sprouting maximizes leaf area index and minimizes the distance to transport water to the stem. These forests are typified by reduced number of canopy strata, abundance of lianas, absence of giant trees and dominance by one or two species (Dallmeier and Comiskey, 1998).

An increased frequency and intensity of storms and hurricanes may shift ecosystems to a less desired stage, with diminished capacities to generate ecosystem services, followed by loss of ecosystem resilience and increased risk of forest fire (Folke et al., 2004). Forests adapted to extreme events recover quickly, but it may be decades before the site will attain the floristic, physiognomic and avifaunal characteristics of the mature forest (Dallmeier and Comiskey, 1998).

Figure 2 shows the Bisley site in Puerto Rico before and after Hurricane Hugo hit in 1989. There was a reduction in the number of families, from nine to eight a year after the hurricane. By 1999, there were 12 or more families, which is comparable to other sites in the region. It appears that the hurricane initially reduced biodiversity, but that recovery took place quite quickly.

3c. Severe Drought

The regions impacted by drought are predicted to expand, and summer drought is expected to increase in frequency, extent, and duration before the end of this century (Archaux and Walters, 2006; Fischlin, 2007). Tropical montane forests will be particularly affected. These forests support ecosystems of distinctive floristic and structural form and contain a disproportionately high number of the world’s endemic and threatened species. Drought in some regions of the Americas may be accompanied by increasing aridity and desertification (Markham, 1996). As summer soil moisture decreases, drought stress increases.

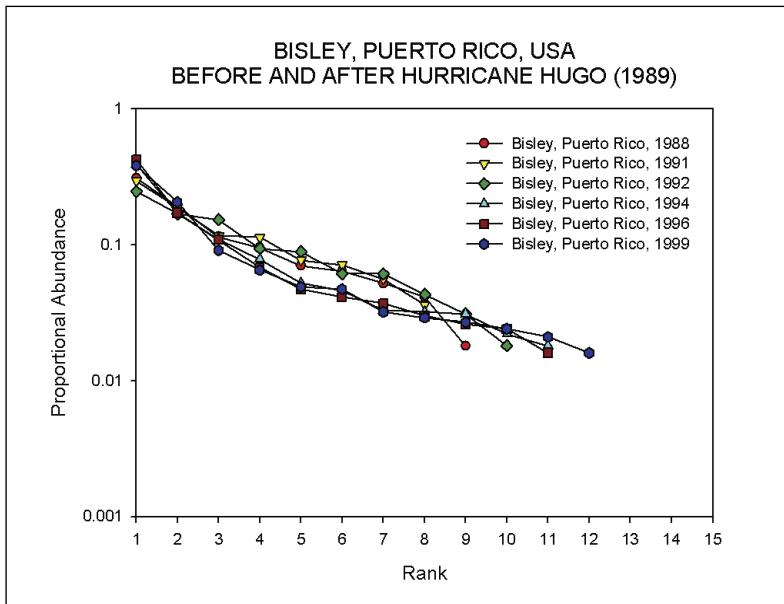


FIGURE 2 Diversity of tree species in Bisley, Puerto Rico, one year prior to the hurricane damage in 1989 and at subsequent measurement periods from 1991 to 1999. Note: Data are currently unavailable for all but the top 10 families ranked from highest to least abundance.

Maximum moisture deficits are expected in northwestern Argentina, the southwestern United States and northwestern Mexico. Central California and the Intermountain West may have significant deficits. North Chile and central and southeastern Argentina are predicted to be dry, and the area affected by very dry conditions may double as a result of climate change and climate extremes (Laurenroth et al., 2004). The evergreens in the Amazon could be transformed to savannah ecosystems within the next century (Killeen, 2007). Savannization of Amazonia and drier biomes in northeast Brazil, along with accompanying desertification, is anticipated because of the synergistic combination of climate change, climate extremes and land-use changes (Nobre, 2007).

Forest biodiversity may be particularly resistant to drought, although the duration of drought may be the most important factor when assessing impact on ecosystems. The relationship between the timing of drought, flowering and pollinators is critical. A delay in flowering due to drought can lead to extinction of pollinators (Harrison, 2000). Prolonged drought can also cause desertification, enabling greater encroachment by woody plants into perennial grasslands and associated land degradation in arid and semiarid regions (Peters et al., 2004). Further impacts of desertification include reduced biological productivity and chronic wildfires.

Extreme drought acts synergistically with other threats. Infestation by bark beetles is closely linked with drought-induced water stress (Allen and Breshears, 1998; Breshears et al., 2005). With increased temperatures, host defences are lowered, allowing pathogens and parasitism to flourish. Extremes can negatively precondition trees and thereby increase their susceptibility to secondary damage through pests and pathogens and to windthrow. Drought combined with high winds leads to increased dust storms and loss of soil and its biodiversity (Krockenberger et al., 2003).

3d. Ice Storms

Most climate models project a decrease in frequency and magnitude of extreme cold events. But there is also some evidence of sharp cooling, and the number and severity of ice storms may actually increase in some latitudes (Varrin et al., 2007). Minimum temperature effects can result in sudden cold injuries that are often lethal; however, the timing of extreme frost events may be more important than temperature (Jentsch et al., 2007).

Ice storms result in reduced access for people in the sugar maple industry to forestland because of flooding, deep snow, or wind- and ice-damaged trees. Mortality of trees is indicated at 75% crown damage. Trees have a high rate of recovery at lower damage levels and changes in composition and loss of syrup production are non-persistent (McCready, 2004). Recently thinned forest plantations, single species ecosystems, and maples and oaks are generally the most impacted by ice; however, susceptible species are often balanced by epicormic branching (rapid crown recovery). As with other extremes, more diverse stands are the best form of insurance against impacts (Neilson et al., 2003).

In January 1998, an area from Kingston, Ontario, to the Maritimes in Canada was struck by the worst glaze ice storm of the century. The impact of the storm was concentrated in the valley of the St. Lawrence River, with the zone around St. Jean-sur-Richelieu, southwest of Montreal, Quebec, being the most heavily hit. Prior to the ice storm, four permanent forest biodiversity monitoring sites had been established in the affected region: two sites at the Mont St. Hilaire Biosphere Reserve, Quebec; a site at Gananoque, Ontario; and a site at Ste-Hippolyte, Quebec. After the storm, a quantitative assessment of the damage to all four 1-ha sites was conducted. The Mont St. Hilaire Biosphere Reserve lay within the zone of greatest damage. The range of crown damage for this storm was 20–50% (Environment Canada, 2003).

Figures 3a and 3b show diversity curves for ice storm-damaged pure sugar maple sites in comparison to undisturbed sugar maple and also to more biologically diverse sites. The maple mixed wood sites at Gananoque, Tiffin, and Long Point, Ontario, Canada, have very similar patterns of proportional abundance, with the two Carolinian sites at Long Point having nine to 11 tree families and the maple mixed wood sites at Tiffin and Gananoque having six and eight tree families respectively (Figure 3a).

The two sugar maple sites in Quebec, whether damaged in the ice storm or not, had four tree families (Figure 3b). The ice storm-damaged forest at Gananoque, Ontario, with eight families, was younger

and different in composition than the two impacted sites at Mont St. Hilaire, Quebec, with almost half the number of families. The maple mixedwood site in Mont St. Hilaire had five tree families in comparison to the maple mixedwood site in Grosse-Île Historic Site, Quebec, with seven tree

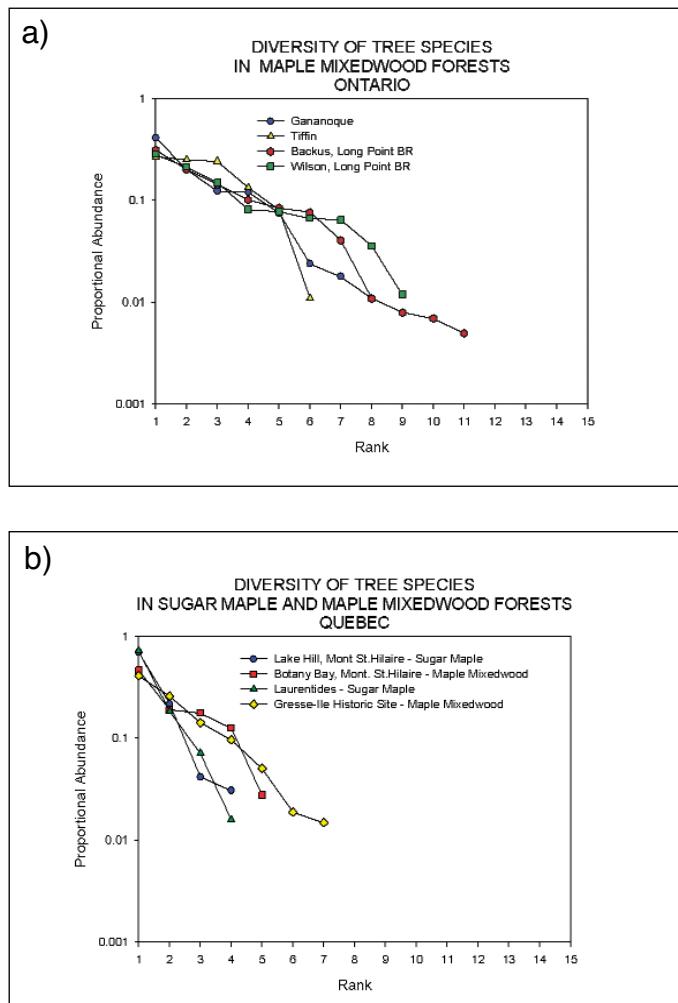


FIGURE 3 a) Diversity of sugar maple site at Gananoque, Ontario, Canada, impacted by ice storm damage in comparison to Carolinian sites at Long Point, Ontario, Canada and b) Diversity of sugar maple at Mont St. Hilaire, Quebec, Canada, ice storm impacted site in comparison to maple mixedwood site in Quebec, Canada.

families. It is unclear whether this reduction in families could be attributed to the ice storm, since less than 70% of the crown was damaged.

3e. Wildfire

Forest fire is associated with global climate change and climate extremes (Lavorel et al., 2007). As the maximum number of consecutive dry days is decreasing in the Caribbean and elsewhere, the number of areas with severe wildfires is expected to rise in the Americas by the end of this century. Fire seasons are expected to lengthen by as much as 30 days in some regions, triggered by increased spring and winter temperature extremes and earlier spring snowmelt (Miller, 2006). An earlier start to the fire season is anticipated, with a significantly greater number of areas experiencing severe to extreme fires.

Already a trend of increasing fire size, amplitude and duration has been observed (Odion et al., 2004). The area burned by forest fires in Canada has risen dramatically since 1970 as summer season temperatures have warmed. The areas burned in the United States have also been on the rise since 1960 (Fishlin, 2007). Large and severe wildfires are predicted to become more common. The areas particularly at risk are boreal forest, taiga, temperate forests, managed stands and forest plantations, streams and fisheries.

Extreme forest fire modifies biodiversity and can result in significant changes in distribution of dominant plant species and younger age distributions (Stocks et al., 1998.). It also affects the understory and bares mineral soil (Lavorel et al., 2007). In this respect, its impact exceeds those of other extreme events (Eversham and Brokaw, 1996) and may incite a more rapid rate of vegetation transformation than other climate-induced change. It can cause temperate dry forests to become grasslands and moist tropical forests to become dry woodlands. With extreme fire, seedling establishment is hindered, plant and animal habitat is modified, and species are at greater risk.

Fire is synergistically linked to El Niño events, hurricanes, drought, lightning strikes, deforestation, forest fragmentation and land-use change. Extreme forest fire is most severe during El Niño years, when drought conditions predominate (Killeen, 2007). Fires in the tropics often follow hurricanes. Since these forests are often not adapted to fire, more than 90% of all canopy trees can be destroyed and the understory completely burned. Even so, recovery may occur with vegetation repopulating the site in five years' time but with different species, causing the forest to be in an earlier successional stage and therefore less able to withstand climate extremes in the future. Fire is more prevalent in degraded forests, so any extreme or human impact that reduces the resiliency of the forest puts it at higher risk of extreme fire. Large forest fires release tons of carbon dioxide into the atmosphere, which acts as an escalating trigger for even more climate extremes and fire.

3f. Intense Precipitation and Floods

The frequency and variability of extreme precipitation showers is increasing. This puts excessive stress on ecosystems that can more readily adjust to reduced precipitation than greater variability in precipitation. Areas vulnerable to extreme and variable precipitation are tropical montane forests,

peat bogs, and arctic, arid and semiarid regions. Intense showers have a particularly significant impact in places like Venezuela, where the risk of erosion may be higher on steep deforested slopes.

The number of flood disasters is expected to increase, and these may alternate in the same regions as droughts. Storms and floods threaten low-lying islands, boreal forest, coral reefs, mangroves, coastal marshes, fisheries, animal habitat and sandy beaches. The combination of floods and high temperature events is also on the rise, especially impacting rivers and wetlands. Ocean warming and ocean acidification is escalating, affecting coral reefs, zooplankton populations and shell-producing organisms, while glacier retreat and permafrost melt is becoming more extensive in polar, mountain and alpine regions. This type of extreme is also linked to greater risk of landslides, avalanches, floods, mudslides and reduced water availability. Simultaneously, sea level rise and storm surges are also increasing, impacting aquifers, estuaries, fisheries, and agriculture and wildlife reserves through saltwater intrusion, land inundation and habitat destruction.

4. Synergies Between Climate Extremes and Other Threats to Biodiversity

The impacts of climate extremes will depend on other significant processes, such as habitat loss and fragmentation. The top threats to biodiversity that are exacerbated by climate extremes include global climate change, habitat destruction, deforestation, invasive species, and fire regime alteration (Ervin and Parrish, 2006, Killeen, 2007). For cerrado vegetation in Brazil, high rates of habitat destruction to cropland may mean that only current reserves will survive (Thomas et al. 2004) and the cerrado may disappear completely by 2030 since it is very suitable for mechanical agriculture (Killeen, 2007).

According to a literature review and assessment by the WWF (2007), summarized in Appendices 2 and 3, the primary threat to biodiversity is deforestation in Brazil, the Caribbean, Chile, Colombia, El Salvador, Guyana, French Guyana, Mexico, Panama, Peru and Venezuela. This suggests that any international effort on introducing incentives for avoided deforestation in Central and South America may have tremendous benefits.

Human impacts decrease ecosystem resiliency and increase vulnerability to climatic hazards (Betts, 2007). Discrete events of novel extreme magnitude and frequency may drive ecosystems beyond stability and resilience (Jentsch et al., 2007). Resiliency may be exceeded this century because of climate change, climate extremes, land-use changes, pollution and overexploitation of resources (high confidence IPCC4 – Fischlin, 2007). The rapid rate of climate change, climate extremes and a fragmented landscape will inhibit the ability of many species to adapt or migrate to regions adequate for survival (Killeen, 2007). Key climate variables may increase in frequency to a point at which species are unable to recover normal or viable populations (Markam, 1996). All of these threats are challenges for mitigation and adaptation and may involve reassessment of human economic activity. A description of a few of the major impacts and why they are of concern, along with recommended adaptations, are listed in Appendix 4.

5. Baseline Monitoring Database

The synergistic interactions between climate extremes and other hazards are impacting ecosystems to such an extent that it is imperative for a global monitoring network to track these changes and assess ecosystem resiliency. To manage for potential biodiversity loss and to provide adaptation options to help ecosystems become more resilient to climate hazards, researchers and policymakers require a baseline monitoring database. Organizations such as the Smithsonian Institution are recognizing the need for such a monitoring network and are starting to put a framework in place.

In 1992, the Smithsonian Institution (Dallmeier, 1992) initiated a global biodiversity monitoring program under the auspices of UNESCO. In the Americas, this forest biodiversity observing network consists of nearly 500 individual observing sites in 20 countries (Figure 4). The design of the sites recognizes that biodiversity conservation is not single-species management but, rather, the ability to manage multi-taxa simultaneously. It is also able to support the four major types of habitat biodiversity monitoring activities: monitoring based on species at risk; monitoring based on population trends; monitoring based on status and trends in habitat; and monitoring based on

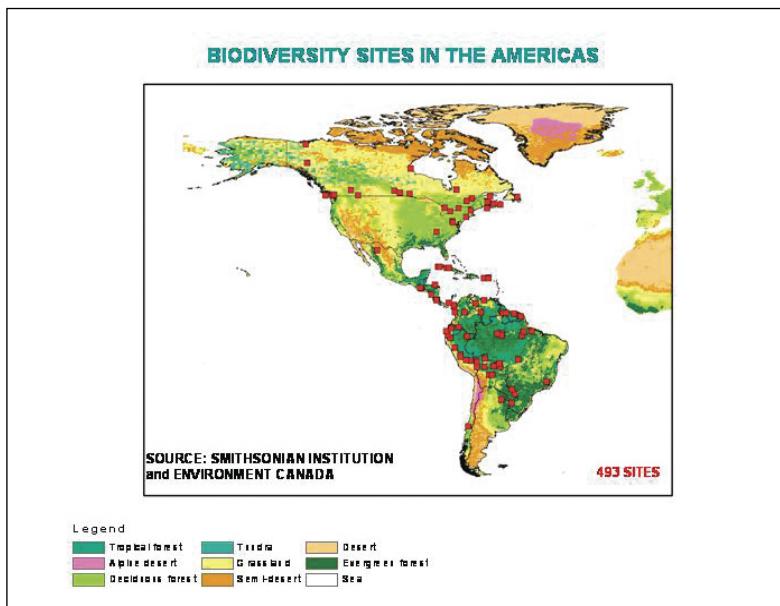


FIGURE 4 Smithsonian Institution forest biodiversity observing sites in the Americas. Source: Smithsonian Institution and Environment Canada

threats to biodiversity. By incorporating standardized 1-ha plot sizes, measurement protocols for multi-taxa and transects across physical, chemical and ecological gradients, the forest biodiversity observing network is able to facilitate unique investigations into the cumulative impacts of climate extremes on forest biodiversity that can increase understanding of climate change and help reduce the adaptive deficit of the Americas (Fenech et al., 2005).

Among the important findings that these sites can help yield are baseline data on climate variability and extremes in ecosystems. The heat-unit-by-family biodiversity model for forests, suggested by Rochefort and Woodward (1992), is a useful means for obtaining such data.

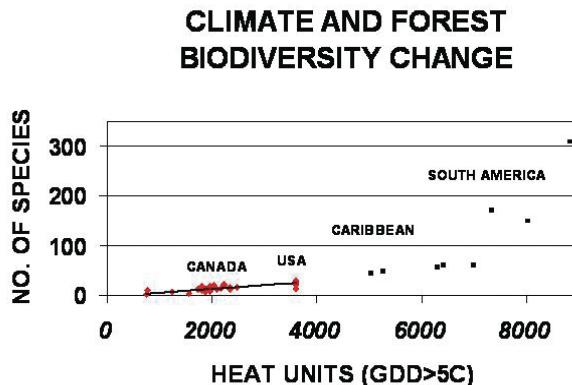
Heat is a powerful trigger of climate extremes. Changes of 1 or 2° centigrade average annual global temperature translate into significant biological impacts, adaptations and vulnerabilities. The heat unit is the accumulation of heat above the base relationship temperature of 5°C commonly referred to as a growing degree day (GDD). This basic relationship can serve as an effective diagnostic tool for gauging expected versus observed climate variability and identifying sites where biodiversity is or is not in equilibrium with the changing climate (Maclver, 1998). By mapping the spatial variability of climate-based biodiversity and then subjecting it to a 2XCO₂ atmosphere, using climate change scenarios, anticipated and future changes in biodiversity can be calibrated and mapped (Maclver, 1998).

Figure 5 shows the number of species and families as related to heat units in Canada compared to eight sites from Virginia, United States, and sites in Panama, Ecuador, Peru, Bolivia, Paraguay, Argentina, Brazil and Venezuela. The South American sites help to provide the upper limit for forest biodiversity at the family levels along with heat units calculated for the Americas (Karsh et al., 2007). Based on sites in Canada, the United States, and Central and South America, preliminary research seems to suggest that the Family Diversity Axis may not be linear but, rather, logarithmic or exponential approaching equatorial regions (Maclver, 1998; Karsh et al., 2007).

In Canada, the heat-unit-by-family-biodiversity model has not only enabled initial verification of the family biodiversity baseline but also allowed for the calibration of biodiversity for mixedwood forest species in southern Ontario. In addition, it has helped to identify areas of southern Ontario that will require enhanced conservation practices for the adaptability of native species, including areas that will be vulnerable to climate extremes and other concurrent impacts such as invasive exotic species.

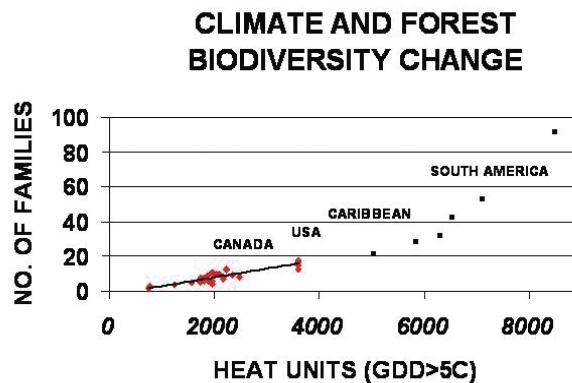
Figure 6 depicts the gradient analysis and the relative linearity of the basic heat by family biodiversity relationship for mixedwood forest sites from Long Point on Lake Erie to Tiffin on Georgian Bay, Ontario, Canada (Maclver, 1998).

a)



SOURCE: KARSH AND MACIVER, ENVIRONMENT CANADA

b)



SOURCE: KARSH AND MACIVER, ENVIRONMENT CANADA

FIGURE 5 Number of a) species and b) families as related to heat units in Canada compared to reference Smithsonian Institution forest biodiversity observation sites in the United States, Caribbean and South America.

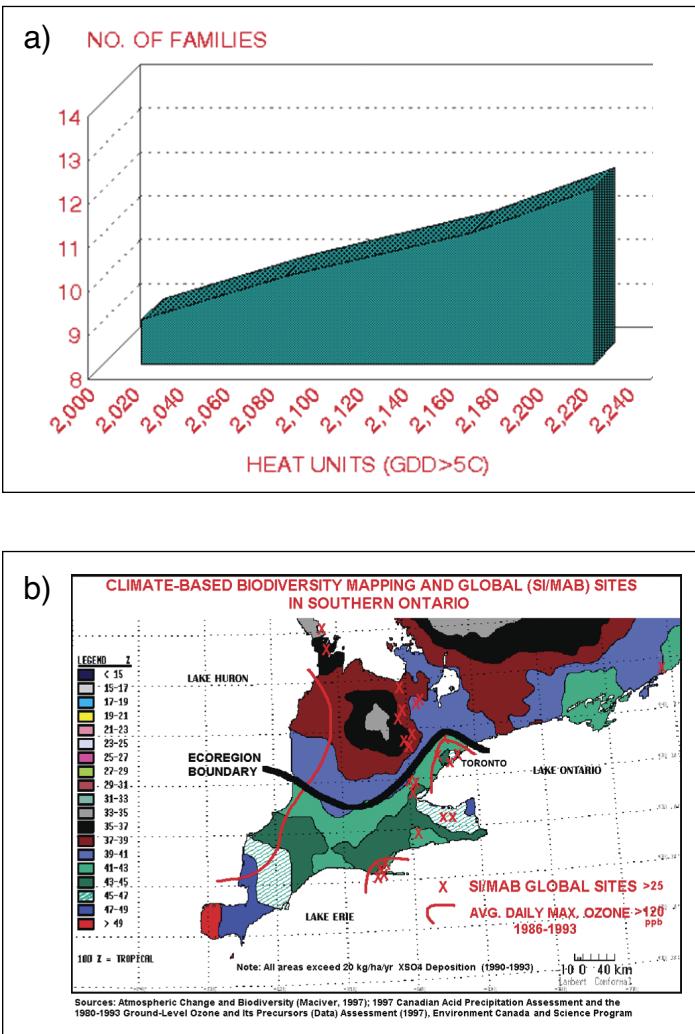


FIGURE 6 a) Heat by family biodiversity for mixedwood forest in southern Ontario, based on Smithsonian Institution forest biodiversity observing sites, and b) cumulative impact of the chemical atmospheres on climate-based biodiversity at Smithsonian Institution forest biodiversity observing sites.

6. Potential New Global Biodiversity Monitoring Sites across the Americas

The most vulnerable ecosystems to climate extremes 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 at high risk of climate extremes and to guide climate change adaptation options.

To meet the full range of monitoring requirements, permanent plot networks must be expanded across the Americas to include sites subject to a broader range of climate extremes, human activities and impacts. Protected areas (IUCN), Global Biosphere Reserves (UNESCO) and Smithsonian global reference sites, based on scientifically sound, standardized monitoring protocols, are essential to provide an effective, community-based platform to monitor changes in ecosystem functioning and resilience.

In Ontario, Canada, analysis showed the tremendous value of using transect studies in evaluating climate impacts on biodiversity. Moreover, with only 11 families at the Canadian network's most diverse location in Long Point, Ontario, it underscored the fact that Canada can ill afford to lose a single species. In Ontario and Quebec, Canada, and in Bisley, Puerto Rico, the analysis further demonstrated the value of using Smithsonian sites established prior to the climate extreme event, allowing for direct comparisons of impacts.

It is recommended that more forest biodiversity observing sites be established in accordance with the Smithsonian Institution protocol across ecological, chemical and climate gradients in highly altered landscapes and vulnerable areas in the Americas to detect change and adaptation response to climate extremes. With sites ranging from the equatorial to polar, climate-biological transects using standardized monitoring and global modelling could be used to further calibrate this analysis. The forest biodiversity global site networks, established to evaluate climate extremes under increasing human impact, would increase their coverage by being connected using GIS, remote sensing-type technology.

The World Wildlife Fund has ranked eco-regions in the Americas by distinct biodiversity features: species endemism, rarity of higher taxa, species richness, unusual ecological or evolutionary phenomena and global rarity of habitat type (WWF, 2007). This is particularly helpful when identifying areas to monitor. Areas in urgent need of protecting are regions in which monitoring sites need to be established. The areas identified as being in need of protection are lowland and montane forests in western Amazonia (Thomas et al., 2004), as well as the Pantanal, Gran Chaco, and Caatinga regions (Killeen, 2007). The best remaining refugia for lowland moist forest species are on the western edge of Amazonia, adjacent to the Andean highlands. It is vital to strengthen and expand protected areas and monitoring networks in the western Amazon. As much forest should be conserved in Amazonia as possible, since species ranges are expected to change drastically (Miles et al., 2004).

Some areas and species should be earmarked for protection, monitoring and restoration simply for their overall significance and contribution to biodiversity. Peat bogs sequester twice as much CO₂ as all the world's forests even though they form only 3% of the global land area. Willow absorbs eight tons of CO₂ in its first growing season. Thirty-five percent of the world's crops depend on pollinators such as bees. Tropical forests have 50% of all plant and animal species, two-thirds of known terrestrial species and the largest number of threatened species. These forests have vertebrates that are very sensitive to the abundance of food reserves, birds and mammals that are affected by unusual weather, and food plants and trees whose flowering and survival, respectively, is highly vulnerable to drought. Thus, all of these ecosystems need to be monitored closely as their total impact on ecosystem resiliency is high.

7. The Case for a UN Global Monitoring Organization

Climate extremes will have a powerful impact on biodiversity and on the human communities that benefit from this biodiversity. Because of the strong linkages between biodiversity and climate extremes, there are many instances at regional, national and international levels where integrated joint actions that address the synergies between the issues are more effective than dealing with each issue separately.

It is expected that biodiversity's natural adaptation responses to a changing climate, especially given other environmental pressures such as habitat loss and fragmentation, will be insufficient to stem the additional losses in biodiversity triggered by climate change. As a result, planned or directed adaptation activities are urgently needed now to slow the increased rates of future biodiversity losses. Maintaining biodiversity as an adaptation strategy allows ecosystems to provide goods and services to communities while societies learn to cope with climate change. Adaptation in support of biodiversity conservation is also essential if United Nations Framework Convention on Climate Change (UNFCCC) objectives and Millennium Development Goals for poverty alleviation, food production and sustainable development are to be met.

The integration of adaptation and mitigation actions within the context of climate extremes, biodiversity conservation and sustainable development all call for greater synergy in implementing the Convention on Biological Diversity (CBD) and other relevant multilateral environmental agreements. Synergies in protecting biodiversity under climate change will be facilitated by proposed joint action on biodiversity and mitigation through international pilot measures to reduce greenhouse gas emissions from deforestation along with adaptation to deal with the changing climate change impacts.

Planned adaptation encompasses efforts to restore resilience to ecosystems, since resilient ecosystems maintain biodiversity, continue to deliver ecosystem goods and services, and protect human, plant and animal communities from climate hazards such as erosion, flooding and drought. A wide range of adaptation activities has been designed or planned by many countries – including Canada, the United States, Mexico, Colombia, Kiribati, Sudan, Nepal, Bangladesh, the United

Kingdom and Finland (CBD, 2006) – but few such adaptation actions have been implemented to date. In many cases, adaptation actions have been delayed because the knowledge base and partnership processes required to support adaptation implementation for biodiversity need to be strengthened first. Studies indicate that many additional species will be lost if adaptation- and resilience-building actions continue to be delayed, while management options will become more limited and expensive and have a lower likelihood of success.

Given that climate extremes and land degradation are major causes of biodiversity loss and that biodiversity conservation and its sustainable use can contribute to both climate change mitigation and adaptation, it is necessary to have an organization responsible for promoting synergy at local, national and international levels. Desertification and land degradation issues affect global climate change through soil and vegetation losses, while biodiversity in turn influences carbon sequestration, thereby helping to regulate climate change. Since climate extremes pose one of the most significant threats to biodiversity, activities that promote adaptation to climate change can also contribute to the conservation and sustainable use of biodiversity, sustainable land use and water management.

All nations in the Americas must be encouraged to recognize the importance of developing synergistic actions on biodiversity, adaptation and climate change that maximize opportunities for successful biodiversity conservation while also helping to slow the rate of future losses of biodiversity. Maintaining and enhancing biodiversity should be part of all national policies, programs and plans for adaptation to climate extremes in order to allow ecosystems to continue providing necessary goods and services, including support for natural disaster preparedness. Such a policy would increase investment in adaptation initiatives that strengthen resilience in natural ecosystems. One potential initiative that shows great promise is offering incentives for the conservation of forests (avoided deforestation) and peatlands. This and other activities that slow deforestation and/or forest degradation could provide substantial biodiversity benefits and help to meet the global goal of reducing the rate of loss of biodiversity by 2010. The creation of a new organization at the United Nations level, responsible for consolidating and increasing the Global Biodiversity Monitoring Network and integrating research on biodiversity and climate, would help immeasurably in developing and facilitating such urgently needed pan-American responses to climate change and extremes.

The disaster which struck New Orleans after Hurricane Katrina in 2005 illustrates how healthy and resilient ecosystems are truly our best defence against the impacts of climate extremes. Hurricane Katrina touched down on a coastal region of the United States that has been under environmental pressure for over a century. Re-engineering of the Mississippi River, accomplished through a system of canals and levees, diverted natural sedimentation flows and steadily eroded coastal wetlands. Development also destroyed barrier islands and oyster reefs that buffered the coast. During the hurricane, the tidal surge was able to travel unimpeded up shipping canals and burst over the levees surrounding New Orleans. Although damage from the storm would have been considerable in any case, breaches occurred more often in areas where wetlands had been destroyed and levees were exposed to wave action. A global monitoring organization is essential to establishing when and where such disasters may happen and to determine when ecosystems are out of equilibrium so that action can be taken before the critical tipping point is reached.

References

- Allen, C.D., and D.D. Breshears. 1998. Drought-induced shift of a forest-woodland ecotone: rapid landscape response to a climate variation. *PNAS*, 95, 14839-14842.
- Archaux, F., and V. Wolters. 2006. Impact of summer drought on forest biodiversity: what do we know? *Ann. For. Sci.*, 63, 645-652.
- Arevalo, J.R., J.K. DeCoster, S.D. McAlister, and M.W. Palmer. 2000. Changes in two Minnesota forests during 14 years following catastrophic windthrow. *J. Veg. Sci.*, 11, 833-840.
- Balvanera, P., A.B. Pfisterer, N. Buchmann, J. He, T. Nakashizuka, D. Raffaelli, and B. Schmid. 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services. *Ecology Letters*, 9, 1146-1156.
- Betts, R. 2007. Biodiversity: Ecosystem and climate functioning. Presentation at Biodiversity-Climate Interactions, Royal Society, London, 12th June 2007.
- Breshears, D.D; N.S. Cobb, P.M. Rich, K.P. Price, C.D. Allen, R.G. Balice, W.H. Romme, J.H. Kastens, M.F. Floyd, J. Belnap, J.J. Aderson, O.B. Myers, and C.W. Meyer. 2005. Regional vegetation die-off in response to global-change-type drought. *PNAS*, 102 (42), 15144-15148.
- CBD. 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, 43 pp.
- Conway, G. 2007. IPCC 4 at the RGS. Presentation at Climate Change: Impacts, Adaptation and Vulnerability, Royal Geographical Society, Zurich, 18th September 2007.
- Dallmeier, F. 1992. Long-term monitoring of biological diversity in tropical forest areas. Methods for establishment and inventory of permanent plots. *MAB Digest Series*, 11, UNESCO, Paris.
- Dallmeier, F., and J.A. Comiskey (eds.). 1998. Forest biodiversity in North, Central and South America and the Caribbean: research and monitoring. *Man and the Biosphere Series*, Vol. 21. UNESCO and The Parthenon Publishing, Carnforth, U.K.
- Environment Canada. 2003. EMAN: Monitoring biodiversity in Canadian forests. Report prepared by EMAN Coordinating office, Burlington, Ontario, Canada, 89 pp.
- Ervin, J., and J. Parrish. 2006. Toward a framework for conducting ecoregional threats assessments. *USDA Forest Service Proceedings*, PMRS-P-42CD, 105-112.
- Eversham, E.M., and N.V.L. Brokaw. 1996. Forest damage and recovery from catastrophic wind. *The Botanical Review*, 62 (2), 113-185.
- Fenech, A., M. Murphy, D. MacIver, H. Auld, and R. Bing Rong. 2005. The Americas: Building the adaptive capacity to global environmental change. Occasional Paper 5, Adaptation and Impacts Research (AIRD), Environment Canada, 20 pp.
- Fischlin, A. 2007. Impacts on the global resource base: ecosystems. Presentation at Climate change: impacts, adaptation and vulnerability, IPCC, Assessment Report Four, Working Group II, Royal Geographical Society, Zurich, 18th September 2007.
- Folke, C., S. Carpenter, B. Walker, M. Scheffer, T. Elmqvist, L. Gunderson, and C.S. Holling. 2004. Regime shifts, resilience, and biodiversity in ecosystem management. *Annu. Rev. Ecol. Evol. Syst.*, 35, 557-81.
- Githaiga-Mwicigi, J.M.W., D.H.K. Fairbanks, and G. Midgley. 2002. Hierarchical process defines spatial pattern of avian assemblages restricted and endemic to the arid Karoo, South Africa. *J. Biogeogr.*, 29 (8), 1067-1087.

- Gough, W.A. and Leung, A. 2002. Nature and fate of Hudson Bay permafrost. *Regional Environ. Change*, 2, 177-184.
- Groombridge, B. (ed.). 1992. *Global biodiversity: status of the earth's living resources*. Chapman and Hall, London.
- Harrison, R.D. 2000. Repercussions of El Niño: drought causes extinctions and the breakdown of mutualism in Borneo. *Proceedings of the Royal Society of London, Series B: Biological Sciences*, 267 (1446), 911-915.
- Huston, M. 2007. Climate extremes and biodiversity. Personal communication.
- IPCC. 2001. *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. J. McCarthy, O. Canziani, N. Leary, D. Dokken, and K. White (eds.). Contribution of Working Group II to the Third Assessment Report of the IPCC, Geneva, Switzerland.
- IPCC. 2007. *The Physical Science Basis: Summary for Policymakers*. A Contribution of Working Group 1 to the Fourth Assessment Report of the IPCC, Geneva, Switzerland.
- Jentsch, A., J. Kreyling, and C. Beierkuhnlein. 2007. A new generation of climate-change experiments: events, not trends. *Front. Ecol. Environ.*, 5 (7), 365-374.
- Karsh, M.B., D.C. MacIver, A. Fenech, and H. Auld. 2007. Climate-based predictions of forest biodiversity using Smithsonian's global earth observing network. Occasional Paper 8, Adaptation and Impacts Research (AIRD), Environment Canada, 10 pp.
- Kharin, V.V., F.W. Zwiers, X. Zhang, and G.C. Hegerl. 2007. Changes in temperature and precipitation extremes in IPCC ensemble of global coupled model simulations. *J. Climate*, 20 (8), 1419-1444.
- Killeen, T.J. 2007. A perfect storm in the Amazon wilderness: development and conservation in the context of the initiative for the integration of the regional infrastructure of South America (IIRSA). *Advances in Applied Biodiversity Science*, No. 7, 99 pp.
- Krockenberger, A.K., R.L. Kitching, and S.M. Turton (eds.). 2003. *Environmental crisis: climate change and terrestrial biodiversity in Queensland*. Cooperative Research Centre for Tropical Rainforest Ecology and Management. Rainforest CRC, Cairns, 30 pp.
- Laurenroth, W.K., H.E. Epstein, J.M. Paruelo, I.C. Burke, M.R. Aguiar, and O.E. Sala. 2004. Potential effects of climate change on the temperate zones of North and South America. *Rev. Chil. His. Nat.*, 77, 439-453.
- Lavorel, S., M.D. Flannigan, E.F. Lambin, and M.C. Scholes. 2007. Vulnerability of land systems to fire: interactions among humans, climate, the atmosphere, and ecosystems. *Mitigation and Adaptation Strategies for Global Change*, 12 (1), 33-53.
- Leemans, R., and A. van Vliet. 2005. Responses of species to changes in climate determine climate protection targets. Environmental Systems Analysis Group, Wageningen, The Netherlands, 5 pp.
- MacIver, D. 1998. Atmospheric change and biodiversity. *Environ. Monit. Assess.*, 49, 177
- Malcolm, J.R., C. Liu, R.P. Neilson, L. Hansen, and L. Hannah. 2006. Global warming and extinctions of endemic species from biodiversity hotspots. *Conservation Biology*, 20 (2), 538-548.
- Markham, A. 1996. Potential impacts of climate change on ecosystems: a review of implications for policymakers and conservation biologists. *Clim. Res.*, 6, 179-191.
- McCready, J. 2004. Ice storm 1998: lessons learned. Sixth Canadian Urban Forest Conference, Kelowna, B.C., Canada, 15 pp.

- MEA. 2005. Ecosystems and human well-being. Biodiversity Synthesis. World Resources Institute, Washington, D.C., 100 pp.
- Miles, L., A. Grainger, and O. Phillips. 2004. The impact of global climate change on tropical forest biodiversity in Amazonia. *Global Ecol. and Biogeogr.*, 13, 553-565.
- Nobre, C.A. 2007. Climate change scenarios and impacts on the biomes of South America. Presentation at CPTEC/INPE, Cachoeira Paulista, SP-Brazil.
- Odion, D.C., E.J. Frost, J.R. Strithold, H. Jiang, D.A. Dellasala, and M.A. Moritz. 2004. Patterns of fire severity and forest conditions in the Western Klamath Mountains, California. *Conservation Biology*, 18 (4), 927-936.
- Olson, D.M., E. Dinerstein, E.D. Wikramanayake, N.D. Burgess, G.V.N. Powell, E.C. Underwood, J.A. D'Amico, I. Itoua, H.E. Strand, J.C. Morrison, J. Loucks, T.F. Allnutt, Ricketts, T.H., Y. Kura, J.F. Lamoreux, W.W. Wetengel, P. Hedao, and K.R. Kassem. 2001. Terrestrial ecoregions of the world: a new map of life on earth. *Bioscience*, 51 (11), 933-938.
- Peters, D. P.C., R.A. Pielke, B.T. Bestelmeyer, C.D. Allen, S. Munson-McGee, and K.M. Havstad. 2004. Cross-scale interactions, nonlinearities, and forecasting catastrophic events. *PNAS*, 101 (42), 15130-15135.
- Rochefort, L., and F.I. Woodward. 1992. Effects of climate change and a doubling of CO₂ on vegetation diversity. *J. Exp. Bot.*, 43, 1169-1180.
- Stott, A. 2007. Biodiversity-climate interactions: adaptation, mitigation and human livelihoods. A policy perspective. Presentation at Biodiversity-Climate Interactions, Royal Society, London, 12th June 2007.
- Thomas, C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F.N. Erasmus, M.F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. van Jaarsveld, G.F. Midgely, L. Miles, M.A. Ortega-Huerta, A. Townsend Peterson, O.L. Phillips, and S. E. Williams. 2004. Extinction risk from climate change. *Nature*, 427, 145-148.
- van Bloem, S.J., A.E. Lugo, and P.G. Murphy. 2006. Structural response of Caribbean dry forests to hurricane winds: a case study from Guanica Forest, Puerto Rico. *J. Biogeogr.*, 33 (3), 517-523.
- Varrin, R., J. Bowman, and P.A. Gray. 2007. The known and potential effects of climate change on biodiversity in Ontario's terrestrial ecosystems: case studies and recommendations for adaptation. Climate Change Research Report CCRR-09, 48 pp.
- WWF. 2007. <http://www.worldwildlife.org/science/ecoregions/terrestrial.cfm159>

Appendix 1: Impacts of Climate Extremes on Biodiversity in the Americas

Climate Extremes	Prediction	Impact Areas (Americas)	Impacts on Biodiversity	Source
El Niño Southern Oscillation Events	<ul style="list-style-type: none"> Increasing in frequency, duration and severity More common in the last 30 years Increases as change accelerates with continued warming Smaller diurnal and seasonal changes 	<ul style="list-style-type: none"> North, South and Central America Unique biomes, small island states, irreplaceable features/wet tropics, border ranges (limited places to shift), land masses below cloud base in Caribbean 	<ul style="list-style-type: none"> Increasing adverse risk to biodiversity Strong correlation with changes in biodiversity accounts for most of observed changes More rapid appearance of ecological response Extremes will intensify already existing trends Initial benefits followed by adverse impacts Species not able to adapt or migrate in some cases if climatic thresholds or tolerances exceeded Not able to sustain high levels of human impact for long periods Increased demand for water; water stress with increased temperatures 	Markam, 1996 Dallmeier & Corniskey, 1998 IPCC, 2001 Krookherberger et al., 2003 Leemans & van Vliet 2005 Killeen, 2007
High Air Temperatures	<ul style="list-style-type: none"> Increasing in variability Current models do not predict increase; others suggest an increase in magnitude and frequency 	Midwest USA, Central America and Pacific Coast, Peru, Ecuador, Bolivia, Mexico, Caribbean, Brazil, Colombia, Peru, north Amazonia	<ul style="list-style-type: none"> Indirect cause of landslides, floods, droughts, hurricanes May be trigger for ice storms in eastern Canada Attributed to increased climate variability Increased dry conditions in some regions Increased risk of forest fires May cause desertification in dryland ecosystems Decline in grasslands with variable precipitation 	Breshears et al., 2005
			<ul style="list-style-type: none"> All across North, Central and South America; Alaska, Banks Island, Alberta, Washington, Colorado, California, Olympic Mountains, Montana, Southeast Arizona, Mexico, Central America, Peru, Argentine Islands, Ecuador, Bolivia, northern Chile, Andes Mountains, Colombia 	Markam, 1996 IPCC, 2001 Krookherberger et al., 2003 Leemans & van Vliet, 2005 Malcolm et al., 2006 Fischlin, 2007 Jentsch et al., 2007 Killeen, 2007 Varrin et al. 2007

Appendix 1: Impacts of Climate Extremes on Biodiversity in the Americas cont'd

Climate Extremes	Prediction	Impact Areas (Americas)	Impacts on Biodiversity	Source
High Air Temperatures (cont'd)		• Raised peat bogs, alpine/mountains, Arctic, Boreal forest, arid and semiarid areas	<ul style="list-style-type: none"> • and negatively influence species responses to high temperatures • Southern ecological boundaries more impacted than northern • Gypsy moth and pear thrips more aggressive; malaria, dengue fever increasing • Earlier budding, leafing or blooming; earlier egg-laying, spawning, emergence from hibernation • Polewards or upwards shift of treeline; animal range shifts • Disruption in animal migrations; altered competitive balances • Warmth-demanding species more abundant in last 30 years • Endemic species replaced by generalists (better competitors) • Small changes can have large impacts on biodiversity • Coral reef bleaching (warmer water temperatures) • Range contractions and shifts • Longer growing season, accelerated maturation rates • Effects on sex determination in many species (incubation temperatures) • New species found in northern latitudes, high mountainous regions • New unusual weather patterns in northern regions; thunder, lightning • Genetic adaptation of insects 	Markham, 1996 Allen & Beashears, 1998 Harrison, 2000 IPCC, 2001 Krockenberger <i>et al.</i> , 2003 Peters <i>et al.</i> , 2004 Breshears <i>et al.</i> , 2005 Archaux & Wolters, 2006
Drought	<ul style="list-style-type: none"> • Increasing in extent, severity, frequency and duration • Total area impacted by drought expanding • Increased summer drying • Increased desertification and aridity 		<ul style="list-style-type: none"> • Eastern and Southwest USA: New Jersey, Delaware, Maryland, Rhode Island, West Virginia; Florida, Texas, Louisiana • Central America and Caribbean • Drying of river beds • Increased risk of some pests, pathogens, disease (e.g. bark beetles) • Mortality (prolonged extreme drought – over 15 months) • Increased heat stress • Increased risk of forest fires and water shortages; accelerates soil erosion • Premature leaf fall, dieback, wilting of trees, deterioration of vegetative cover 	

Appendix 1: Impacts of Climate Extremes on Biodiversity in the Americas cont'd

Climate Extremes	Prediction	Impact Areas (Americas)	Impacts on Biodiversity	Source
Drought (cont'd)		<ul style="list-style-type: none"> • South American coastline • Northeastern South America • Southern Peru • Southwest Bolivia • Northeast Brazil • Chile, Argentina • Northern Mexico • Tropical montane forests 	<ul style="list-style-type: none"> • Some taxa increase; less adapted taxa decrease • Good resistance to drought – but duration of drought a factor • May increase biodiversity by reducing dominance of most abundant plants • Increased risk of deforestation • Increased risk of increased use of chemicals • Altered phenology; reduced flowering and reproductive success • Reduced below and above ground biomass • Reduced cover of perennials; rapid colonization of annuals and biennials • Increased rates of species extinctions • Increased risk of windthrow • Decreased crop yields and food security • Increased risk of dust storms when combined with high winds • Greatest impact on very young or old plants, species adapted to cold or wet conditions, and species with low reproductive rates or limited mobility 	Huston, 2007 Jentsch et al., 2007
Desertification	<ul style="list-style-type: none"> • Increasing: expansion of existing areas 	<ul style="list-style-type: none"> • Arid and semiarid regions 	<ul style="list-style-type: none"> • Reduced biological productivity • Change of vegetation area: encroachment of woody plants into perennial grasslands • Land degradation 	Peters et al., 2004
Fire	<ul style="list-style-type: none"> • Increasing in frequency, severity, duration, size, amplitude • Increase in areas burned • Increase in areas with severe fires • Earlier start to fire season and longer fire seasons • Shorter fire return intervals 	<ul style="list-style-type: none"> • Both USA and Canada have seen increases in areas burned in the last 35 years • West Central and Northwestern Canada in boreal forest and taiga, St. Lawrence region • Western USA, Florida 	<ul style="list-style-type: none"> • Possibly most harmful on biodiversity: more rapid rate of vegetation transformation than other climate-induced change • Seedling establishment hindered • Plant and animal habitat modified • Mortality of fire-sensitive species (rainforests, vine forests). • Changes distribution of dominant plant species; affects understory • Bares mineral soil; younger age distributions and earlier successional stages may result • Converts temperate dry forests to grasslands and moist temperate forests 	Everham & Brokaw, 1996 Markham, 1996 Dallmeier & Comiskey, 1998 Stocks et al., 1998 Krockenberger et al., 2003 Odion et al., 2004 Lavorel et al., 2007 Betts, 2007 Killeen, 2007

Appendix 1: Impacts of Climate Extremes on Biodiversity in the Americas cont'd

Climate Extremes	Prediction	Impact Areas (Americas)	Impacts on Biodiversity	Source
Fire (cont'd)		<ul style="list-style-type: none"> Western coast of South America; Argentina Mexico, Nicaragua (Bosawas BR) 	<ul style="list-style-type: none"> • dry woodlands; transforms vegetation (lower NPP) • Increases risk of invasive species and feral animals • Impacts streams and fisheries; higher stream temperatures • Highest impact in forest plantations, shrub and open forest areas; degraded forests, temperate forests, boreal forest, taiga 	IPCC, 2001 Krockenberger et al., 2003
Heat Waves	<ul style="list-style-type: none"> • Increasing in frequency, intensity, duration and severity • Increase in heat index • Increase in dryness 	<ul style="list-style-type: none"> USA: Rockies, North and South Dakota, Illinois, New York, Maine, Arkansas, Texas 	<ul style="list-style-type: none"> • Increased heat stress and mortality (month-long heat waves) • Increased extinction of sensitive species, mortality as temperatures rise above tolerable thresholds for too long a period • Moose not able to withstand high temperatures 	IPCC, 2001 Krockenberger et al., 2003
Extreme Precipitation	<ul style="list-style-type: none"> • Increasing frequency of extreme showers • Increasing variability and intensity; more wet periods • Decreasing in subtropics • Increasing in northern regions 	<ul style="list-style-type: none"> USA: New England, California, Texas Venezuela, Uruguay, Argentina, Brazil, Paraguay, Bolivia, Peru, Haiti Tropical montane forests (cloud cover), raised peat bogs 	<ul style="list-style-type: none"> • Increased difficulty of ecosystems dealing with increased variability of precipitation events • Increased biomass production by plants in semiarid USA • May result in increased deer and mice populations and increased browsing stress • May change competitive ability among plants • May be related to earlier fire season 	IPCC, 2001 Krockenberger et al., 2003
Storms	<ul style="list-style-type: none"> • Increasing in frequency, duration and intensity • Storms more widespread 		<ul style="list-style-type: none"> • Central America, Caribbean, Pacific Coast; linked to warmer, wetter climate and less sea ice (open water provides a source for moisture, heat) • Low lying islands, boreal forests, coral reefs, mangroves, marshes 	Markam, 1996 IPCC, 2001 Folke et al. 2004 Archaux & Wolters, 2006
Floods + High Temperatures	<ul style="list-style-type: none"> • Increasing 		<ul style="list-style-type: none"> • Rivers, wetlands 	Krockenberger et al., 2003

Appendix 1 : Impacts of Climate Extremes on Biodiversity in the Americas cont'd

Climate Extremes	Prediction	Impact Areas (Americas)	Impacts on Biodiversity	Source
Dryness + High Temperatures	<ul style="list-style-type: none"> Increasing in certain regions 	<ul style="list-style-type: none"> Tropical regions 	<ul style="list-style-type: none"> Dieback of humid tropical forest; plants absorb less carbon through photosynthesis than is released through soil respiration, accelerating further warming. Livestock and wildlife prone to heat stress; rainforests suffer 	Krockenberger et al., 2003
Drought + High Winds	<ul style="list-style-type: none"> Increasing 	<ul style="list-style-type: none"> Tropical regions 	<ul style="list-style-type: none"> Caribbean Islands Most of South America Gulf of Mexico, North Atlantic Tropical montane forests, coral reefs and mangroves particularly vulnerable to increasingly intense tropical cyclones Triggered by El Niño-type weather patterns and ocean warming Increase in tropical cyclone peak wind and precipitation intensities 	<ul style="list-style-type: none"> One of the most important disturbances after fire: destroy forests, change competitive interactions among plants and alter successional pathways Reduced diameter, basal area, number of stems, biomass High adaptive response Full recovery rate long (hundreds of years) Increased biodiversity: less dominance of abundant species Significant sprouting; multi-stemmed trees Reduced above-ground biomass; increased NPP (disturbances release nutrients); complete deforestation Long-term impact on forest structure and function; less desirable storm forests, more impact on dry slow-growing forests Reduced wind resistance Prevents pioneers reaching canopy (early mortality for large stems) due to mortality, wind damage, falling debris Increased fire, landslides Diversity maintained (alternate mechanism for forest turnover) but possible decrease between events Increased range in gaps; increased light Accelerates succession; survival rates highest in species with rapid growth Increased damage in even-aged forests Increased freshwater runoff Loss of habitat

Appendix 1: Impacts of Climate Extremes on Biodiversity in the Americas cont'd

Climate Extremes	Prediction	Impact Areas (Americas)	Impacts on Biodiversity	Source
Floods	<ul style="list-style-type: none"> Increasing in severity, frequency, intensity and duration Increased variability of river flows and water availability Increasing risk of winter floods and coastal flooding Increasing number of flood disasters; may alternate with drought 	<ul style="list-style-type: none"> Canada, USA, Mexico Caribbean: Haiti, Dominican Republic Central America: Belize, El Salvador, Costa Rica South America: north Peru, southwestern Bolivia, eastern Brazil, Chile, Argentina, Uruguay, Paraguay, Venezuela, Colombia, Guyana, Ecuador Coastal habitats, beaches, mangrove areas, deforested areas on steep slopes 	<ul style="list-style-type: none"> Land inundation High sedimentation May stimulate lush vegetation Deterioration of vegetative cover 	IPCC, 2001 Krockenberger et al., 2003
Ice Storms, Heavy Snow Events, Frost, Cold Waves, Cold Events	<ul style="list-style-type: none"> Decreasing frequency and magnitude of extreme cold events Milder winters, increasing in magnitude and extent Sharp cooling; frosts increasing Frequency and size of ice storms increasing as more heat is trapped in lower atmosphere 	<ul style="list-style-type: none"> Eastern Canada and USA; Canadian Arctic, Mount Baker, Washington; Black Hills, South Dakota South America: Argentina, Brazil 	<ul style="list-style-type: none"> Mortality with 75% crown damage High adaptability to damage, high rate of recovery at lower levels; epicormic branching Recently thinned conifer plantation more affected Less flexible species (maples, oaks) more affected than more flexible species (pines, birches) May increase biodiversity by reducing dominance of most abundant species Reduced access to forest because of flooding, snow, wind- and ice-damaged trees Direct damage to trees by wind, snow, ice More diverse stands are best form of insurance Severity depends on ice accumulation, duration, area affected, wind speed; timing may be more important than temperature Caribou deaths: snow and freezing rain bury food sources May result in sudden cold injuries that are often lethal 	Neilsen et al., 2003 Krockenberger et al., 2003 McCready, 2004 Jentsch et al., 2007 Huston, 2007 Varrin et al., 2007

Appendix 1: Impacts of Climate Extremes on Biodiversity in the Americas cont'd

Climate Extremes	Prediction	Impact Areas (Americas)	Impacts on Biodiversity	Source
Ice Storms, Heavy Snow Events, Frost, Cold Waves, Cold Events (contd)			<ul style="list-style-type: none"> • May destroy forests, change competitive interactions among plants, alter successional pathways and advance succession 	Markam, 1996 IPCC, 2007 Fischlin, 2007 Conway, 2007 IPCC, 2007
Ice and Snow Melt, Glacier Retreat, Permafrost Melt, Winter Warming	<ul style="list-style-type: none"> • Increasing (especially in the last 25 years) • Sea surface temperatures increasing • Fewer cold extremes • Milder winters • Increased winter rainfall 	<ul style="list-style-type: none"> • Bering Sea, Arctic Ocean, Alaska, Hudson Bay; Rockies • USA: New Hampshire; Glacier National Park, Montana • South America: Colombia, Ecuador, Peru, Bolivia, Venezuelan Andes, Argentina • Polar regions, high mountains 	<ul style="list-style-type: none"> • Sharp drop in summer water flows; increasing erosion • Increased frequency of landslides and avalanches; increased risk of floods and mudslides • Local biodiversity adversely impacted; sea bird decline • Loss of ice sheets • Increased risk of sea level rise, negatively affecting mangroves which buffer against flooding, high winds and erosion • Increased risk of winter river floods • Earlier river thaw, spring ice-out and spring snow melt (may affect fire regimes) • Decreased sea ice and snow; increased thawing of permafrost • Glacier retreat • Reduced water availability with melting of tropical glaciers, leading to increased desertification and aridity, increased pests and diseases and increased impact on soybean production • Earlier spring discharge from snow melt 	CBD, 2006
Sea Level Rise, Coastal Flooding, Storm Surges	<ul style="list-style-type: none"> • Increasing, becoming more rapid • Influenced by increasing ice melt and coastal storms • Collapse of West Antarctic ice sheet might impact sea level suddenly • Triggered by rising air and ocean temperatures 	<ul style="list-style-type: none"> • USA: Hawaii, West Coast, California, Louisiana, Florida Keys, Chesapeake Bay • Caribbean: Bahamas, Bermuda • Mexico • Central America: Panama, Costa Rica, El Salvador, Belize • South America: Argentina, 	<ul style="list-style-type: none"> • Saltwater intrusion of aquifers, estuaries • Beach habitat lost • Increased land inundation • Slow but steady loss of wetlands and drylands • Saltwater inundation of coastal mangrove forests; since 1980, 20% of mangroves gone; 25% more fish on reefs close to mangroves gone • Half of all agricultural lands may be subject to salinization & desertification by 2050 • Negative impact on fish stocks 	

Appendix 1: Impacts of Climate Extremes on Biodiversity in the Americas cont'd

Climate Extremes	Prediction	Impact Areas (Americas)	Impacts on Biodiversity	Source
Sea Level Rise, Coastal Flooding, Storm Surges (cont'd)		<ul style="list-style-type: none"> Brazil, Colombia, Galapagos, Guyana, Ecuador, Peru, Chile, Venezuela, Uruguay Mangroves, coral reefs, coastal marshes, low-lying islands, deltas 	<ul style="list-style-type: none"> Increased storm surges Wildlife reserves submerged 	<ul style="list-style-type: none"> Decline in zooplankton populations Coral reef ecosystem collapse Increased competition from algae Coral reef bleaching (since 1980) Increasing risk of hurricanes Increasing risk of extreme events Sea bird decline Decreased dry season mist; may result in species extinction and declines of frogs, toads and lizards Shoreline and species shifts northwards Upward shift in mountain birds Negative impact on any shell-producing species
Ocean Warming and Ocean Acidification	<ul style="list-style-type: none"> Increasing 	<ul style="list-style-type: none"> USA: West Coast, California, Florida Keys Caribbean: Bahamas, Bermuda Mexico South America: Panama, Galapagos, Ecuador 		<ul style="list-style-type: none"> Markham, 1996 IPCC, 2001
Landslides, Avalanches, Earthquakes Volcanoes		<ul style="list-style-type: none"> Increasing in frequency Landslides influenced by increasing deforestation on steep slopes in South America 	<ul style="list-style-type: none"> USA Mexico Caribbean: Haiti, Puerto Rico, Dominican Republic Central America: Guatemala, El Salvador, Honduras, Nicaragua, Costa Rica, Panama, Coastal Ecuador South America: Venezuela, northern Peru, Guyana 	<ul style="list-style-type: none"> Reduced above-ground biomass; increased NPP (disturbances release nutrients) Debris flow and mudslides Global climate impacted

Appendix 2: Hazards to Biodiversity by Country (South and Central America)

Hazards to Biodiversity	Argentina	Bolivia	Brazil	Caribbean	Chile	Colombia	Costa Rica	Cuba	Dominican Republic	Ecuador	El Salvador
Agriculture	4	5	15	14	2	7	3	6	2	4	1
Agri-industry (palm oil, charcoal, peat, salt extraction)			3	1	2	2		1			1
Animal/plant extinctions	5	3	1		1	1					1
Avalanches											
Biodiversity loss	1		1	2	1	1		2		1	
Buildings and infrastructure				4		4					
Climate warming (air, ocean heating)		1									
Deforestation/ logging	3	3	20	16	6	10	3	6	2	3	2
Desertification	*		1		1						
Disease											
Displacement of indigenous people										1	
Drought											
Earthquake					*	*	*	*	*	*	*
Fires: wildfire and human-set fires	3	2	10	7	2	1	1	4	1	1	
Habitat destruction and fragmentation	1	3	5	6	1	4	1	1	1	4	
Hunting and poaching	6	3	4	5	1	4	1	2	2	2	
Hurricanes											
Illegal wildlife and plant trade	3	4	2	2		1		4	1	1	
Introduced plants/animals and invasive species	1		4	10	5	2	1	2		2	
Land conversion	2	2	6	6	2	2	1	1			
Lightning											
Mudslides			1	14	7	2	1	1	3	1	
Mining	2	1									
Narcotic crops (opium, heroin, marijuana)											
Oil extractions/gas/oil spills	2		2		2		2				
Overexploitation of plants and animals	1	1	7	1	2	1	3	1	5	3	
Overshifting	1		3	3						1	
Population increases and settlements	3	7	8	1	9	5	2		2	2	
Public awareness deficient/conflicts		1	18	6	4	6	3	4	2	6	1
Ranching and grazing	7	1									

Appendix 2: Hazards to Biodiversity by Country (South and Central America) cont'd

Hazards to Biodiversity (cont'd)	Argentina	Bolivia	Brazil	Caribbean	Chile	Colombia	Costa Rica	Cuba	Dominican Republic	Ecuador	El Salvador
Roads	4	3	7	6	3	3					3
Sea level rise	1	3	6	2	3	5	1	1	1	2	1
Soil erosion	2	7	7	2			2	1	*	1	
Tourism		*									
Tropical storms	2	13	9	2	5	3	3		1	1	
Urbanization/development		*									
Volcanic eruptions											
War											
Waste/improper dumping											
Water drainage/salinization/diversions	2	2	2	2	2	1		2	1	1	1
Water pollution	1	1	8	2	6	1	1	1	1	1	1
Water shortages/sedimentation	1	3	2	2	2	3	3	1	1	1	1
Number of reported sites in literature	11	5	42	21	8	16	6	6	2	6	2
Disasters Report Scale											
Desertification	4										
Earthquake		5	5				5.5		5	4.5	5.5
Drought		4									
Hurricanes		5									
Lightning											
Tropical storms/floods											
Volcanic eruption		4.5	4						4		4

* Very Significant Occurrence: see disasters report scale.

Caribbean countries not listed separately in this table include Anguilla, Antigua, Bahamas, Barbados, Cayman Islands, Dominican Republic, Haiti, Martinique, St. Vincent and Trinidad

Appendix 2: Hazards to Biodiversity by Country (South and Central America) cont'd

Hazards to Biodiversity	French Guiana	Guatemala	Guyana	Honduras	Mexico	Nicaragua	Panama	Peru	Venezuela
Agriculture	1	1		1	17	2	3	7	8
Agri-industry (palm oil, charcoal, peat, salt extraction)	3		1						
Animal/plant extinctions				1	9		2		1
Avalanches									
Biodiversity loss									
Buildings and infrastructure									
Climate warming, air, ocean heating)	1				7				3
Deforestation/ logging	1			1	2	1		1	3
Desertification									
Disease									
Displacement of indigenous people						1			
Drought							1		
Earthquake		*					*		
Fires: wildfire and human-set fires	1	1	6			1	4		
Habitat destruction and fragmentation		1	1		11		1	4	4
Hunting and poaching	1	1	1		13	1	1	3	6
Hurricanes					10	1	1	1	4
Illegal wildlife and plant trade									
Introduced plants/ animals and invasive species					4		1		2
Land conversion	1				8		3	1	3
Lightning									
Mudslides									
Mining	1		2		4	1	1	6	4
Narcotic crops (opium, heroin, marijuana)								1	
Oil extractions/gas/oil spills	1				2		1		6
Overexploitation of plants and animals					12	1	2	1	5
Overshifting		1	4				3	3	
Population increases and settlements						9	1	3	5
Public awareness deficient/conflicts						6	1	1	3
Ranching and grazing						18	1	3	6

Appendix 2: Hazards to Biodiversity by Country (South and Central America), cont'd

Hazards to Biodiversity (cont'd)	French Guiana	Guatemala	Guyana	Honduras	Mexico	Nicaragua	Panama	Peru	Venezuela
Roads				10			3	1	6
Sea level rise			1	1	9	1	3	2	1
Soil erosion			1	7	1				6
Tourism	1								
Tropical Storms									
Urbanization/development	1	2		1	12	1	4	3	5
War			1	1	2	1			
Waste/improper dumping Water draining/salinization/ diversions				1	7			1	6
Water pollution	1		1	1	9	2	1	3	4
Water shortages/sedimentation	1			2	5	1	1	2	1
Number of reported sites in literature	1	2	1	36	2	5	10	13	
Disasters Report Scale									
Desertification									
Earthquake	4.5								
Drought									
Hurricanes									
Lightning									
Tropical storms/floods									
Volcanic eruption									

* Very Significant Occurrence; see disasters report scale.
 Caribbean Countries not listed separately in this table include Anguilla, Antigua, Bahamas, Barbados, Cayman Islands, Dominica, Haiti, Martinique, St. Vincent and Trinidad

Appendix 3: Summary of Threats to Biodiversity by Country (South and Central America)

Country	Primary Concerns	Secondary Concerns	Geo-hazard
Argentina	Ranching, Grazing, Over-hunting	Agriculture, Road construction, Desertification	
Bolivia	Agriculture, Illegal wildlife trade	Logging, Road construction, Population increases, Hunting, Habitat destruction	
Brazil	Deforestation, Ranching	Mining, Urban encroachment and development	Species are showing impacts from increased temperatures, drought and desertification
Caribbean	Deforestation, Agriculture	Ranching, Fires, Urbanization, Introduced plants and animals	Earthquakes, volcanic eruptions, tropical storms and drought
Chile	Deforestation, Introduced plants and animals	Ranching	Earthquakes
Colombia	Deforestation	Ranching, Agriculture, Water pollution	This is an area that is vulnerable to avalanches and mudslides, frequently triggered by soils that have been destabilized as a result of logging
Costa Rica	Soil erosion	Deforestation, Sedimentation, Ranching, Urbanization, Agriculture	Severe earthquake zone
Ecuador	Ranching, Agriculture, Habitat destruction	Deforestation, Overexploitation of plants and animals	Fairly severe earthquake zone
El Salvador	Deforestation, Population pressure		Fairly severe earthquake zone; also subject to lightning strikes
Guatemala	Urban encroachment		Earthquakes
Guyana & French Guiana	Deforestation, Mining	Over-hunting, Water pollution, Habitat destruction, Tourism	
Honduras & Nicaragua	Agriculture, Water pollution	Deforestation, Soil erosion, Sedimentation, Urbanization, Hunting, Improper dumping of waste	Earthquakes
Mexico	Deforestation, Ranching, Agriculture	Urbanization, Hunting, Overexploitation of plants and animals, Habitat destruction	

Appendix 3: Summary of Threats to Biodiversity by Country (South and Central America) cont'd

Country (cont'd)	Primary Concerns	Secondary Concerns	Geo-hazard
Panama	Deforestation, Urbanization	Soil erosion, Population increases, Ranching, Flood construction, Agriculture, Land conversion, Overexploitation of plants and animals	
Peru	Deforestation, Agriculture	Mining	
Venezuela	Deforestation, Agriculture	Water diversions, Ranching, Roads, Hunting, Oil extraction, Tourism	

Appendix 4: Climate Change Impacts and Potential Adaptations for Biodiversity

Hazards and Climate Change Impacts	Biodiversity Applied Adaptation
Agriculture: Agriculture is the largest driver of land-use change in the Americas. Already, 50% of the Cerrado ecosystem has been converted to farmland. Highly mechanized modern agricultural techniques are able to overcome limitations of tropical soils for agriculture, enabling agriculture to keep expanding wherever there is arable land (Killeen, 2007).	An increase in the biodiversity of the farming system may help to reduce the contribution to drought. Banks of drought-resistant, flood-resistant, saline-resistant seed varieties can be used to respond to climate extremes. Protect pollinators and their habitat: 35% of the world's crops depend on pollinators such as bees.
Aquaculture: Mangroves are being converted to shrimp farms at very high rates; 35% of mangroves have already been lost (MEA, 2005).	Protect and replant mangrove areas.
Administrative problems and lack of financial resources	Prioritize protection of coastal regions, pollinators, endemic species, rainforests and wetlands. Provide legal protection for lands. Regulate lands and commodity markets to reduce or eliminate complete deforestation of the Amazon. Implement efficient regulatory measures to counter market forces (Killeen, 2007). Reward agricultural producers for conservation of wetlands and for provision of ecological goods and services. Reward forest conservation by providing incentives. Offer financial compensation for areas of avoided deforestation: payment for the environmental service of not harming the rainforest. Pay rent for carbon storage.
Biofuels: Biofuels are among the greatest threats to the conservation of Amazon wilderness areas and hotspots. The projected market for biofuels is so large that it could stimulate deforestation far beyond the most pessimistic scenarios (Killeen, 2007). Sugar cane is grown to produce alcohol and oil palm to produce biodiesel oil. The African oil palm and elephant grass, which are ideally suited for use as a biofuel flourish and replace natural vegetation in the tropics. Oil palm emits isoprene, which produces more ozone, resulting in detrimental effects (Betts, 2007).	Assess the difficult tradeoff with biofuels. Biomass from diverse prairies can make biofuels without annual tilling, fertilization and pesticides. Perennials have more root mass than crops such as corn, which must be replanted annually are more stable, have fewer requirements and can still produce biofuels.
Decrease in extent and thickness of sea ice	Reduce greenhouse gas emissions.
Dams: Flooding of reservoirs causes declines in fish diversity (Killeen 2007).	Avoid mega-hydroelectrical projects on primary rivers (Killeen, 2007).
Deforestation: Deforestation is occurring at very high rates across the Americas, with Brazil having the highest absolute forest loss. The loss of butterfly habitat in Mexico and the loss of gallery forests in Amazonia are of particular concern. A savannah ecosystem requires cover for wildlife and is too	Restore peatlands; peat bogs sequester twice as much CO ₂ as all of the world's forests. Implement avoided-deforestation programs. Lower the annual deforestation rate by 5%; this will reduce disasters and the avoided emissions will result in a \$650-million-a-year credit (Killeen, 2007). Forests aid in the

Appendix 4: Climate Change Impacts and Potential Adaptations for Biodiversity cont'd

Hazards and Climate Change Impacts	Biodiversity Applied Adaptation
<p>exposed if the adjacent gallery forests disappear (Killeen, 2007). Forests in Central and South America are often converted for other uses such as agriculture, ranching and biofuels. Deforestation in these regions is occurring in a climate where precipitation is decreasing and temperature is increasing compounding the stress on trees. Deforestation affects the process of evapotranspiration, which reduces precipitation in the ecosystem and expands arid conditions. All of these conditions exacerbate tree mortality. Deforestation also entails an increase in emissions of greenhouse gases. This is one of the greatest challenges to biodiversity facing us (Stott, 2007).</p>	<p>amelioration of climate extremes. Plant vegetation to protect against floods and coastal erosion. Plant mangrove belts and tree shelter belts (Conway, 2007; IPCC, 2001). Establish timber harvest cycles of 100 years to allow ecosystems to recover between extreme events. Practice proactive planting: the hundreds of years that it takes for natural biodiversity to occur is too long given the impacts and stresses coming with anticipated rates of climate change and extremes (Environment Canada, 2003).</p>
Desertification	Plant species tolerant to higher temperatures.
Drought	Increase variety of species; include succulents in cropping system. Plant drought-resistant seed varieties. Keep river corridors forested as this makes ecosystems more resilient to drought.
Extinctions of plant and animal species	Practice in-situ and ex-situ conservation. Maintain genetics as well as species diversity to enhance ecosystem resilience (Reusch et al., 2005). The death of species is the responsibility of all. We have to act urgently.
Eutrophication/Decreased water quality	Plant/protect species important to improving water quality, e.g., mangroves.
Flooding	Plant mangroves to diffuse tropical storm waves.
<p>Fragmentation: Fragmented landscapes may not allow for the redistribution of populations to accommodate shifting climates. Edge effects penetrate at least 300 m, so remnants smaller than this in area generally result in biodiversity loss. Forest fragmentation and land degradation increases risk of wildfire. Fire and logging that follow in the wake of fragmentation allow for regeneration of pioneer species and an increase in invasive species. Isolation and homogenization of biota in protected areas (Killeen, 2007).</p>	<p>Establish conservation corridors designed to promote biodiversity conservation. Conserve the hills, ridges and valleys in Brazil and Guyana as wildlife reserves.</p>
<p>Hunting: Intensive hunting is causing local extinctions of vertebrate fauna in the Americas. As seed dispersers are reduced, tree reproduction is negatively affected (Killeen, 2007).</p>	<p>Work with local communities to reduce hunting to sustainable levels. Work with timber companies to reduce logging associated hunting and wildlife trade. Work with governments to provide scientific data on hunting impacts.</p>

Appendix 4: Climate Change Impacts and Potential Adaptations for Biodiversity cont'd

Hazards and Climate Change Impacts	Biodiversity Applied Adaptation
Greenhouse gas emissions	Need rapid implementation of technology and strategies for carbon sequestration to decrease greenhouse gas emissions (Thomas et al., 2004).
Increases in extreme events: storms/fires	Proactively plant more 'resistant' species according to anticipated impact. Diverse ecosystems cushion against climate uncertainty, are more productive, better withstand and recover from climate extremes, pests and disease, and increase stability.
Increased permafrost melt	Reduce greenhouse gas emissions.
Increased pressures on habitats	Maintain natural diversity of species; reduce fragmentation and human impact.
Infectious diseases	Reduce encroachment on animals' natural habitats. Establish preventative measures in areas where humans and wildlife live in close proximity.
Inundation of fresh water	Plant salt-tolerant species.
Invasive species	Control or eradicate invasive species.
Loss of migratory wildfowl and mammal breeding and forage habitat	Create new reserves with flexible boundaries. Conserve large blocks of forest to provide for the minimum distance for edge effects and to give rare species adequate range area for survival. Special consideration should be given to the West Amazon – the most diverse and most stable climate. Use corridors to connect ecosystems.
Lack of respect for ecosystems: Human lack of respect and care for ecosystems is reflected in the quality of water resources.	Education is very important, as is the participation of all stakeholders. Need to see environmental rights as human rights. Human beings have an ethical duty to conserve Earth's species, which have an intrinsic value over and above the benefits they provide. Conservation should be seen as a moral obligation to preserve our priceless, irreplaceable heritage (Killeen, 2007). Value species for their aesthetic, spiritual and intellectual inspiration.
Mining: Diamond, gold, copper and coal are all mined in the Americas; mining is even allowed in national parks in Bolivia. Diamond mining in the Northwest Territories affects migration routes for caribou. Mining interrupts the high and low water flows in rivers, reduces sediment loads and disrupts the migratory behavior of fish (Killeen, 2007). It also pollutes and destroys vegetation and wildlife, leaving residues that impact neurological function and increase risk of birth defects.	Implement land-use planning. Develop alternative technology. Restore natural sites where there has been mining. Enact regulations to protect reserves and parks.

Appendix 4: Climate Change Impacts and Potential Adaptations for Biodiversity cont'd

Hazards and Climate Change Impacts	Biodiversity Applied Adaptation
Oil and gas extractions/oil spills: Oil spills are particularly problematic in Bolivia and Peru, where high rainfall and unstable topography increases their risk of occurring (Killeen, 2007).	Pursue alternative energy sources. Use improved production technologies. Phase out older oil tankers.
Overgrazing	Encourage sustainable grazing management techniques.
Reduced colonization success	Assist species regeneration.
Reduced water supply	Plant drought-tolerant species.
Reduction in wetland areas	Preserve wetlands because they control floods by storing large volumes of water and help reduce erosion by slowing runoff. They also have the potential to remove and store greenhouse gases from the Earth's atmosphere. Wetlands are important for waterfowl and key spawning, nursery and feeding areas for fish. They provide habitats for 600 species of wildlife.
Roads: Highway construction in the cloud forests of the Amazonia leads to extinction of species in areas of high endemism. Improved highways lead to deforestation, affecting both carbon emissions and continental precipitation patterns (Killeen, 2007).	Implement land-use planning to reduce impact.
Urban encroachment and development/population expansions: With urban expansion, vast wetlands are threatened by human encroachment.	Implement land-use planning to reduce impact. Educate the public and raise awareness.
Water depletions: Water depletions cause rivers to run dry, groundwater tables and aquifers to drop, and lakes to vanish. Freshwater depletions are occurring in the Everglades. Lake level declines and a reduction in wetlands are also taking place in Mexico. The deterioration of wetlands, rivers and riparian habitats has a disproportionately high impact on biodiversity. The loss of more than two-thirds of natural river flow results in a loss of biodiversity. This has a serious effect on the long-term health of the ecosystem, including on fish and other organisms (Krockeberger et al., 2003).	Enact regulations. Plant trees and introduce water conservation measures.

Occasional Paper 1: November 2004, Climate Change and the Adaptation Deficit, Ian Burton

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